CHAPTER 2

LITERATURE REVIEW

This literature review comprises of two sections including delayed onset muscle soreness's characteristics, and the preventative strategies of delayed onset muscle soreness.

2.1 Delayed onset muscle soreness's characteristics

2.1.1 Definition

Delayed onset muscle soreness (DOMS) is a common condition of individual effect to some kinds of exercise especially unaccustomed/or strenuous exercise. DOMS shows the sign of dull sensation, aching pain, usually feel when moving or palpation of the affected muscle, combined with tenderness and stiffness. Pain and stiffness usually felt in muscles about 24 to 72 hours after the exercise. (Armstrong, 1984; Clarkson et al., 1992; Miles and Clarkson, 1994).

2.1.2 The etiology of DOMS and its mechanism

Muscle damage after unaccustomed activities or exercise is a frequent physiological consequence in daily life. Some activities such as walking down stairs or downhill, and lowering a heavy object or weight, muscles are lengthened under force generation, resulting in lengthening a (eccentric) contraction which has the potential to initiate greater injury to muscles. The type of exercise caused of muscle damage is called "Exercise-induced muscle damage" (Clarkson et al., 1992; Miles and Clarkson, 1994).

The etiology of DOMS is still unclear. DOMS is mostly described in local structure but it may cause from upper motor neuron, as central fatigue (Cheung et al., 2003). Mechanisms of DOMS on local structure or muscle area have been hypothesized into 6 categories are lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation, and enzyme efflux. Exercise can generate lactic acid, the accumulation of toxic metabolic waste product may cause of pain. However, this theory is seem to not accept for DOMS because the turnover rate within 1 hour after exercise and is not correlate to the soreness rating that is happened in 24-48 hours post exercise. Exercise lead to compress blood vessel, cause ischemia and accumulate pain substances. This initiated a 'vicious cycle' stimulate pain nerve endings cause of muscle spasm. However, investigations using EMG activity in sore muscle are remaining controversy. Eccentric exercise, which lengthen the muscle, and produce high tension on muscle fibers and connective tissue, may cause their disruption. Exercise may strain the connective tissue, and the damage lead to muscle soreness. Some studies measure urine excretion hydroxyproline and hydroxylysine that are a component of collagen degradation after exercise to support this theory. Serum creatine kinase (CK) activity is often used as a maker for muscle damage, and is considered a reliable indicator of muscle membrane permeability. The disruption of the contractile component of muscle tissue, especially at the level of the z-line has shown following eccentric exercise. There are the occurrence of disrupted sarcomeres in myofibrils and damage to the excitation-contraction (E-C) coupling system. It has been postulated that an inflammatory response leads to macrophage accumulation and prostaglandin (PGE_2) release after exercise. PGE_2 would sensitize type III and IV pain afferents, making the muscle tender to movement and palpation. Eccentric exercise can cause edema due to an increase in intra- and extracellular water content lead to swelling of muscle fibers. After exercise may increase intracellular Ca^{2+}, it has been emphasized that Ca^{2+} accumulation can activate proteases and phospholipases resulting in further injury concerned in muscle damage. This is also deleterious to cell-membrane and sarcoplasmic-reticulum integrity and causes a change in membrane permeability as enzyme efflux theory. However, an integration of two or more of these theories has been used to explain the DOMS phenomenon (Armstrong, 1990; Cheung et al., 2003).

2.1.3 DOMS characteristics and the symptoms

DOMS is characterized by its typical symptoms. The symptoms of DOMS include muscle soreness, decrease joint range of motion (ROM), decrease muscle force production, swelling and increase plasma CK level. The study of DOMS characteristics demonstrated to time interval of symptom's changes. Nosaka et al. (2002); Dannecker et al. (2005); Hubal et al. (2007) studied the characteristics of DOMS in elbow flexors which were induced by eccentric exercise. They demonstrated that DOMS is characterized by increasing soreness sensation in 24 to 48 hours following the activity, with a peak pain level usually 24 to 72 hours after exercise. The soreness normally subsides within 5 to 10 days depend on time consumption of the healing process. ROM reduction occurs immediately after exercise and bottoms out on day 2-3 after exercise. The loss of ROM appears to return to normal within 10 days after exercise. It has been proved that muscle strength is impaired from the damaged muscle. Clarkson et al. (1992) reported that high force eccentric exercise has been shown to result in strength losses of up to 60% immediately after exercise, and strength can take over 10 days to be fully recovered.

Nosaka et al. (2002) also demonstrated that muscle strength was reduced immediately after exercise and seems to be slowly recovered than the other signs. Other parameters such as edema or swelling and localized inflammatory response also happen after muscle damage. Swelling gradually develops a few days after exercise, reaching peak values at 5 days after exercise. There does not seem to be a correlation between swelling and muscle soreness, because their time courses of symptoms are different (Clarkson et al., 1992). Many studies evaluated the characteristics of DOMS in different muscles including neck and shoulder muscles (Nie et al., 2005), wrist extensor muscles (Slater et al., 2003; 2005), the first dorsal interosseous muscles (Bajaj et al., 2001), muscle of lower extremity such as quadriceps (Bowers et al., 2004), hamstrings (Brockett et al., 2001) and calf muscles (Tegedar et al., 2002). Unfortunately, the results of their characteristics can not directly compare because of different in the DOMS induction methods; intensity, number of repetition and mode of exercise. In order to understand the cause and nature of DOMS, it is essential to accurately and reproducible quantify the insight of soreness. However, it presents many problems as it is intrinsically subjective and has established difficulty to measure accurately. Mense and Stahnke (1983) studies pain in animal to characterized the afferent nerve and measure the firing frequencies in response to graded stimuli. However, this technique can not be used in human subjects. Thus, study DOMS in human have to rely on asking the subject to report the degree of pain present and functional changes. Many methods have been used to quantify rating of pain, including VAS, graphic rating scales, and some sensory evaluation. In addition, many tests have been used to measure movement function, such as ROM assessment, force measurement, and response time. However, there is still no standardized model measuring of characteristics in DOMS research. Pain from DOMS can be evoked by muscle palpation, contraction and stretching, all mechanical stimuli do not evoke any sensations of pain in an unexercised individual. So that it should be referred to as tenderness, rather than soreness. The most important characteristic of DOMS is tenderness, a kind of mechanical hypersensitive. In the damaged region, there is lower in pain threshold cause of hypersensitive to stimuli (hyperalgesia). Hyperalgesia is characterized by decrease in the threshold for eliciting pain which is divided into two forms; primary and secondary hyperalgesia. The primary hyperalgesia is respond to both mechanical and thermal stimuli whereas the secondary hyperalgesia is respond to mechanical stimuli only (Wright et al., 1992). DOMS has been examined in the responding of mechanical pain threshold (i.e., pressure pain threshold (PPT)). Slater et al. (2003; 2005) suggested that PPT was an effective index in measuring the extended of muscle tenderness. There are some evidence supports of a role for large fiber mechanoreceptors in DOMS. Weerakkody et al. (2001) demonstrated that muscle mechanoreceptors, including muscle spindle, play a role in generating DOMS and could be stimulated by vibration. Allen and Proske (2006) postulated that muscle receptors appear to be involved in two different roles which are automatic (unconscious) control and conscious sensation. Conscious sensation, specifically, kinesthesia, or position sense is a major role of muscle receptors. Some studies have investigated position sense after muscle fatigue and damage after exercise. It has been reported that eccentric exercise lead to a disturbance of muscle receptors with declined response in position sense and reduced muscle force (Walsh et al., 2004; Brockett et al., 1997). This kind of sense could be associated with the symptom of DOMS. DOMS is mostly described in local structure but it may cause from upper motor neuron, as central fatigue. Bisset et al. (2006) showed that wrist angle deficits cause slower response times and delayed in speed of upper-limb movement in the chronic lateral epicondylalgia group, muscle or connective tissue damage may lead to changes in recruitment pattern or changes in the temporal sequencing of muscle activation patterns cause the presence of muscle dysfunction. Central sensitivity changes caused by DOMS may explain the increase in referred pain frequency and enlarged pain areas, and muscle soreness might facilitate the central components of temporal summation to mechanical stimulation (Allen and Proske, 2006; Nie et al. 2006).

2.1.4 Influential factors related to the intensity of DOMS

Miles and Clarkson (1994); Cheung et al. (2003) reported that the soreness following eccentric exercise has often been reported to be most severe in the distal portion of the muscle near the myotendinous junction. However, the localization of DOMS has also been found more sensitive to pain in muscle belly (Slater et al., 2003; Nie et al., 2005) and in tendon bone junction site (Gibson et al., 2006). The results are still uncertain in the most severe localization of DOMS. The severity of symptoms and distribution of pain associated with DOMS are related to the intensity, duration, and type of exercise performed. Other factors may affect DOMS such as, type of muscle (Weerapong et al., 2004; Friden and Lieber, 1992; 2001), part of muscle (Jamurtas et al., 2005), joint angle (Nosaka and Sakamoto, 2001), sex and age differences (High et al., 1989; Brooks and Faulkner, 1996; Strazdins and Bammer, 2004; Dannecker et al., 2005). At the same exercise velocity, two-joints and one-joint muscles respond to the same eccentric exercise protocol differently. Friden and Lieber (1992); Weerapong et al. (2004) reported that two-joints muscle was likely to experience more damage than one-joint muscle. Friden and Lieber, 2001 also reported that type II (fast) muscle fibres are more susceptible to eccentric exercise-induced muscle damage than type I (slow) fibres. The shape of muscle has been proposed as a factor affecting outcome of muscle damage following eccentric exercise. Fusiform muscles are more susceptible to eccentric exercise muscle damage than pinnate muscles (Friden and Lieber, 2001). Jamurtas et al. (2005) showed that the arm (elbow flexors) eccentric exercise induced larger decreases and slower recovery of strength, and larger increases in blood markers of muscle damage than the leg (Quadriceps) exercise. Nosaka and Sakamoto (2001) showed that exercise in large joint angle is more susceptible to eccentric-exercise-induced muscle damage than in small joint angle. Women are more likely to suffer more from musculoskeletal pain than man (Strazdins and Bammer, 2004). It also appears that women are more sensitive to pain than men (Ge et al., 2004). However, some previous studies for example, High et al. (1989); Rinard et al. (2000) found no significant difference between male and female in the sensation and development of DOMS after eccentric exercise. Dannecker et al. (2003) found that females tended to report less pain at 48 hours after exercise than males. The studies of DOMS in sex differences are still conversely. Brooks and Faulkner (1996) reported that muscles of old rats are more susceptible to eccentric exercise-induced muscle damage and have more prolonged deficits in muscle mass and force compared with the young animals.

2.1.5 Biochemical marker

Clarkson et al. (1992); Jamurtas et al. (2005); Nosaka and Sakamoto (2001) showed that muscle damage indicators, such as plasma creatine kinase (CK) levels which demonstrate CK activity increases after exercise, peaked on the fourth day and took several days to return to their normal level. No relationship between CK and any other indicators of muscle damage has been found because of the large inter-subject variability and the small sample size used in such studies. There is also detecting myoglobin (Mb) as an indicator of muscle damage. Jamurtas et al. (2005) demonstrated that Mb increased significantly from the pre-exercise value at 72 hours and 96 hours after exercise, which showed the magnitude of exercise-induced muscle damage. However, CK is a routinely used to analyze as the indicator of muscle damage in the previous studies (Clarkson et al., 1992; Nikolaidis et al., 2007).

From these reviews, major characteristics of DOMS have been clarified including muscle soreness, strength, ROM, swelling and CK activity. These characteristics are frequently assessed in the studies of DOMS.

2.2 Preventative strategies of delayed onset muscle soreness

It has been concern of that DOMS prevention is the most important part of training and rehabilitation. Physical therapy methods and modalities could be the idea for the prevention of DOMS. Some potential physical therapy applications to prevent muscle damage from strenuous exercise are traditional interventions including therapeutic exercise, physical modalities, and massage. These possibly preventative methods for DOMS could be divided into 2 strategies in term of passive and active strategies.

2.2.1 Passive strategies

2.2.1.1 Stretching

Application of stretching before the exercise as a preventative maneuver for muscle damage is regular practice. Stretching is believe to help to reduce the tension on the muscle-tendon unit that affect on the visco-elastic component of tissue leading to increase the compliance of muscle, reduce muscle stiffness, and consequently less force will be produced in the muscle during a specified stretch. It results in improvement of muscular flexibility possibly reduces muscle and connective tissue damage (Cheung et al., 2003; Weldon and Hill, 2003). High et al. (1989) demonstrated that static stretching and/or warm-up prior exercise did not prevent DOMS resulting from exhaustive exercise. Rodenburg et al. (1994) also found no effect of a preventative combination of a warm-up, stretching exercises and massage on the maximal force, the flexion angle of the elbow, and the plasma creatine kinase activity for DOMS of forearm flexors. However, previous studies did not prove the effective of static stretching on the prevention of DOMS. Other types of stretching are dynamic stretching and proprioceptive neuromuscular facilitation (PNF) technique that may be effective in reducing eccentric exercise-induced muscle damage and DOMS. PNF is a passive muscle lengthening, which perform after a contraction of antagonistic muscle. PNF stretching is one of the most effective stretching techniques which has been claimed to increase muscle flexibility (Sharman et al., 2006; Spernoga et al., 2001). Spernoga et al. (2001) reported using a single set of PNF stretching, which demonstrated a significant increase in flexibility. Unfortunately, this technique has not been yet evaluated for the condition of DOMS.

2.2.1.2 Massage

Massage is a possible preventative strategy for DOMS due to the fact that it can increase muscle blood flow, muscle temperature, muscle flexibility, and reduce tissue adhesion in which it could reduce injury risk factors (Weerapong et al., 2004). Rodenburg et al. (1994) reported that an intervention involving massage produced a statistically significant reduction in muscle soreness. However, these studies, massage was used to apply after the eccentric exercise. No investigation for an effectiveness of massage on the prevention of muscle damage was found. The isolate usage of massage before exercise for preventing is warrantee for evaluation.

2.2.1.3 Heat application

Heat application may influence in the level of muscle damage, for some degrees due to that it can increase muscle-tendon extensibility. Warm-up or heat application aim to elevate muscle temperature, increase muscle blood flow, and increase neurological excitability before starting exercise (Weerapong et al., 2004). These effects may reduce the damage from exercise. However, Nosaka et al. (2004) reported the effect of increasing muscle temperature that had no attenuating effects on the severity of muscle soreness associated with eccentric exercise. Symons et al. (2004) also failed to provide the prophylactic effect of deep heat on the symptoms of DOMS. By the other way, Evans et al. (2002) demonstrated that passive warm-up by using short-wave diathermy performed before eccentric exercise had more beneficial than active warm-up or no warm-up conditions in reducing swelling but did not help to diminish the loss of muscle strength, ROM, or soreness from muscle damage. Rahmani-nia et al. (2004) found the effects of warm up in reducing the severity of muscle soreness induced by eccentric exercise. Physical activity conducted before eccentric exercise have been reported to alleviate muscle soreness, the rise of CK, the fall of contraction force and decrease in range of motion the follow eccentric exercise. Mayer et al. (2006) demonstrated that continuous low-level heat wrap therapy has some benefits in the prevention of low back DOMS. The latest publication of the preventative study of DOMS with the heat, Skurvydas et al. (2008) showed the leg immersion in warm water before stretch shortening exercise could reduce muscle soreness after the exercise. Taking in to account, the previous studies of these passive warm up method for prevention of DOMS are still vary and need the controlled studied design to evaluate its effects.

2.2.2 Active strategies

2.2.2.1 Repeated bout effect

Weerapong et al. (2004) has reviewed the articles of DOMS prevention. She recommended "repeated bout effect" is supposed to be one of effective approach for the prevention of eccentric exercise muscle damage. It has been reported that the repeated bout exercise could affect on protective adaptation in muscle damage, as showed in soreness sensation, strength, and ROM loss, when these indications of the second bout of eccentric exercise are associated with the first bout. The repeated bout effect would have neural, mechanical, and cellular adaptation for the prevention of muscle injury (McHugh, 2003). Cleary et al. (2002) found an effective prophylaxis for perceived pain and muscular tenderness associated with DOMS is the performance of an eccentric exercise bout 6 to 9 weeks before a similar exercise bout. Nosaka and Newton (2002) showed that after the first bout of submaximal eccentric exercise of elbow flexors, the muscle strength took about 6 weeks to return to the baseline, whereas the recovery rate of muscle strength from immediately to 4 days post-exercise was faster after the second to eighth bouts compared with the initial bout. They also demonstrated that no increases in plasma CK activity were observed and development of muscle soreness was small after the second to eighth bouts.

2.2.2.2 Warm-up

In studies concerning the prevention of DOMS with warming up, researchers thought that training is the way to influence the severity of muscle damage. Nosaka and Clarkson (1997) found that 100 isokinetic concentric contractions of the elbow flexors before eccentric exercise of the same muscles resulted in less muscle damage than eccentric exercise alone. In the other way, Gleeson et al. (2003) showed that concentric training before eccentric exercise increased the magnitude of exercise induced muscle damage which demonstrated in muscle strength, circumference, ROM, and muscle soreness. The published literatures have shown uncertain results of training on severity of muscle damage.

Regarding to the review literatures, there is little scientific evidence to prove the effectiveness of prevention methods and little hypothetical foundation for recommending the success of the preventative physical therapy applications on DOMS due to limitation in scientific supported evidences. The preventive study for DOMS is still necessary in training as well as rehabilitation, for application to understand the scope of DOMS reflects the extent of muscle damage and its characteristics.