CHAPTER II
LITERATURE REVIEW

A difference in sitting posture can affect trunk muscle activation because of changes in lumbar curvature and pelvic angle which cause differences in lumbopelvic stabilizer activation, lumbar multifidus (LM) and internal oblique (IO) muscles (O'Sullivan et al., 2006). Moreover, a recent study reported that the force level on lower back muscles, especially LM, was strongly related to the median frequency slope (MF slope). In other words, sitting postures are a direct influencing factor to lower back fatigue (Dedering et al., 2002). In addition, the fatigability of the lumbopelvic stabilizers may result in low back pain (LPB) at a later time (Harrison et al., 1999).

1. The muscles controlling the trunk

The spinal muscle system is a vital biomechanical system that has an important role in maintaining stability of the human spine (Panjabi, 1992). If the trunk muscles do not work properly, the spine will be an unstable stage to carry the physiological compressive loads from the upper body (Panjabi et al., 1989). The best coordinative movements and balance depend on specific and relative action of trunk muscles. The trunk muscles, which produce the torque, can be adapted by internal and external forces. Without trunk muscle control, the spinal structures may be injured by compressive force (Ng et al., 1997).

Static postures, such as sitting postures, require a lot of spinal stability. Trunk muscles have an important role in providing spinal stability (O'Sullivan, 2000). Bergmark (1989) hypothesized that the extent of trunk muscle activation may influence human stability and movement. There are two types of trunk muscle systems: global muscle system and local muscle system. (Bergmark, 1989)

The "global muscle system" consists of rectus abdominis muscles, external abdominal oblique muscles and iliocostalis lumborum pars thoracis muscles. These muscles produce general gross trunk stabilization and generate large torque. As these muscles do not directly attach to the lumbar spine, they are not capable of having an influence on the lumbar spinal segments (O'Sullivan, 2000).

The "local muscle system" consists of lumbar multifidus muscles, psoas major muscles, quadratus lumborum muscles, iliocostalis lumborum muscles, longissimus lumborum muscles, transversus abdominis muscles, diaphragm and posterior fibers of internal oblique muscles. These muscles directly attach to the lumbar vertebrae that provide the lumbar segmental stability and directly control each segment of the lumbar spinal column. Therefore, they play an important role in providing stability to the lumbar spine (O'Sullivan, 2000).

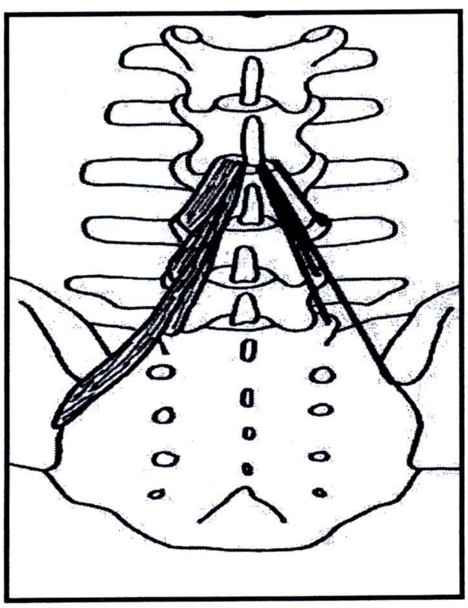

Figure 2 Attachment of lumbar multifidus muscles

Although the global muscle system can produce large torque that provides an effective posterior sagittal rotation and extension of lumbar spine (MacDonald et al., 2006), a sitting posture is a static posture in which the spine is perpendicular to the earth. Therefore, this posture requires the main muscles in the local muscle system, especially lumbar multifidus (LM) muscles and internal oblique (IO) muscles to maintain the segmental lumbar spine (Panjabi et al., 1989). The LM muscles are called neutral lumbar lordosor, have numerous fascicles (Wilke et al., 1995). Their origin spreads from inferolateral aspect to the inferior tip of the spinous process and lamina at one vertebral level and they insert to two or five spinal levels inferiorly onto the facet joint capsule, mamillary process, lamina, medial aspect of posterior superior iliac spine (PSIS) and posterior surface of sacrum (Macintosh et al., 1986) (Figure 2). In 1973, Gray et al proposed that the trunk extensors including LM muscles can produce several trunk movements, such as extension, lateral flexion and rotation. However, LM muscles have pure action to stabilize muscles and are prime mover muscles for vertebral movement (Donisch et al., 1972). Previous studies have used electromyography (EMG) to investigate LM muscle properties and showed that these muscles has more type I muscle fibers than type II muscle fibers when compared to other trunk muscles (Bajek et al., 2000). So, LM muscles are more likely to have a

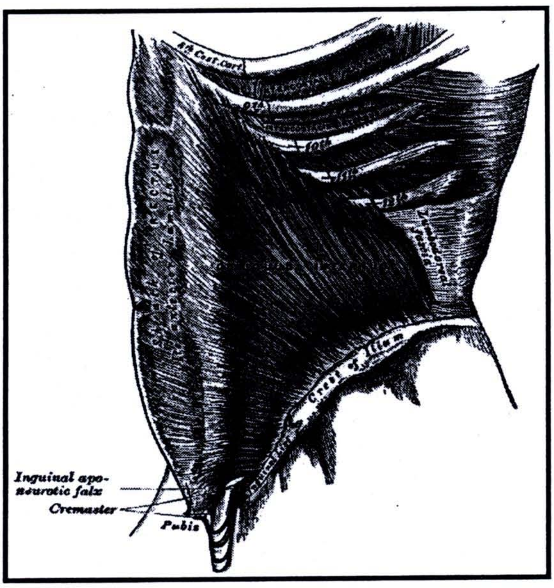

Figure 3 Attachment of internal oblique muscles

high endurance than other trunk muscles. A previous study proposed that cocontraction of spinal stabilizing muscles is necessary. IO muscles, which cocontract with LM muscles, have the ability to increase lumbo-pelvic stability (O'Sullivan et al., 2002). IO muscles originate from the thoracolumbar fascia, anterior two-thirds of the iliac crest and lateral half of the inguinal ligament. The insertion of these muscles are inferior borders of rib 10-12, linea alba and pectin pubis via conjoint tendon (Figure 3). They have more type I fibers than type II fibers resulting in great endurance capacity. Their important roles are to provide a laterally stabilizing influence on the lumbar vertebrae via the thoracolumbar fascia and to control intraabdominal pressure (Cresswell et al., 1992). Moreover, they produce large increases in spinal stability and decrease compressive loads (O'Sullivan et al., 2006).

In conclusion, LM muscles and IO muscles play an important role in maintaining the stability of the trunk.

2. Mechanism of muscle fatigue

Muscle fatigue is a complex phenomenon that affects functional and exercise performance. Trunk muscle fatigue results from several activities: static loading activities such as prolonged transportation or bag holding (Althoff et al., 1992; Puntumetakul et al., 2009), dynamic loading activities such as activities that require repetitive trunk movement or walking (Tyrrell et al., 1985; Rodacki et al., 2005) and vibratory load activities such as driving and prolonged sitting (Bonney et al., 2003).

Trunk muscle fatigue, especially of lumbar multifidus muscles and internal oblique muscles that are important in sitting, results in damage to lumbar structures such as intervertebral discs and spinal joints. Deficiency of activation of these muscles leads to reduced effective transfer of physiological loads from upper body to lower structures (O'Sullivan et al., 2006). A change in the biomechanical balance of trunk muscles and lumbar spine is a cause to provoke low back pain symptoms.

The definition of muscle fatigue has three main parts to consider. These are the reducing ability to generate the maximal force of muscles, reducing muscle contraction velocity and delayed muscle relaxation time (Enoka, 2008). And this definition is different from muscle weakness, which is defined as an inability of the muscles to develop an initial appropriate force to the circumstances. The major mechanisms which increase muscle fatigue can be separated into two. There are central fatigue and peripheral fatigue (Gandevia, 2001; Allen et al., 2008).

The first mechanism, central fatigue, is defined as muscle fatigue caused by the central nervous system. This results in the declination of force production of prime mover muscles. The body system has to send feedback by group III (non-spindle afferent neuron) and group IV (unmyelinated afferent neuron) muscle afferents to the willed movements cortex, motor cortex, supraspinal and propriospinal level, corticospinal tract and motor neurons of the spinal cord. These cortice and motor neurons are stimulated to increase drives to the prime mover muscles. The feedback signals are present to recruit motor units of synergistic muscles to assist the prime mover muscles. This effect may be a neurophysiological benefit to resist fatigue (Gandevia et al., 2001).

The second mechanism, peripheral fatigue, is defined as muscle fatigue caused by changing neuromuscular junctions. This mechanism can be divided to two ways. The first way presents at the molecular level of muscle fibers, when the human performs sustained or repetitive activities that continuously produce action potentials (AP) at sacrolemma and T-tubules regions of muscle fibers and enhance sodium-potassium pumps (Na^+- K^+ pumps) failure. These effects reduce AP generation at neuromuscular junction and sacrolemma. Moreover, the reduction of adenosine triphosphate (ATP) and the increment of magnesium (Mg^{2+}) show in muscle fatigue that directly inhibits voltage sensors on T-tubules (voltage sensor inactivation). This situation relates to phosphate (P_i) accumulation that is a cause of inhibition opening of ryanodine one receptors (RyR1 receptors), which are on the sarcoplasmic reticulum (SR). At the same time, P_i interacts with calcium (Ca^{2+}) in SR that displays calcium-phosphate (Ca^{2+}- P_i) precipitation in SR. Interestingly, it is the combined elements of these that lead to reduction of the amount of Ca^{2+} available for release from SR. The reduction of ATP and gradual increment of acid in cellular muscle lead to decrease in velocity of interaction between Ca^{2+} and myofibrillar protein of muscle fibers such as troponin C.

In the relaxation phase, muscle fatigue displays a deficiency to delay the relaxation time of muscles in that ATP is reduced, because this mechanism decreases SR-Ca^{2+} reuptake and increases adenosine diphosphate (ADP) and these can affect SR-Ca^{2+} leakage. All elements of peripheral fatigue induce the increment of muscle fatigue (Allen, 2008) that may be a cause of low back pain (Danneels et al., 2002).

The second way is used to describe the fatigability of muscles when they are stretched. The activating lower trunk muscles in the static flexion period are known to receive viscoelastic elongation as well as in tendon and ligament (Weir et al., 2005; Morse et al., 2008) when stretched passively. The viscoelastic elongation of the muscles due to passive static flexion stretching produces fatigue responses including reduced motor unit activity, reduced muscle fiber conduction velocity and reduced muscle force generating capacity (Avela et al., 2004; Morse et al., 2008). When muscles were stretched, the muscle fiber diameter decreases and the muscle fiber conduction velocity along muscle fibers declines (Håkansson, 1957). The muscle circumference is reflected by the muscle fiber diameter. There is a positive correlation between the muscle circumference and the mean of the muscle fiber conduction velocity (Sakamoto and Li, 1997). It has been reported that a reduction in the muscle fiber conduction velocity may induce a reduction in muscular fiber membrane excitability and neural adaptation during sustained muscle activation that may lead to fatigue development (Stulen and De Luca, 1981; Clark et al., 2003; Allen, 2008). Furthermore, the decrease in myofilament overlapping in stretched muscles could modify the regulatory myosin light chain phosphorylation (Yang et al., 1998). This possibly results in impairment of the sensitivity of the myofilaments for intracellular calcium concentration with increasing muscle length (Maffiuletti and Lepers, 2003). Therefore, the stretched muscles lead to higher contractile failure and fatigue than optimal muscle length (Desbrosses et al., 2006).

In conclusion, muscle fatigue is caused by two mechanisms: central fatigue and peripheral fatigue.

3. Factors influencing muscle fatigue

Trunk muscle activation, either of the global muscle system such as thoracic erector spinae muscles or local muscle system such as lumbar multifidus muscles and internal oblique muscles, has an important role to maintain stability of the spine (Bergmark, 1989) and pelvis. These muscle systems influence both static and dynamic postures, for instance sitting, standing, walking and running. However, if the muscles have prolonged contraction, the muscle forces will be decreased and this is called "muscle fatigue" (Enoka et al., 2008). The muscle fatigue will be different in individuals or in different circumstances depending on factors such as muscle fiber type, gender, age, body mass index (BMI), temperature, working type and sitting posture.

3.1 Muscle fiber types

Previous studies have reported that skeletal muscles of mammalian, such as humans, are classified from expression of myosin heavy chain (MHC) isoforms. The major fiber types are type I, type IIa, type IIx and type IIb. However, recent review will describe specific type I fibers (fast isoform) and type II fibers (slow isoform), which express in human muscles. The fiber type classification has relevance in the context of fatigue, and relates to metabolic changing process. A fast isoform assumes ATP faster than a slow isoform and it fatigues faster than a slow isoform (Allen et al., 2008) or it can be explained that a fast isoform has greater endurance than a slow isoform. In relation to fatigue, muscle endurance may be relevant to mitochondrial density of muscle fibers and capability to use oxidative metabolism. Therefore, a fast isoform generally has higher fatigue resistance than a slow isoform (Essen et al., 1975).

3.2 Gender

Males and females have some differences of anatomical structures and physiological system of muscles that affect fatigability of muscles during work (Enoka, 2008). Previous studies have demonstrated that a capability for sustained muscle contraction at low contraction intensity is associated with endurance time in females rather than in males (Hunter et al., 2005), but it is not present in maximal contraction intensity (Baudry et al., 2007). However, histological studies of the erector spinae muscles indicated that muscle fiber size in males is larger than in females (Mannion et al., 1997). Thus, males are stronger than females when they are working on a same task (de Ruiter et al., 2007). Interestingly, females are weaker than males because muscular structures of females consist of type I muscle fibers, rather than type IIa muscle fibers and type IIb muscle fibers. The boundaries of type I muscle fibers are larger than other fiber types. Therefore, females have a higher cross sectional area of type I muscle fibers than males (females 73%, males 56%) (Kankaapää et al., 1998).

Mannion et al (1997) proposed that the type I muscle fibers and type II muscle fibers ratio (type I:II muscle fibers) in females is greater than in males. This result was similar to the research of Clark et al. (2003), who studied effects of gender differences on back muscle activation during sustained sub-maximal contraction at 50% maximal voluntary contraction force (MVC) using electromyography (EMG). The results showed a larger decrease in median frequency and endurance time in males than in females. This effect can suggest that males have more fatigue than females, because females' muscles consist of greater type I muscle fibers, which have a great capability to use the oxidative mechanism (Rall et al., 1985) when compared to type II muscle fibers. Therefore, the advantage of type I muscle fiber results in little accumulation of waste products such as acid (H^+) and extracellular potassium (extracellular K^+).

3.3 Age

Age has a direct relevance to muscle endurance. Younger people's muscles have full development that increases the amount of muscle fibers, size of muscle fibers and effectiveness of muscle activation. On the other hand, older people's muscles have declination of amount of muscle fibers (Frost, 1983) by about 39% of all muscle fibers when compared with younger people (Limburg et al., 1991). This effect leads to decreased muscle strength (Young et al., 1984), especially trunk muscles, which are the main muscles to stabilize the spine and pelvis. In older people, these muscles depend on sacropenia that is a state of declination of skeletal muscle mass. This state is a cause of decreasing amount of motor units that contributes to delayed time of motor unit recruitment (Erim et al., 1999) and decreased skeletal muscle strength (Doherty et al., 1993). In histological studies, sacropenia is a major cause to decrease type II (fast twitch) fibers (Trappe et al., 2001). This cause results in increasing type I muscle fibers and type II muscle fibers ratio (type I:II area ratio). Therefore, older people have a longer time than younger people when exercising or working with isometric efforts and dynamic efforts at low contraction intensity to moderate contraction intensity (Bilodeau et al., 2001).

Kankaapää et al. (1998) investigated the relation between age and back muscle fatigue using isometric Sørensen back endurance test. This result showed significantl moderate relevance between age and back muscle fatigue. Moreover, muscle fatigue resistance in older men is slightly greater than in younger men. This finding suggests that back muscle endurance capacity slightly increases with age but not up to age 50 years. In contrast to this research, Baudry et al. (2007) studied peak torque of ankle dorsiflexors during maximal isometric contraction. They found that peak torque of this muscle in younger people is greater than in older people. This result suggests that younger people are stronger than older people. This effect may results from changing of Ca^{2+} in excitation-contraction coupling mechanism.

3.4 Body mass index (BMI)

Body mass index has an important role in muscle fatigue. Kankaapää et al. (1998) studied effects of body mass index (BMI) on fatigability of back muscles. They found a high negative correlation between back muscle fatigue and BMI and they concluded that females with high BMI fatigue are faster than females with normal BMI and low BMI.

3.5 Temperature

Differential fatigability of muscles depends on air temperature. Working muscles at low temperature are fatigued more slowly than at high temperature. However, the relaxation time of muscles at low temperature is slower than at high temperature and force production of muscles at low temperature is lower than at high temperature. The slow fatigability of muscle at low temperature, especially from 22°C to 37°C, is because high temperature can affect neuromuscular transmission failure (de Ruiter et al., 1999) and lead to decreased sacroplasmic reticulum-calcium (SR-Ca^{2+}) release (Westerblad et al., 1993).

3.6 Working types

Rohrbach et al. (2003) studied the effects of respiratory muscle (diaphragm and rib cage muscles) fatigue when participants inspired against a load that was 67% of maximal inspiratory pressure. They found that the amount of this muscle fatigue was not related to the duration of sustained breathing that results in factors such as CO_2 accumulation and decreasing oxygen saturation, probably caused task failure.

Task failure has been studied in extremity muscles. One study has compared the performance of two similar tasks (Hunter et al., 2004). The first task referred to as the position task required the participants to support an inertial load and to maintain a constant joint angle for as long a time as possible. The participants were commanded to view the position that was attached to a constraint and the participants were required to maintain a constant force, which was equivalent to the force exerted during the position task and the participants viewed force feedback on a monitor. This result showed that the neural strategy underlying the same motor units differed between two tasks and a position task is more fatiguing than a force task.

3.7 Sitting postures

Asian males often spend their time sitting on the floor to work in their houses and workplaces due to their life-style (Callaghan et al., 2001). In accordance, in Thailand, which has a mixture of Buddhist and Thai culture, this is reflected by two cultural sitting postures; crossed sitting and heel sitting postures. These two sitting postures are the most common postures of Thai males that can be observed in Thai ceremonies and during working such as at cremations or sitting in daily life. But these two postures may result in trunk muscle fatigue, especially of the lumbar multifidus muscles and internal oblique muscles because these muscles must continuously contract for prolonged periods and this may affect the impairment of translation of oxygen within muscles (Callaghan and Dunk, 2002). This effect can eventually be a cause of muscle and spinal structure pain and injury.

The crossed sitting posture and heel sitting posture are perpendicular and erect postures. These upright postures depend on trunk muscle activation that stabilizes several structures of the trunk (O'Sullivan et al., 2006). Thus, trunk muscles have an important role to produce postural balance against gravity. The major trunk muscles consist of lumbar multifidus muscles, transversus abdominis muscles (O'Sullivan et al., 2002; Snijders et al., 1995) and internal oblique muscles (Bergmark, 1989) that are the lumbo-pelvic stabilizers. These trunk muscles produce stability of the human spine, especially lumbar spine and pelvis (Dankaerts et al., 2006; O'Sullivan et al., 2006) and these muscles influence human sitting (O'Sullivan et al., 2006). Therefore, back muscles and abdominal muscles usually co-contract to generate the stability and balance to the spine during sitting.

The crossed sitting posture can be found in daily activities such as meditation sitting and this posture is a comfortable posture that people choose for working such as sitting to write and sitting to work at handicrafts. The Thai crossed sitting posture can be classified to three sub-postures, such as ordinary crossed sitting posture, even crossed sitting posture and complex crossed sitting posture. However, the ordinary crossed sitting posture is the popular crossed sitting posture which is the most comfortable crossed sitting posture. This posture consists of relaxation of thorax, the pelvic anterior rotation to obtain a neutral lumbar lordosis, both hips flexion, both knees flexion crossing each leg to place the calf of one leg on the top of the opposite foot. The opposite leg is placed on the cushion or floor (Office of the National Culture

Commission, 2009). Biomechanical analysis can be used to describe this posture that it is composed of slight thoracic kyphosis, decreasing lumbar lordosis, slight pelvic anterior tilting, both hips flexion and external rotation, both knees flexion. This posture has a large base of support and the body weight is onto both ischial tuberosities and both thighs.

The heel sitting posture can be found in ceremonies and some activities of modern life-style people, such as heel sitting to pick objects from a shelf, and heel sitting while making fine arts. This posture can be classified into two sub-postures, such as heel sitting with the hips resting on the heels posture and heel sitting with the hips resting on the plantar of the feet posture. However, the most common heel sitting posture is heel sitting with the hips resting on the heels posture. This posture consists of relaxation of thorax, pelvic anterior rotation to obtain a neutral lumbar lordosis, both hips flexion, both knees flexion and contact to a cushion or floor, both ankles dorsiflexion and both ischial tuberocities rest on the heels (Office of the National Culture Commission, 2009). Biomechanical analysis can be used to describe this posture that is composed of slight thoracic kyphosis, decreasing lumbar lordosis, slight pelvic anterior tilting, both hips flexion, both knees flexion, both ankles dorsiflexion. This posture has a large base of support and the body weight is onto both knees, both heels, both metatarsophalangeal joints and all toes.

These sitting postures are upright and perpendicular postures in which local trunk muscles directly act to stabilize spinal structures. The productive population spend more time in a sitting posture, resulting in prolonged contraction of stabilizing muscles, and leading to muscle fatigue. Each posture has a different biomechanics, such as lumbar curve and pelvic angle. O'Sullivan et al (2006) reported that the lumbo-pelvic upright sitting posture has more lumbar lordosis and pelvic anterior tilting than the slumped sitting posture. Then lumbo-pelvic upright sitting posture can activate more lumbar multifidus and internal oblique activation than another posture. In biomechanical evaluation, the crossed sitting and heel sitting postures have a different lumbar lordosis and pelvic angle, and it may be assumed that the crossed sitting posture has less lumbar lordosis and pelvic anterior tilting than the heel sitting posture. They may have a non-equivalent lumbar multifidus and internal oblique activation that leads to different fatigue of these muscles. This may influence greater fatigue in the heel sitting posture than in the crossed sitting posture. Therefore, prolonged contraction and a lot of motor unit recruitment in main local stabilizing muscles may affect local muscle fatigue in sitting postures. The previous study stated that sitting on the floor for 30 minutes could clearly provide differences in upper trunk and lower trunk muscle activations (Nag et al., 1986). Therefore, the result from this previous study can be applied to measure the fatigability of lower trunk muscles. Because of the differences of muscle activation resulting from the different floor sitting postures, 30 minutes may be used to assess the muscle fatigue during prolonged contraction in sitting postures.

In conclusion, muscle fatigue is influenced by muscle fiber type, gender, age, body mass index (BMI), temperature, work type and sitting postures. The influence of these factors can be described by saying that a fast isoform is more fatiguing than a slow isoform. Females are less fatigued than males. Older people are less fatigued than younger people during working in low to moderate intensity tasks. Obese people are more fatigued than lean or normal BMI people. Muscles at higher temperature are more fatigued than at lower temperatures. A position task is more fatiguing than a force task. And sitting postures may influence back muscle fatigue.

4. Assessment methods of trunk muscle fatigue

Progressive developments in science have created new methods to assess human muscle fatigue. These devices are based on the definition of muscle fatigue as "maximal capacity to generate force or power output reduces from initial generation" (Vøllestad, 1997). The advantages of these methods reveal the point of fatigue occurring in muscles. However, literature reviews have proposed that fatigue measuring methods have different reliability and validity. Thus, choosing a proper method is important to get reliable data from muscles. Recently, there are three common non-invasive methods which are used to assess muscle fatigue such as mechanomyography (MMG), near-infrared spectroscopy (NIRS) and surface electromyography (sEMG).

4.1 Mechanomyography (MMG)

Mechanomyography (MMG) is one of the new non-invasive methods, which is used to investigate motor unit activities. MMG reflects the intrinsic mechanical activities of muscles, such as intramuscular pressure, muscle stiffness

(Yoshitake et al., 2001) and mechanical muscle vibration (Tatara, 2003). MMG records muscle activity signals using acceleration or sound transducers (Watanabe et al., 2001) and these signals are refined using piezoresistive silicon accelerometers in a surface mount package to provide reliable data of muscle fatigue (Tatara et al., 2001).

Orizio et al (1996) proposed that declination of MMG amplitudes occur during the fatigue phase of muscles and they found that have delayed relaxation time in fatigued muscles rather than normal muscles. Moreover, MMG is a useful device in complex working environments and areas with heavy electromagnetic pollution where sEMG usage is not feasible (Tatara et al., 2001). However, its reliability is low level (r = 0.43-0.46) (Al-Zahrani et al., 2008).

4.2 Near-infrared spectroscopy (NIRS)

Near-infrared spectroscopy (NIRS) is a new non-invasive optical technique which is used to investigate levels of tissue oxygenation, hemoglobin (Hb) oxygenation and blood volume in the contracting muscles (Pereira et al., 2007; Hamaoka et al., 1996). NIRS is a good reliability device (r = 0.69-0.84) (Kell et al., 2004). NIRS absorbs photons in the range 700-1,000 nanometers from hemoglobin (Hb), myoglobin (Mb) and cytochrome oxidase (Pereira et al., 2007) in small blood vessels, such as arterioles, venules or capillaries (Mancini et al., 1994).

Yoshitake et al (2001) studied lower back muscle fatigue using simultaneous recording of NIRS. This result showed that muscle blood volume and oxy-hemoglobin dramatically decreased at the onset of contraction and remained almost constant throughout the rest of contraction. This outcome was clearly relevant to muscle endurance. Therefore, NIRS can assess the cause of fatigability of muscles (Pereira et al., 2007).

4.3 Surface electromyography (sEMG)

Surface electromyography (sEMG) is a most widely used method that relies on physiological responses of muscle fatigue (Vøllestad, 1997). The electrical activity of motor units can be picked up by surface electrodes and the power spectrum and amplitude of the signal can be analyzed. Before the analytic process, the signal is sent to amplifiers to amplify this signal. The amplifying process changes a small signal of microvolts to a large signal of millivolts. Next, the amplifying signal is sent to the bandpass filter that filters out contaminating signals or noise. Then, the pure signal from the muscles is sent to a monitor to display as an electromyogram.

Recently, several studies have used sEMG to investigate numerous muscle conditions, such as investigating muscle strength (Keller et al., 2000), pathology of muscle diseases (Geisser et al., 2005), muscle activity (O'Sullivan et al., 2006; Dankaerts et al., 2006), muscle endurance and muscle fatigue (Kankaapää et al., 1998; Lariviere et al., 2002).

The sEMG method for measuring fatigability of muscles can show the quantity of fatigue. The power spectrum analysis of sEMG is used to indicate the localized fatigue using assessment of changes in the EMG waveform. The electromyographic frequency analysis can quantify the different fatigue rates of the individual trunk muscles and the sEMG amplitudes may be a good representation of the motor unit activity during muscle fatigue (Ng et al., 1997). Recently, sEMG has used two variables to investigate muscle fatigue, such as the median frequency (MF) and the root mean square (RMS) value.

The median frequency (MF) is a modulating signal that is used to evaluate muscle fatigue. It is defined as the frequency that divides the power density spectrum into two regions of equal power and it has high sensitivity to measure the muscle fatigue in early phases of fatigability (Mannion et al., 1997). The declination of median frequency (MF) slope during contraction represents the index of muscle fatigue. The benefits of this variable for muscle fatigue are less sensitivity to noise and high sensitivity to detect the fatigue rate of muscles during contraction (Solomonow et al., 1990). Therefore, several researchers have used median frequency (MF) and endurance time to evaluate muscle fatigue. Additionally, it is a basic outcome of sEMG (Mannion et al., 1997; Roy et al., 1997; De Luca, 1997; Sparto et al., 1997).

Roy et al (1995) studied comparison of back muscle strength in trunk extension between lower back pain patients and normal subjects in a rehabilitation program by spectral electromyography. The results showed significant change of MF post rehabilitation of lower back pain patients.

Mannion et al. (1997) studied fatigability in isometric endurance tests and the relation between muscle fatigue and endurance time of erector spinae muscles at T10 and L3 levels using MF in normal subjects. They found significant change of

MF at L3 greater than T10 and significant change of endurance time of erector spinae muscles which were greater in females than in males.

The root mean square (RMS) value is a derived EMG signal that is calculated by squaring each data point, summing the squares, dividing the sum by the number of the observations and taking the square root. These processes change the peak-to-peak or raw signal to be a positive value that can show the fatigability of muscles (Cram et al., 1998). Ng et al. (1997) investigated the change of EMG amplitude and EMG frequency in iliocostalis lumborum muscles (IL) and multifidus muscles (LM) during a trunk holding test in healthy males. This result showed that LM had greater MF than IL; however, it does not have any change of RMS in both muscles. Therefore, MF is a suitable variable to measure the fatigability of muscles.

In conclusion, the devices used to investigate the fatigability of trunk muscles are mechanomyography (MMG), near-infrared spectroscopy (NIRS) and surface electromyography (sEMG). However, sEMG is a widely used device because it is a high reliability method. Median frequency (MF) is a common outcome measurement of sEMG that accurately describes the fatigability of trunk muscles.

5. Reliability of surface electromyography (sEMG)

Several previous researches studied reliability of muscle fatigue measurement of trunk muscles that showed good to excellent reliability (Ng et al., 2003).

Ng and Richardson (1996) studied the reliability of within-day and between-day EMG power spectral values measurements of fatigue rate of back muscles, which are iliocostalis lumborum muscles and multifidus muscles. They found that good reliability for initial MF of within day and between-days in both muscles (ICC=0.86 for iliocostalis lumborum and ICC=0.79 for multifidus) while reliability of the MF slope of multifidus is good and MF slope of iliocostalis lumborum is moderate (ICC= 0.56 for iliocostalis lumborum and ICC=0.78 for multifidus).

Ali et al. (2001) investigated the reliability of electromyographic power spectral analysis of the paraspinal muscles. The results showed high reliability of MF slope of multifidus and iliocostalis within-day (ICC=0.65-0.82). However, reliability between-days of MF slope is found to be good for multifidus and moderately good for iliocostalis (ICC=0.60-0.85).

Ng et al. (2003) reported between-day reliability of EMG amplitude and frequency of six bilateral trunk muscles such as lumbar multifidus (LM) and internal oblique (IO) during isometric axial rotation exertions. Results of this study showed that good intraclass correlation coefficient (ICC=0.75–0.89) to excellent (ICC≥0.90) reliability for both EMG amplitude and frequency values in the six trunk muscles.

In conclusion, sEMG is a good to excellent method that can be used to measure trunk muscle fatigue.

6. Visual analogue scale (VAS)

The visual analogue scale (VAS) is an instrument that has been used to measure localized muscle fatigue. It is a 10 cm long horizontal line with anchors at the two ends reading "no fatigue/discomfort at all" and "worst imaginable fatigue/discomfort" (Kumer, 2006). Therefore, it is an acceptable instrument to consider task-related fatigue.

Hansen et al. (1998) studied the effects of mat and shoe softness during prolonged upright work for two hours based on comfort assessment using VAS related to lower back. This result revealed significant increase in the discomfort of lower back from 6 to 30% and did not have any effects on discomfort due to floor or shoe softness.

Kumer et al. (2006) examined the discomfort symptoms of lower back using VAS during exerted maximal voluntary contraction (MVC) and 40% MVC. They stated that although VAS could be a clear reflective indicator of lower trunk discomfort symptom, it was not the best indicator. Thus, the researcher might use VAS with another measurement, such as EMG.

Iwakiri et al (2008) evaluated the effects of cooking with or without the support of a standing aid during providing meals on subjective discomfort in 13 body regions including the lower back region using VAS. They suggested that a standing aid can alleviate discomfort symptoms in lower back and legs while preparing food and VAS has the power to detect the lower trunk discomfort.

7. The correlation between normalized median frequency slope (normalized MF slope) and the trunk discomfort

In clinical evaluation, both subjective and objective assessments can reflect the fatigability of muscles, however, the subjective discomfort feeling may be over-rated by actual individual feeling (Dedering et al., 2002). For this problem it is necessary to evaluate subjective sensation in parallel to objective evaluation as normalized MF slope of sEMG.

Dedering et al. (1999) studied the correlation between EMG normalized median power frequency slope and Borg rating scale to measure lower back muscle fatigue. This result revealed that there was a moderately significant correlation between EMG median power frequency slope and Borg rating scale ($r = 0.41$-0.50). They suggested that the close relationship between the two variables could be useful in clinical testing.

Dedering et al. (2002) examined the relationship between normalized MF slope and subjective examination by Borg CR-10 of back muscle fatigue in healthy subjects using a four-level staircase protocol. They proposed that the subjective ratings and slopes illustrated a low correlation ($r \leq 0.43$). Therefore, clinicians or researchers should not use subjective ratings for prediction of the normalized MF slope in this protocol.

However, there is controversy about the correlation between normalized MF slope and subjective examination. Moreover, previous studies (Dedering et al., 1999; Dedering et al., 2002) only evaluated the correlation between the normalized MF slope and Borg rating scale rather than find the correlation between the normalized MF and VAS. In addition, the Borg rating scale adds a factor of "lack of energy" (Dedering et al., 2002) which may used to assess the moderate to high exertion of muscles rather than low exertion such as sitting. Therefore, the correlation between the normalized MF slope and VAS should be explored.