CHAPTER 2

LITERATURE REVIEW

This literature review comprises of four sections. The first section covers principle of a STS movement. The second section provides a review of anatomy of lower extremities. The third section provides a review of measurement of knee extensor muscle strength and endurance. The last section provides the review of functional STS tests.

2.1 Biomechanics of the sit-to-stand movement

Moving from sitting to standing (sit-to-stand or STS) is a form of movement commonly found in activities of daily life and is important in initiating other movements. Roebroeck et al (12) described that STS is a movement that controls the center of mass (CoM) of the body from low to high in the standing position without losing balance. STS movement can be explained by the kinematic and kinetic variables that standing from sitting is the movement in the horizontal plane as a result of the forward rotation of the upper body, while, the stretch of the lower extremity controls the vertical movement.

Nuzik et al (13) investigated the STS movement in 55 participants (20-48 years old) using a chair with 18 inches in height at self-selected speed. From kinematic analysis of the changes of body segments, 2 phases of STS movement were defined. The first, flexion phase was characterized by only the head movement in forward direction and second, extension phase presenting by the lower body segments in extended direction.

In 1990, Schenkaman et al (14) studied the STS movement and divided into 4 phases. The first phase (flexion-momentum phase or phase I) started with initiation of the movement and finished before the buttocks were lifted from the chair seat. In the period of phase I, the trunk and pelvis rotated anteriorly (toward flexion), generating upper-body momentum. The participant's femurs, shanks, and feet were not move. (Figure 1)

The second phase (momentum-transfer phase or phase II), started when the buttocks were lifted from the seat of the chair and finished when reached the maximum ankle dorsiflexion angle. Momentum transfer occurred when the momentum of the upper body developed in the flexion-momentum phase was transferred to the total body that made total-body moved upward and anterior.

The third phase (extension phase or phase III). Phase III was started after maximal ankle dorsiflexion and finished when the hip first stopped to extend. The point which hip extension was completed was difficult to indicate by using the plot of the hip angle. The researchers preferred to use the angular velocity of hip motion to define the end of phase III. Full extension was reached when hip angular velocity reached to 0°/sec.

The fourth phase (stabilization phase or phase IV). Phase IV started when the hip extension velocity reached 0°/sec and continued until all movements related with stabilization in standing were completed. The end point of phase IV was not easily indicated because there was no easy method to identify the difference between the postural movements caused by rising from chair and normal postural sway.

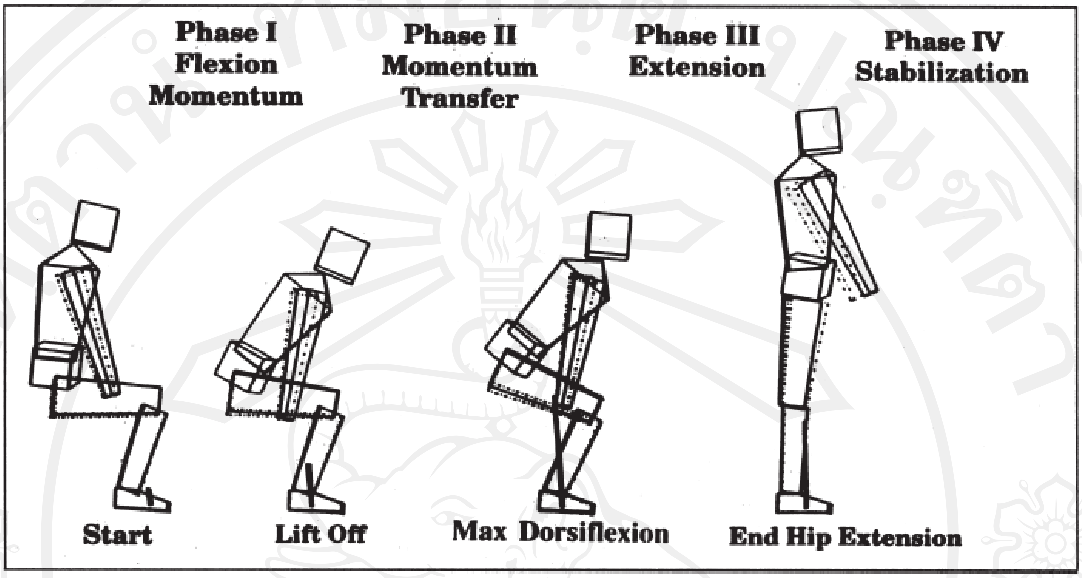

Figure 1 Four phases of sit to stand movement (14)

2.1.1 Sit to stand Movement Determinants (15)

From previous studies, the ability to perform the STS movement is strongly correlated with some factors such as seat height, use of armrest, foot position and lower extremity strength. These factors have been classified as chair related, strategy related and strength related determinants.

Chair-Related Determinants (15)

Seat height: The minimum seat height for successful rising for elderly people should be at least 120% of lower leg length. A decrease of seat height makes the STS movement more difficult or even failed. A lower seat makes it difficult to initiate a STS movement. It leads to increased angular velocity of the hip approximately 100% in order to stand and to more repositioning of the feet because of a lower seat height increases the displacement of the body's CoM over a larger distance. On the other hand a higher chair seat makes it easy to complete STS movement becauses decreasing in moments at hip and knee (up to 60% and 50%, respectively)

Armrests: When rising from chair with armrests, the moments at knee and hip reduce approximately 50% of the extension moment needed to perform the STS movement without influencing the range of motion of the joints.

Strategy-Related Determinants

Foot positioning: Shepherd et al (16) studied the effect of foot position at posterior, preferred and anterior positions. The result showed that the feet placed in posterior position provided shorter movement time, decreased hip flexion and knee extension speed and lower hip extension moment. While anterior placement position of the feet increased time in pre-extension phase caused increasing in STS movement time.

Trunk positioning/movement: Rising from a chair with more than 90° trunk flexion starting position led to a longer movement time than normal STS movement, the duration of the extension phase also became longer and slower time to seat-off. But the range of motion of the knee and ankle did not change.

Muscle strength determinants

Muscle strength is one of the variable that is necessary in successful of a STS movement. There are two major muscle groups involving in a STS movment: the knee extensor and hip extensor muscles. The knee extensor muscle and hip extensor muscles contribute 72% and 27% respectively (2). Weakness of knee extensor and hip extensor muscles lead to difficult or even unsuccessful movement as shown in elderly people or patients who had strength deficit of the lower extremity muscles. Muscle strength comprises of three main factors as follows (17, 18).

1. Force that generated by agonists muscle group (sum of force that each muscle generated)
2. The work of antagonists muscle group that coordinate with agonists muscle group.
3. Biomechanics of beam system

Moreover, there are several factors that affect muscle strength as follows.

1. Muscle architecture: The angle at which muscle fibers insert into the aponeurosis, the pennation angle, affects the force exerted on the tendon. This force can be calculated as the product of force generated by all fibres and the cosine of their pennation angle, assuming that the aponeurosis is parallel with the tendon. The larger the pennation angle, the lower the resolved force, leading to a reduction in resultant power per muscle volume. That means a pennate muscle produces lower force than a parallel-fibred muscle of the same volume (19).

2. Fatigue: High-intensity exercise leads to a rapid decline in contractile function known as skeletal muscle fatigue. Fatigue cause reducing in strength because the energy supply is lower while lactic acid is high in blood supply. Lactic acid is dissociated into lactate and H^+. Lactate ions would have effect on muscle contraction.
3. Training: An increase in strength can be achieved by resistance training exercise. Improvement in both neural adaptation and hypertrophy of muscle cause muscles to generate more force than sedentary people without resistance training.
4. Age: Maximum muscle strength is found in individual in range of 20 – 30 years old of age. After then muscle strength will gradually decrease. Maximum muscle strength of 65 years of age is approximately 80 percent of the strength of that one had between 20-30 years.
5. Sex: From the differences in physiology and structure of skeletal muscle, the male body is stronger than women. Due to the size of muscles and bones that larger from testosterone hormone effect. The average women have the strength and number of muscle fibers that are approximately two thirds of men. Moreover, difference in muscle strength between sexes also depends on the physical activity of woman or man. The male's participation in sport and activities help promoting muscle strength. While most women perform light activity such as housework, office work and crafts work.

2.1.2 EMG pattern of lower extremity muscles during a sit to stand movement

Several studies investigate the biomechanics of standing up and sitting down. Several reports indicated findings related to electromyographic (EMG) activity during the STS movement. In 1999, Khemlani (20) studied EMG profiles of selected six muscles of lower extremity during the STS movement. The results showed that, tibialis anterior muscle was the first muscle working to provide stability to the ankle and control the movement of the shin for initiate movement of the body in forward direction. Then rectus femoris and biceps femoris muscle have contraction. The rectus femoris muscle assists in the movement of the hip flexion and gives stability to the knee before knee extension phase because rectus femoris muscle is biarticular muscle. Iliopsoas muscle plays other important role on the pelvis at the start of hip flexion the movement. While the biceps femoris muscle commonly works as a knee flexor muscle which can provide pulling force to the shank backward at the ankle and instead of working to counter the activity of rectus femoris muscle to control stability of the knee shin. Moreover, biceps femoris muscle plays the role of initiating hip extension to stand up straight. After that vastus lateralis muscle was the next muscle to be contracted. It starts to activate just before the initiation of knee extension phase. It was the main force to stretch the knee. Gastrocnemius and Soleus muscles were the last muscles to be contracted, with onsets after thighs off a seat. It has been suggested that both of these muscles may contribute to postural stability during standing up and contribute to postural adjustments in the STS movement. Figure 2 outlines the pattern of muscle function associated with STS movement.

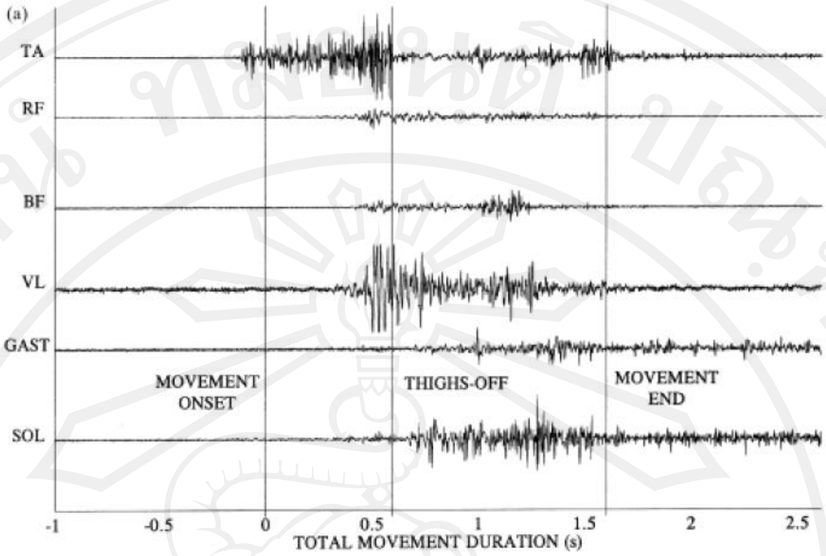

Figure 2 The pattern of muscle function associated with STS movement (20).

2.2 Anatomy of lower extremity (21, 22)

Lower extremities are part of human body which load body weight and play important role in locomotion. Lower extremity bones are strong structures which carry body weight and cooperate with neuromuscular system to make the movement. The lower extremity consists of the hip, thigh, leg, and foot. It is consisted of the femur , tibia , fibula, patella and foot bones. Muscles of the lower extremity can be divided into 4 regions: hip, thigh, leg and foot regions.

2.2.1 Muscle of the gluteal region

Gluteus maximus muscle is the largest and most superficial of the three gluteal muscles (gluteus maximus, gluteus medius and gluteus minimus muscles). This muscle is attached from the posterior gluteal line, posterior surface of sacrum and coccyx, and sacrotuberous ligament and inserts at gluteal tuberosity of the femur. The action of this muscle is to do hip extension.

Gluteus medius muscle is attached from the external surface of the ilium between the posterior and anterior gluteal lines and inserts at greater trochanter of the femur. The actions of this muscle are to do hip abduction and internal rotation.

Gluteus minimus muscle is the smallest of the three gluteal muscles. This muscle is attached from external surface of the ilium between the anterior and inferior gluteal lines and inserts at greater trochanter of the femur. The actions of this muscle are to do hip abduction and internal rotation.

In deep layer of gluteal region have 6 muscles such as gemellus, inferior, gemellus, superior, obturator externus, obturator internus, piriformis and quadratus femoris muscles. The action of these muscles is to do hip external rotation.

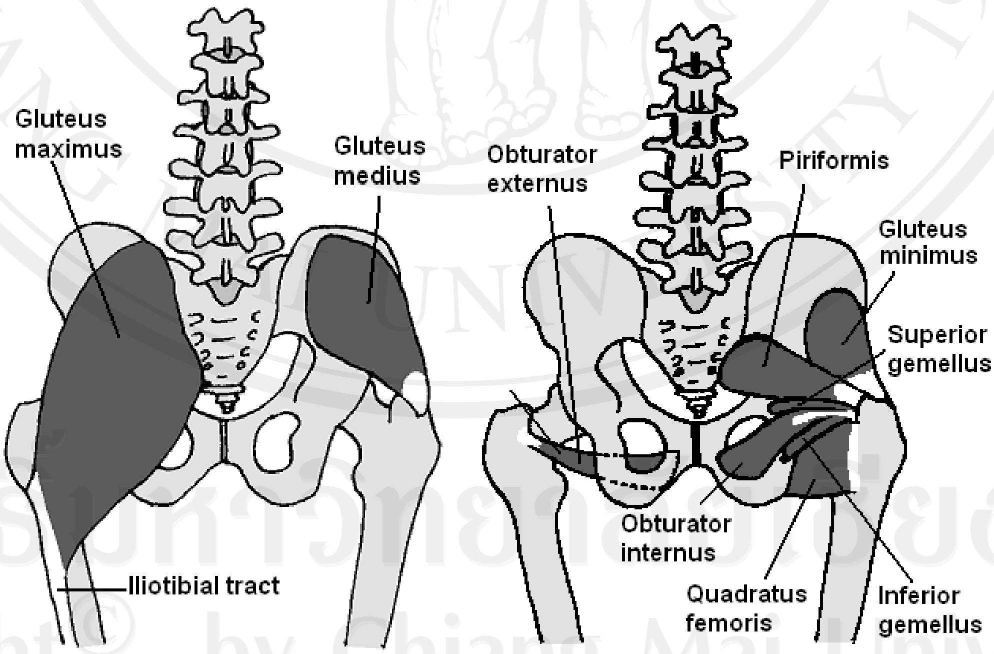

Figure 3 Muscles of the gluteal region (23)

2.2.2 Muscles of the thigh distribute in to 3 groups

Anterior group

Quadriceps femoris muscle is the large muscle, combine with 4 muscles: rectus femoris, vastus intermedius, vastus medialis and vastus lateralis. Rectus femoris muscle has origin on anterior inferior iliac spine and superior broader of acetabulum. Vastus lateralis muscle is attached from greater trochanter and lineaaspera of femur bone. Vastus intermedialis muscle place behind rectus femoris muscle which is attached from Anterior and lateral shaft of femur. Vastus medialis muscle place in medial size of thigh which has origin on linea aspera of femur bone. All four muscle tendons which called patella tendon inserted at the patella bone and extend down to the tibial tuberosity. All of 4 muscles have main action as knee extensor, and the rectus femoris muscle additionally flexes the hip joint as well.

Sartorius muscle is the long muscle that attached from the anterior superior iliac spine and cross down obliquely to insert at pes anserinus on the medial side of the knee. The sartorius muscle has role as a flexor on both the hip and knee joints.

Medial group

Adductor magnus muscle is attached on inferior ramus of pubis and ischial tuberosity, it inserts at linea aspera of femur bone. The main role of this muscle is a powerful hip adductor.

Adductor longus muscle has origin on pubic symphysis and has insertion at linea aspera of femur bone. The action of this muscle is to do hip adduction and flexion.

Adductor brevis muscle is attached on inferior ramus of pubis and goes to insert at lineaaspera of femur. The action of this muscle is to do hip adduction and flexion.

Pectineus muscle has origin on superior ramus of pubis and has insertion at posterior part of femur bone. The action of this muscle is to do hip adduction and flexion.

Gracilis muscle is attached on pubic symphysis and goes to insert at the medial side of the shaft of the tibia bone. The action of this muscle is to do hip adduction.

Posterior group

Biceps femoris muscle is a 2 heads muscle, a long head is attached on ischial tuberosity and a short head is attached on linea aspera of femur. Both heads have insertion at head of fibula bone and lateral surface of tibia bone.

Semitendinosus muscle has origin on ischial tuberosity and has insertion at medial side of the proximal head of the tibia bone.

Semimembranosus muscle has origin on ischial tuberosity and has insertion at medial condyle of tibia bone.

All of these muscles are known as hamstrings muscle which has the main action on extend hip and flex knee.

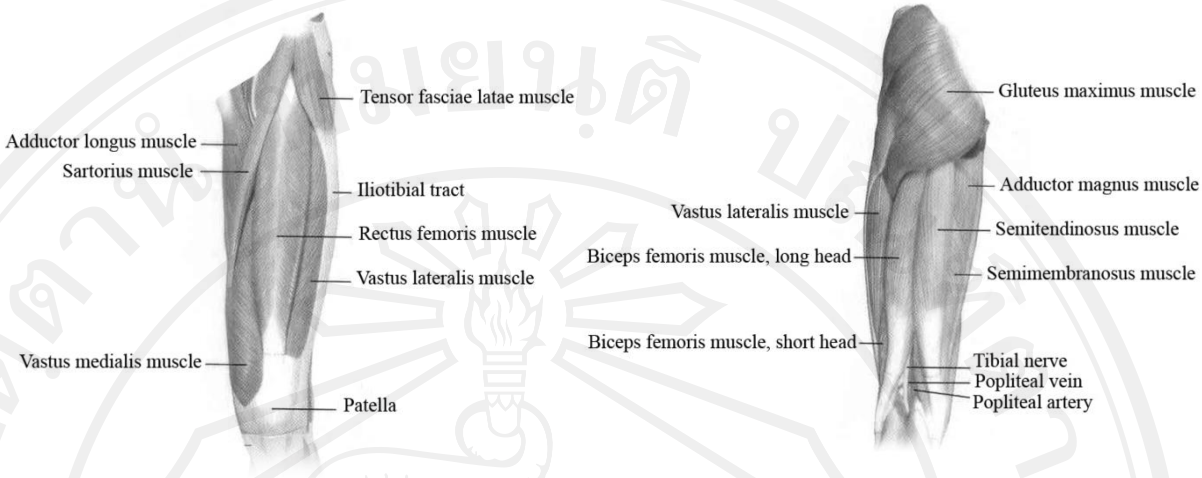

Figure 4 Muscles of the thigh (24)

2.2.3 Muscle of the leg distribute into 3 groups

Anterior group

Anterior group combines with tibialis anterior, extensor hallucis longus, extensor digitorum longus and peroneus tertius muscle. This muscle group is attached on lateral condyle of tibial bone, interosseous membrane and anterior surface of fibula bone. They insert at tarsals, metatarsals and phalanges bone. The main role of this muscle group is to do ankle doriflexion and digits doriflexion.

Lateral group

Lateral group combine with peroneus longus and peroneus brevis muscle which attached on lateral side of fibula bone and insert at metatarsals bone. The main role of this muscle group is to do ankle plantar flexion and ankle evertion.

Posterior group

Posterior group is combined with 2 subgroups: superficial and deep layer. For superficial layer compound with gastrocnemius, soleus and plantaris muscle. Gastrocnemius muscle attaches on medial and lateral condyles of femur bone. Soleus muscle attaches on proximal of tibia and fibula bone. Plantaris muscle attaches on femur superiorly lateral condyle. All of 3 tendons are joined in to calcaneal (achilles) tendon that inserts at calcaneus bone. The main role of this muscle group is to do plantar flexion.

Deep layer combines with popliteus, flexor hallucis longus, flexor digitorum longus and tibialis posterior muscle. This muscle group has origin on femur, tibia, fibula bone and posterior interosseous membrane and has insertion at tarsals, metatarsals and phalanges. The main role of this muscle group is to do ankle plantar flexion, digits plantar flexion and ankle inversion.

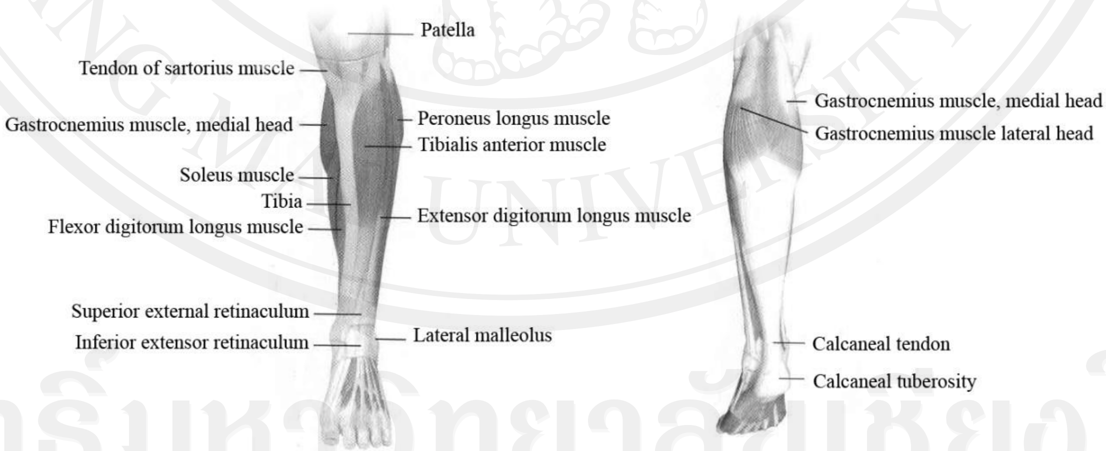

Figure 5 Muscles of the leg (24)

2.3 Measurement of muscle strength and endurance

2.3.1 Muscle strength measurement

Strength is an important part of the physical fitness. Many methods can be used to measure the strength of the muscles. Examples of standard methods in strength measurement are as follows.

One repetition maximum (1RM) method

One repetition maximum is the maximum amount of weight one can lift in a single repetition to measure the muscle strength and to assess training programs (25). However, the excessive efforts from musculoskeletal loading in 1RM testing may not be recommended for some people such as the elderly, cardiac patients, adolescents, and some sedentary people.

Isometric dynamometry

Isometric dynamometry is a method that measure muscle strength by tested force against the equipment. The test measurement is performed in a stationary condition (isometric contraction). Examples of the pieces of equipment used in this method include hand-held dynamometer and load cell. For measurement muscle, participants perform three maximal effort of knee extension with resting periods of 2 minutes between trials. If maximal values are lesser than 10% variability, the highest value of these three contractions is considered as the maximum voluntary contraction (MVC). However if an MVC variability is more than 10%, participants are required to perform the fourth trial to get three data that variability lesser than 10% (26).

Figure 6 Measurement of knee extensor muscle strength by use of hand-held dynamometer (27)

Isokinetic dynamometry

For isokinetic dynamometry, angular velocity at various levels can be adjusted to provide the speed of the test close to the speed of muscle contraction in each activity. For measurement of knee extensor muscle strength the participants are measured by isokinetic dynamometer in sitting position. The participants are tested for the maximal effort of concentric muscle contraction at selected angular velocities through a range of 5-95 degree of knee extension. For measurement of hip extensor muscle strength the participants are measured by isokinetic dynamometer in supine position. The participants are tested for the maximal effort of concentric muscle contraction at selected angular velocities through a range of 0-120 degree from full hip flexion to the neutral (28). All torques will be corrected for the effects of gravity on the lower leg segment (29). Five repetitive maximal concentric contractions perform for a test trial (29). The maximal concentric peak force of knee and hip extensor muscles from the three middle contractions will be recorded as peak torque values. Three middle contractions are used for preventing the effect of variability of motions which may produce at the beginning and nearly to stop motion. The knee and hip extensor muscle torque can be expressed relative to body mass (Nm/kg) to allow comparison across individuals (29).

Figure 7 Measurement of quadriceps muscle strength

by use isokinetic dynamometer

Leg press strength

Leg press is multi-joint movement that participant pushes a weight away from them by using their legs. The leg press can be used to evaluate overall lower extremity strength in isotonic, isometric and isokinetic dynamometry. Isokinetic leg press uses the isokinetic dynamometer same as normal single joint measurement. For ConTrex MJ isokinetic dynamometer, the participants are sitting on the seat that the backrest inclines 60° with floor. The tested foot attaches to the knee adapter which connected with dynamometer. Then the participants are facilitated to do the maximal effort of push the leg to extension at selected angular velocities (28). Five repetitive maximal concentric contractions perform for a test trial (29). The maximal concentric peak force of quadriceps muscle from the three middle contractions will be recorded as peak torque values. Three middle contractions are used for preventing the effect of variability of motions which may produce at the beginning and nearly to stop motion. The knee extensor muscle torque can be expressed relative to body mass (Nm/kg) to allow comparison across individuals (29).

2.3.2 Muscle endurance measurement

Muscle endurance is an important part of the physical fitness that indicates the ability of muscle to sustain repeated contractions against a resistance for an extended period of time. This is in contrast to muscular strength, which is the greatest amount of force that a muscle or muscle group can exert in a single effort. Many methods are used to measure the endurance of the muscles. Standard methods commonly used to measure the strength of muscles are described in the following section.

Isometric dynamometry

Isometric dynamometry is a method that measure muscle endurance by tested force against the equipment. The test measurement is tested in a stationary contraction (isometric contraction). The equipment that used in this method is load cell. For measurement of muscles endurance participants are instructed to maintain a pressure representing 60% of their MVC until exhaustion. A computer screen supply as a feedback to help participants maintain the contraction force at 60% MVC. Participants are strongly encouraged to attempt until force pressure reduce to 50% MVC. Muscle endurance is assessed by the time to fatigue, defined as the time which start when participants perform isometric contraction reach to 60% MVC and end at the force reduce to 50% MVC (26).

Isokinetic dynamometry

Isokinetic dynamometry is generally used to measure muscle strength, however, it can measure muscle endurance in low load high repetitive concept. For measurement muscles endurance the participants can be measured by isokinetic dynamometer. In Kawabata et al's study (30), participants were tested for the maximal effort of concentric muscle contraction at high angular velocities (180° per second) through a range of motion. Fifty repetitive maximal concentric contractions were performed for a test trial. The fatigue rate was used to represent the muscle endurance variable.

2.4 Functional sit-to-stand test

Due to some limitations of the isokinetic dynamometry in routine clinical testing, functional test is an alternative method that can be used to measure this particular part of physical fitness. STS is one of the functional tests often used in elderly to evaluate the leg strength. At present, there are several kinds of STS test, such as 5 repetition, 10 repetition and 30 second STS tests. For the 5 repeated and 10 repeated STS tests, participants perform the maximum effort to stand up and sit back 5 or 10 times as fast as possible. The outcome is time which start when the tester say "Go" and stop when the participants fully standing on the 5^{th} or 10^{th} repetition (6, 9). For 30 second STS test, participants perform maximum effort in repeated stand up and sit back as fast as possible. The outcome is the number of completed stand within 30 sec (more than halfway at the end of 30 sec is count as a full stand). The incomplete stand is not count (7).

Several previous studies were interested in the relationship between knee extensor muscle strength and STS test. The results of these previous studies suggested that the STS test is not consistently associated with knee extensor muscle strength (8, 9). In 2009, Takai et al (6) studied in 57 elderly about the relationship between cross-sectional area, maximum isometric voluntary contraction force of knee extensor muscles and the time to complete a 10 repeated STS test. The results confirmed that there was no relationship between time to complete a 10 repeated STS test and each of cross-sectional area and maximum isometric voluntary contraction force. However the power index calculated by time to complete a 10 repeated STS test, body mass and estimated CoM displacement was highly correlated with cross-sectional area (r = 0.80) and the maximum isometric voluntary contraction force (r = 0.73). This study indicated that the power of STS test was the variable which can used to assess knee extensor muscle strength in elderly individuals.

The power STS which is calculated from three variables: body weight, leg length and time that completed in STS test can be used as indicator for measuring the knee extensor muscle strength in elderly (6).

The relationship between muscle endurance and STS test has been suggested that STS test is not consistently associated with knee extensor muscle endurance (10). However there is no report in the relationship of power sit-to-stand and knee extensor muscle endurance at present.