CHAPTER II

REVIEW OF LITERATURE

2.0 Introduction

The purpose of this review will explore previous literature related to quantifying and comparing the level of muscle activation in exposure to traditional free weight, nautilus machine and elastic resistance exercises. This review will also discuss the acute neuromuscular hormonal responses following training with the aforementioned exercise modalities.

2.1 Variable Resistance Training

Before any resistance training prescription various features of musculoskeletal system must be considered. One of the most important parameters in this regard is known as the mechanical advantage of a musculoskeletal system (Elliott *et al.,* 1989). Mechanical advantage has been shown to be the direct product of length-tension relationship of the corresponding prime movers. It is well known that the torque generating capability of a muscle group varies with changes in the joint angle (the angle – torque relationship). For example, elbow flexors exhibit an ascending-descending strength curve in which at the full extension (beginning of lifting phase) muscle force capability is low, strength increases when approaching to the 90° and then decreases at the end of concentric phase again (Kulig *et al.,* 1984). This concept has been explained by changes in the length of the lever arm which influence the magnitude of resistance and changes in the length of the muscle which influence the rate of muscle strength (Baechle and Earle, 2000).

Mechanical advantage has also been highlighted as one of the most dominant underlying mechanism which can result in best muscle tension stimulation across all segments of the ROM. Numerous investigators speculated that equipments which is able to distribute an adequate external force in accordance with the length-tension relationship of skeletal muscles are also able to elicit greater neuromuscular adaptation (Anderson *et al.*, 2008). This is despite the fact that previous studies demonstrated that conventional dynamic constant external resistance (DCER) exercises cannot accommodate the external force required in some part of the ROM.

The DCER training has always been conveyed with some criticism about its drawback in providing an inefficient strength curve (Anderson *et al.*, 2008; Cronin, McNair and Marshall, 2003; Elliott *et al.*, 1989; Hodges, 2006). One of the most important concern which has been proposed against DCER is the large deceleration phase which has always been observed during the end of concentric phase in exercises such as biceps curl and knee curl (Anderson *et al.*, 2008; Cronin *et al.*, 2003). In this category of exercises, given that the torque generating capability is higher at the beginning of lifting phase, using a traditional DCER makes a magnitude of torque at the beginning of lifting motion which would shift to the end and decrease muscle stimulus (Harman, 2000).

It has been shown that a fast concentric motion would result in a high acceleration of leverage system and consequently require greater level and longer period of deceleration to terminate lifting motion (Hodges, 2006). Scientific evidence has shown that within the deceleration phase, not only the tension wouldn’t rise in the muscle but also the muscular system requires increasing muscle tension in the antagonist muscle to facilitate ending the motion (Page *et al.*, 1993).

In addition to these criticisms, a number of other concerns directed against DCER exercises manifested as:

1. Inability to simulate many sport specific skills by free weight exercises.

2. Dependence of the DCER apparatus on gravity and inertia which limit the number of exercises possible to perform with it.

3. Cumbersome and costly weight machines are always designed for practicing one or two muscle groups.

In conclusion, the inefficiency of DCER exercises in creating maximal neuromuscular tension across some ranges of joint angle in conjunction with concerns regarding the pattern of movements have convinced sport investigators and athletes looking for another viable mode of training which minimize these shortcomings (Anderson *et al.*, 2008).

The other criticism against DCER training is directed at exercises such as bench press and squat. In this type of exercise due to length tension relationship of the active muscle, the torque generating capability is weaker at the beginning of lifting phase (Ebben and Jensen, 2002; Elliott *et al.*, 1989; Wallace *et al.*, 2006). Therefore, using DCER, the magnitude of the load will be selected based on force generating capability of the subject at the weakest position. In such cases, given that the muscles are relatively stronger at the end of lifting, the low level of external load (selected for the beginning of concentric phase) would be shifted to the stronger joint angles and result in an inefficient neuromuscular activation. In fact, the inadequate level of external force at the stronger segments always does not approach the muscle into maximal stimulation.

Elliott and colleagues (1989) have entitled this weakness of DCER exercises as a "sticking point". A sticking point is described as the most disadvantaged joint angle in which incapability of external load in stimulating the musculoskeletal system can effectively limit the muscle strength development (Anderson *et al.,* 2008). Encouraged by this matter, there have been great attempts among sport scientists to minimize the sticking point via utilizing a mode of resistance training which provides higher loading at positions which musculoskeletal system is stronger.

Many investigations have approved that to gain the ability of generating maximal muscle force production (maximal strength) throughout various segments of ROM, the mechanical advantage of the active muscles must be considered. For this purpose, different modalities of resistance training have been suggested which among them accommodative dynamometers have been highlighted as the most beneficial mode of exercise (Manning *et al.,* 1990). However, high cost of these electronic dynamometers (e.g. Cybex and Biodex) has confined its application to the rehabilitational setting. Accordingly, athletes and recreational lifters have been seeking alternative modes of exercise which can offer advantages of isokinetic contractions and eliminate the shortcomings of conventional free weight. Based on this background, sport scientists recommended a series of exercise modalities which are now known as variable resistance training (VRT).

The VRT exercises are recommended to compensate the shortcomings of DCER. The designer of VRT exercise devices should consider the musculoskeletal structure of a particular limb and design their apparatus to change the magnitude of provided external resistance based on mechanical advantages and length-tension relationship of the active muscle. In other words, VRT exercise devices are being designed to be able to generate the greatest resistance for the strongest position of the muscle and the lowest resistance for the weakest position (Graves *et al.*, 1989).

Manning and colleagues (1990) identified VRTs as an exercise modality that "attempts to accommodate the muscle changing level of force output throughout the range of motion by varying the resistance produced". Fleck and Kraemer (2004) describe VRT apparatus as a training device which attempt to match the user's strength curve. They advocated the use of a VRT device as an exercise modality which can cause significant increase in strength. However, despite wide range of application among athletes and recreational lifters, very few scientific investigations have been devoted to scrutinize the possible physiological adaptations following training protocols using VRT training.

2.2 Nautilus Machine exercises

The inception of Nautilus Machine (NM) was based in 1948 upon the question; "what would be the effect if a device could be designed to require hard muscular work throughout the entire length of a muscle as opposed to a small fraction of the that length" (Nautilus Sport / Medicine Industries, 1980). In fact, the designers of Nautilus Machine exercise devices were truly aware of this key point that the interaction of every muscle and corresponding joint (musculoskeletal system) produce a unique strength curve (Wolf, 1980). In other words, they acknowledged this critical concept that torque generating capability of a muscle varies across the ROM.

Therefore, they speculated that to overcome the shortcoming of free weight exercises (DCER) the muscle must be overloaded throughout the entire range of motion by an external resistance which could match the strength capability of the muscle. For this purpose, they designed a type of training machine in that Cam-pulley was used to balance the resistance curve of machine with strength curve of active muscle by changing the biomechanical moment arm. These types of machines were designed to create a varying resistance curve in accordance with user's strength curve.

Figure 2.1 Nautilus Machine Leg Extension

After manufacturing nautilus training machines, many studies were required to substantiate the principle of NM exercises, however, only few research investigations have been documented in this regard. In a research by Cabell and Zebas (1999), they compared the maximum torque curve of elbow flexors during performing dynamic contractions by isokinetic dynamometer and Nautilus Multi-biceps Machine (NBM). For this purpose, they recruited 10 healthy subjects to perform biceps curl exercises by isokinetic dynamometer and (NBM) at selected velocity of $30.s^{-1}$, $45.s^{-1}$, $60.s^{-1}$. The data demonstrated that similar ascending-descending maximal torque curves for elbow flexors were obtained during both modes of exercise. With the exception at the middle of range of motion (45° to

75° of elbow flexion), the initial (15°-35°) and ending (80°-120°) segments of elbow flexion, significantly higher torque values have been observed for the NBM resistance curve than the maximum torque curve. The resistive torque curve of the NBM also demonstrated a flatter curve than the maximal isokinetic torque curve.

In another research by Manning and colleagues (1990) the effects of 10-week training program by DCER and VRT have been measured on strength development through all ROM in 49 healthy male and female subjects. In this investigation, both training groups performed their training on a Nautilus knee extension machine. Variable resistance was supplied by using a cam pulley and constant resistance was provided by a round sprocket. After completion of a 10-week training protocol, significant increases were found in isometric and dynamic strength in both VRT and DCER through the entire range of motion. The investigators speculated that VRT may have greater mechanical advantages during training due to varying the resistance provided. They have also suggested the possibility of greater potential for strength gain within the VRT group because of relatively greater external resistance provided within various segments of the range of motion.

Graves *et al.,* (1989) also investigated the effect of 10-week VRT training during limited ROM knee flexion exercises on strength development. In this research 59 male and females were randomly assigned in three training groups. One group were trained in a limited range of (0 - 60°), the second group limited at (60° - 120°) knee flexion and third group the full ROM. Following completing the three training protocols, investigators observed similar full ROM benefits in the half ROM resistance training as well. They indicated that VRT machine could provide a uniform training stimulus throughout entire ROM. However, opposing the main idea in VRT exercises, they demonstrated that the torque generating capabilities of VRT machine did not perfectly correspond to muscle maximal torque capabilities.

2.3 Elastic resistance

Elastic resistance has been defined as the property of an elastic material that returns to original resting position after stretching. What makes an elastic device a beneficial mode of training in the strength and conditioning domain is the magnitude of force which it produces when it recovers after a deformation. Elastic resistance (ER) has been considerably suggested by therapist and fitness instructors as an effective exercise device for a wide range of applications in the rehabilitation and fitness setting. A large body of literature shows the advantage of early, progressive rehabilitation exercise for all types of musculoskeletal conditions. These benefits include restoration of range of motion; decreased pain; decreased neural inhibition; quicker return of muscle function; and improved performance in sports and all daily activities (Hintermeister *et al.*, 1998; Hintermeister *et al.*, 1998b; Hopkins *et al.*, 1999; Tyler *et al.*, 2005; Decker *et al.*, 1999; Matheson *et al.*, 2001; Myers *et al.*, 2005; Page *et al.*, 1993; Swanik *et al.*, 2002). Rehabilitation concepts now emphasize functional activities and retraining of normal loading and movement patterns. It is especially important to regain full neurological coordination of the surrounding muscles and connective tissues, since that is the true source of joint stability. An important component in addressing these needs is the frequent use of exercise tubing, which can be accomplished at home, without substantial supervision (Mikesky *et al.*, 1994). Clinical literature has supported the advantages of rehabilitational training protocols by ER exercises for all types of musculoskeletal conditions (Decker *et al.*, 1999; R. Hintermeister *et al.*, 1998; Hopkins *et al.*, 1999; Matheson *et al.*, 2001; Muhitch, 2006; Schulthies *et al.*, 1998; Simoneau *et al.*, 2001).

Figure 2.2. Elastic tubing training device

In a research study by Hopkins *et al.*, (1999), they emphasized that the process of rehabilitation after Anterior Cruciate Ligament (ACL) injury or ACL reconstruction is a challenging issue. This is because applying the conventional exercise for quadriceps strength enhancement endangers the ACL graft. Based on this issue, they used elastic bands to study the rate of muscle activation in 3 muscles from anterior and posterior leg during carrying out 4 close chain exercises. The four selected exercises included: Unilateral one-quarter squat, lateral step up, flex cord (elastic material) front pull and flex cord back pull. They found elastic band as a safe mode of exercise, particularly within front pull motion, for ACL graft. They reported that within front pull exercise due to greater activation of hamstring muscle group (semitendenosus and biceps femoris) in comparison with quadriceps (vastus lateralis and vastus medialis) less stress was administered on ACL Graft. They also noticed that strong coactivation of hamstring muscles during a front pull exercise introduces elastic band as a safer means of activating quadriceps rather than the raditional quarter squat or lateral step-up.

In another study with very close methodology Schulthies *et al.,* (1998) measured the electromyographic activity of quadriceps and hamstring muscles (VMO, VL, ST, BF) during 4 elastic tubing closed kinetic chain exercises in postoperative patients with anterior cruciate ligament (ACL)-reconstructed knees. The exercises comprised of front pull, back pull, crossover, and reverse crossover. The EMG activity range from 25% to 58% of maximum voluntary isometric contraction was detected for various muscles in the 4 exercises. Although this range of EMG exhibited very low levels of muscle activation, they rather emphasized on this activation rate and suggested clinicians to use elastic exercises during early ACL rehabilitation stage.

On the other hand, since setup is easy to learn and requires little facilities, the ER device has been recommended to be used by patients with no gym or weightlifting experience (Mikesky *et al.,* 1994; Simoneau *et al.,* 2001). Duncan *et al*., (1998) prescribed ER training as a part of home-base cardiac rehabilitation protocol for individuals with mild and moderate stroke. Mikesky *et al.,* (1994) also suggested elastic exercise for home-based resistance training programs because they found ER as a practical and effective means of eliciting strength gains in adults over the age of 65. In their investigation, the adherence to, and the efficacy of a 12-week home-based progressive resistance training program was investigated for older adults utilizing elastic tubing (mean age, 71.2 years). The exercise group in this research exhibited a significant improvement in isokinetic knee extension (12%) and flexion (10%) strength.

Hintermeister and colleagues (1998) have investigated the rehabilitational effects of ER training by designing a series of different exercises on a progressive mode for rehabilitation of the knee after injury and surgery. Double knee dip, leg press, hamstring pull, single knee dip and side-by-side jump have been the exercises offered in this research in a gradual progression. Interestingly, although the exercise device in this research was the same (elastic tubing or thera-band), the data has indicated that the changes in exercise selection guarantee the progressive tension application for the given muscle. In addition, the recoil force of an elastic resistance device has been shown to be able to stimulate muscle for strength and endurance development and prevents excess strain on the joint in a rehabilitation protocol. Based on rate of muscle activation in each exercise they recommended a progressive exercise routine which can be accomplished via a correct exercise selection. For this purpose they recommended double knee dip, leg press, and hamstring pull the first stage (immediate), single knee dip for intermediate, and side-by-side jump for late rehabilitation protocol (the exercises in previous stogies are applicable in the current stage). They also proclaimed that wide variety of patients from those with non operative injuries to post-operative patients can utilize this exercise routine.

Elastic tubing is frequently used in shoulder joint rehabilitation. The goals of shoulder rehabilitation include progressive strengthening of the rotator cuff muscles, along with all of the muscles that move and stabilize the shoulder joints (Kibler, McMullen and Uhl, 2001). Traditionally, expensive machinery that isolated the muscles (and even controlled the speed of movement - "isokinetics") were thought to be needed; however, elastic tubing has been found to be a safe, effective method of providing progressive resistance exercises (Kibler *et al.*, 2001). An easy and commonly utilized program has been recommended to be started with an exercise routine using resistance tubing. This is initially performed within a limited, pain-free range of motion, building to full range as pain subsides. Once good exercise mechanics and control are demonstrated, a self-directed program of home exercises is always prescribed. Elastic tubing also permits exercises to be performed in diagonal and multiplanar motions, which are especially useful in functional shoulder rehabilitation for athletes.

In a research investigation conducted by Hintermeister *et al.,* (1998) the shoulder rotator cuffs have been studied according to the electromyographic activity pattern of muscle and applied load during shoulder rehabilitation exercise. They selected the resistance of the elastic tubing according to the initial resistance required for an entry level in a shoulder rehabilitation patient. Although healthy and active subjects have been assigned for this study, researchers selected the lower resistance of elastic band to simulate initial level of muscle activation required for the patient at the beginning of rehabilitation process to prevent injury of soft tissue. They suggested that rehabilitation exercises incorporating elastic resistance necessitate controlled movements and low initial loading which effectively target the rotator cuff and are appropriate for post injury and post operative patients.

Willett *et al.,* (1998) also a conducted a research in order to examine the effect of knee extension exercise by elastic resistance to evaluate the activation of vastus medialies oblique (VMO) and vastus lateralis (VL) ratio. In this research they used a 33 cm long loop of green thera-band. They indicated knee extension exercise using elastic resistance exercises can create 48% of MVIC muscle activation in VMO and VL and is an effective exercise for quadriceps strengthening. However they noticed that performing weight bearing knee extension exercise in contribution of elastic resistance cannot be effective for selectively activating the VMO more than VL.

Matheson *et al.,* (2001) studied muscle activation pattern (EMG) during 8 seated quadriceps exercise using free weight, elastic resistance, isokinetic dynamometer and IET device (Isoinertia apparatus). They reported that different seated quadriceps resistance exercises elicit various mean average quadriceps EMG activities. They demonstrated how different types of resistance lead to various patterns and magnitude of tension provided during exercise. They notified that despite the consistency of external resistance provided by conventional isotonic exercise apparatus, an undulating torque production EMG activation pattern was detected due to the changes in length-tension relationship and length of moment arm through the ROM. They inferred that the maximum resistance that can be moved is dependent on the muscle force generated at the weakest joint angle. Based up on this finding, it has been recommended that different levels of external torque could be provided by various exercise apparatus in a progressive knee rehabilitation training protocol. In this strategy, elastic resistance material (because of low level of resistance) and free weight exercises (because of inefficiency in providing maximal resistance in whole joint angle) have been recommended for the initial stages of rehabilitational protocol. However, highest peak and average EMG amplitude have been exhibited by the isokinetic machine.

Most of previous investigations about ER training have been in rehabilitation after injury or surgery. However, there are few research studies insisted that on preventing injuries rather than curing, particularly among athletic community (Myers *et al.,* 2005; Page *et al.,* 1993; Swanik *et al.,* 2002). One of the initial investigations in this domain was performed by Page *et al.,* (1993) on collegiate baseball pitchers. In this research, Thera-band tubing was used to improve shoulder stability and enhance performance of baseball pitchers by strengthening the posterior rotator cuff in an eccentric contraction form. They concluded that utilizing ER not only prevents overuse injuries in baseball pitchers but also enhances proprioceptive interaction between agonist and antagonist muscle in the shoulder and improves performance. One decade later, Page and Ellenbecker (2003) wrote a comprehensive book on the application of ER for rehabilitation and injury prevention in different sports**.** They emphasized in ER as an excellent mode of training for enhancing stabilization of joints in exposure to different stresses and overuse injuries in upper and lower extremities.

Further support for this concept come from a research study by Swanik and colleagues (2002). In this investigation, swimmer`s shoulder, has been identified as “the most common orthopedic pathology in competitive swimmers” and it has been introduced as a collection of symptoms such as rotator cuff tendonitis, impingement syndrome, instability and subacromial bursitis that are consistent among swimmers. In this study subjects participated in a 6-week functional training program that consisted of 7 exercises by elastic resistance and dumbbell to improve the posture as well as to reduce pain in the shoulder. Significantly less incidence of shoulder pain was reported among swimmers who participated in the aforementioned training protocol. Although the training protocol did not result in strength improvement in resistance trained group, the reduction of shoulder pain has been indicated as desirable neuromuscular adaptations that could culminate to improving muscle performance.

In another study on swimmer`s shoulder, Kluemper *et al.,* (2006) advocated the idea of using elastic resistance for preparation of athletes and noted that stretching anterior shoulder soft tissue and strengthening posterior shoulder muscle with ER could reduce forward shoulder posterior and cause pain attenuation in competitive swimmers. Swimmers were selected for this investigation because 35 % of them at all levels reported shoulder pain. The possible cause of this pain has been associated with the strength imbalance of the anterior shoulder muscle which would result in protraction of scapula and pulling the shoulder forward. However, 6-weeks of a stretching and strengthening protocol by elastic training corrected the posture (acromion process closer to the wall) and reduced the pain in the shoulder joint. Based on this data elastic strength training has been highlighted as a positive element in injury prevention among swimmers.

Page and Ellenbecker (2003) also reported that instability of glenohumeral joint in exposure to different stresses, enhancement scapulothrocic dynamic stabilization and overuse injuries of elbow and wrist make upper extremities an excellent candidate for application of elastic band for rehabilitation and injury prevention in relevant sports. Based on this school of thought, Muhitch (2006) conducted an investigation to study the effects of utilizing free weight and Thera-Band elastic devices on shoulder rehabilitation. For this purpose, she compared the average and peak muscle activation of three shoulder rehabilitation exercises. Eight healthy male subjects completed 3 shoulder exercises and electromyographic data was collected from anterior deltoid, middle deltoid and biceps brachii muscles. The magnitude of external resistance was equalized by using a 10 pound dumbbell and a black Thera-Band elastic device. She found no significant difference in the level of muscle activations between the two devices. Therefore, she concluded that both elastic resistance and free weight devices affected the working muscle in the same manner. However, despite observing similar muscle activation levels between elastic resistance and free weight, since low level of external resistance applied in this research, the results must be interpreted cautiously for the athletic setting.

The boundaries of applying elastic resistance have not been limited to rehabilitational purposes. A number of scientists have suggested ER training for achieving further musculoskeletal adaptations in healthy and trained populations (Behm, 1988; Treiber *et al.*, 1998). These studies have advocated the proficiency of ER in providing sufficient muscle tension throughout the range of motion and speculated that ER may result in further muscular adaptations in healthy and trained individuals (Hodges, 2006; Hughes *et al.*, 1999; Lim and Chow, 1998; Muhitch, 2006; Myers *et al.*, 2005; Ward, Paolozzi, Maloon and Standard, 1997). This concept supports Matheson *et al.*, (2001) that states "elastic resistance is a viable alternative to the use of free weights of similar resistance".

In an investigation by Lim and Chow (1998) electromyographic activity of selected arm muscles has been compared between dumbbell and elastic tubing devices while performing biceps curl exercises. Each of 10 healthy subjects performed one set of 5 repetitions in two different intensities of 10-RM and 20-RM for each exercise device (2 load × 2 devices). In fact, as opposed to previous studies in this research no equalization has been assigned between training modes; rather, 10-RM and 20-RM was assigned as the criterion for exercise intensities. In both Pectoralis Major and Biceps Brachii muscles significantly higher values were observed for the elastic device in late concentric and early eccentric, while statistically higher values were observed for dumbbell at early concentric and late eccentric phase of movement. For Brachioradialis dumbbell elicited significantly higher value in early concentric and late eccentric than elastic resistance. It is very interesting that in all other segments of range of motion elastic devices elicited equal muscle stimulation compared to dumbbells. On the basis of these data, they concluded that two resistance apparatus resulted in different level of muscle activation within different segments of range of motion. However, they also noted that considering other issues such as safety of exercise, elastic resistance is preferable to free weights for individuals with low upper body strength.

After proposing the initial thought of using ER for developing muscle performance among healthy and trained individuals in mid 1990s, a number of research studies were conducted to compare the benefits and shortcomings of the ER device and traditional free weight training (Ghigiarelli, 2006; Lim and Chow, 1998; Page and Ellenbecker, 2003; Wallace *et al.,* 2006). Ward and colleagues (1997) highlighted the thera-band as a strengthening device and proclaimed that no significant differences in strength scores were found at post-training between the thera band and free weight groups. They concluded that regarding the principle of "specificity of training and neural learning" a training protocol using thera-band can be as effective as much as free weight exercises. A research study by Matheson and colleagues (2001) also advocated this idea that elastic tubing demonstrated similar EMG activation and peak load in comparison to the free weight exercise performed at the same angular velocity. They concluded that elastic training is a viable alternative to the use of free weights of similar resistance.

Hughes *et al.,* (1999) calculated and compared shoulder torque provided by elastic resistance and free weight apparatus during a shoulder abduction exercise. Subjects were asked to perform 5 repetition of shoulder abduction with 6 tubing colors (totally 30 repetitions) in a way that in every repetition, arm positions were momentarily hoeld at angles of 30°, 60°, 90°, 120°, and 150°. They assessed the moment of strain in elastic-tubing and calculated the torque generated at the shoulder joint which is the product of the recoil force of elastic resistance and perpendicular distance from the line of action of the band to the shoulder joint axis of rotation. In accordance with research expectations, they demonstrated strong linear relationship between tubing tension and tubing elongation through entire range of motion. However, interestingly, an ascending-descending pattern of strength curve (torque angle curve) was observed for both modes of resistance exercises (elastic band and weight training).

The ascending-descending strength curve demonstrated by Hughes *et al.,* (1999) could partially resolve the concern over using elastic resistance and completion of the concentric phase. In fact, some previous investigators have been skeptical that, because tensile force in the ER device increases with further elongation, a subject may not be able to generate adequate muscle torque to overcome the corresponding force at the end of the concentric phase. Their assumption had been based on physiological characteristic such as filament overlapping at the end of concentric phase and ascending resistance curve of the elastic material. However, Hughes and colleagues (1999) demonstrated how mechanical factors such as alteration in the length of the resistance arm (the perpendicular distance from joint axis of rotation to the point of resistance application), angle created by the force vector and longitudinal axis of the limb (angle of band to the arm) can offset the linear pattern of resistance-angle curve of elastic material to change it to ascending-descending pattern of torque-angle curve.

Further evidence advocating ER for athletic purposes comes from research studies by Treiber *et al.,* (1998) with the purpose of determining the effects of resistance training on shoulder strength and serve performance. In this study, in opposition to the previous research, not only college tennis player were appointed as subjects but also their performance (the peak and average velocity of services) was estimated by nonclinical and functional performance tests (eight maximal services). They utilized elastic tubing and light weight dumbbells instead of an Isokinetic dynamometer. They noticed that although previous research had observed enhancement of serve velocity and shoulder rotator strength for the trained players using the isokinetic dynamometer, access to an isokinetic machine is restrictive for the athletic population. Therefore, they proclaimed substitution of elastic tubing and lightweight dumbbells instead of the isokinetic dynamometer. After administrating 4-week training protocol with these affordable training devices they observed 17 to 24 % increases in shoulder strength, as well as improvement in serves velocity in college tennis players. In spite of the fact that scientists reported significant impact of elastic resistance (17 to 27 %) in improving physical fitness in untrained and trained individuals, little attention was given to elaborate and interpret the causes of these adaptations. In other word, among those scientists that inspected the influence of elastic training on physical fitness of individuals, few of them analyzed the underlying adaptations.

Hostler *et al.*, (2001) described a significant increase in percentage of muscle fibers (IIAB), muscle cross section area, capillary contact and capillary ratio per fiber type after 8 weeks of training with sport cords. Because in this research they had one experimental group (sport cord trainers) they couldn’t compare the results with the adaptations from other resistance training mode.

Another unique mechanical advantage of elastic resistance exercises is the fact that utilizing elastic material makes the participant able to accelerate the limb throughout the whole concentric phase of contraction (Anderson *et al.,* 2008; Hodges, 2006; Wallace *et al.*, 2006). As has been outlined in the literature, all lifts involve some acceleration at the beginning from zero to upward velocity and some deceleration near top of the lift to bring the bar`s velocity back to zero (Baechle and Earle, 2000). With this acceleration pattern, the agonist muscles exercise stress in excess of the bar weight early in the range of motion but muscle stimulation less than the bar weight toward the end of the range of motion. The lifter decelerates the bar by either (a) reducing upward force on the bar and/or (b) pushing down against the bar using the antagonist muscle. In either case, the deceleration phase has the effect of providing less resistance to the agonist muscle late in the ROM”. However Hodges, (2006) elucidated that the mechanical advantage of an elastic material in increasing the external moment of force as more elongated, eliminate the activation of antagonists in creating a decelerating force and makes the prime movers to increase the force tension in the entire ROM.

In conclusion, regarding this evidence and given the documented benefits of ER in an athletic setting such as the ability to perform exercises similar to a sport-specific pattern and providing an ascending-descending strength curve, it would be of interest to introduce ER as a viable training apparatus for enhancing physical performance in athletes. However, more investigations are required to measure the magnitude of muscle stimulation and elaborate underlying mechanisms of strength development when performing exercise by ER.

2.4 Material properties of elastic resistance

Not all sports require the same state of strength, power and endurance. Consequently, based on selected exercise intensity and current state of strength, different individual needs different magnitude of external resistance to lead the neuromuscular system to the threshold of adaptation. Therefore, manufacturers of resistance exercise apparatuses design their devices in the way that it could provide various levels of external load. The manufacturers of elastic resistance devices also have taken this concept into account and have been producing elastic material in a spectrum of resistance in the way that it could be utilized for various applications. Thera-bands and tubing are being produced in several color-codes and each color denotes a specific resistance level (Simoneau *et al.,* 2001). Selecting the resistance of the elastic material among different applicants depends on the initial state of the health and fitness (e.g. injured individual vs. healthy and strong athlete) and the goals of training program (e.g. increase strength, coordination, balance or athletic physical performance like power and quickness). Scientists unanimously believe that regardless of the initial length, the magnitude of strain in an elastic device is a function of thickness of material and percentage of deformation during the trial (Hughes *et al.,* 1999; Patterson *et al.,* 2001; Simoneau *et al.,* 2001).

In order to avoid undesirable aspects of an elastic training protocol such as overtraining and/or undertraining, scientists recommended accurately measuring the amount of resistance that can be generated by various types of tubing denoted by color-codes and different percentages of elongation in elastic material (Patterson *et al.,* 2001). The procedure of this measurement comprises of calculating the linear prediction equation for elastic material. For this purpose, a looped peace of tubing was stretched in series with a load cell in 25% increments to 250% of its original length (www.thera-band academy.com). The average load cell value of 3-5 trials at each percentage of elongation represent recoil of force provided by elastic material. However, nowadays most of the manufacturers of elastic resistance devices are measuring the recoil of force for their products and publishing the magnitude of resistance per centimeter along with tables. Table 2.1 provides details about Thera-band stren4gth index for various color of elastic material. The behavior of an elastic material under tension is described in physics by Hooke`s law (for more information see Page and Ellenbacker, 2003).

Table 2.1. Average Force (pounds) for Thera-Band Elastic Bands.

% Elongation	Yellow	Red	Green	Blue	Black	Silver	Gold
50%	2	25	3	4.5	6.5	8.5	14
100%	3	4	5	7	9.5	13	21.5
150%	4	5	6.5	9	12.5	17	27.5
200%	5	6	8	11	15	21	33.5
250%	6	7	9.5	13.5	17.5	25.5	40

NOTE: "Percent Elongation" refers to the amount of stretch in the band or tubing compared to resting length. For example, a 100% elongation equates to stretching a band to twice it's resting length. The Table is adapted from Hughes *et al.,* (1999) Resistance Properties of Thera-Band® Tubing During Shoulder Abduction Exercise. J Orthop Sports Phys Ther, 29(7), 413-420.

Hughes *et al.,* (1999) assessed resistance characteristics of 6 color code of thera-band tubing (Hygienic Corporation, Akron, Ohio) as the product of the band recoil force. They assessed the moment of strain in elastic-tubing during performing shoulder abduction exercise. In accordance with research expectations, they demonstrated strong linear relationship between tubing tension and tubing elongation through the entire range of motion. They reported the magnitude of tension in elastic materials from minimum of 3.3 N for the yellow to a maximum of 70.1 N for silver tubing during 30° and 150° of shoulder abduction exercise, respectively. Elastic tubing deformation was expressed in relation with original length (resting length) of elastic material from minimum of 18% stretch (low angle of abduction) to 159% (extreme range of shoulder motion).

Simoneau *et al.,* (2001) assessed magnitude of tensile force of elastic band and tubing material (Hygienic Corporation, Akron, Ohio) to establish stress strain relationship. Linear actuator was utilized to provide control repeated mechanical stretching and force cell to measure the tension produced by the elastic material. They selected a 20- and 40-cm length yellow, green and black color of elastic material as representators of different resistance spectrum and stretched each unit at 100% and 200% of elongation. In advocate of the finding by Hughes and colleagues (1999), relatively linear relationship was found between percentage of deformation and the tension provided by tubing and bands. Furthermore, an ascending-descending pattern of strength curve has been reported following calculation of torque generating shoulder internal and external rotators. They exhibited higher resistance that elastic band can provides in compare elastic tubing types in some colors of elastic material.

In another research study by Patterson *et al.*, (2001) material properties of 6 color codes of Thera-Band Tubing (Hygienic Corporation, Akron, Ohio) has been quantified by a standard material testing machine. Similar results as Simoneau *et al.*, (2001) and Hughes *et al.*, (1999) were reported in this research, except that part which Patterson and colleague found a nonlinear resistance curve in the initial stretching phase and linear behavior after 50% of elongation. However, neither Simoneau nor Hughes did mention any thing about this issue and they reported linear resistance curve throughout entire range of motion. Nevertheless, the magnitude of force generated by various color code of elastic material in was not significantly different in compare with previous research studies. In conclusion, in order to avoid relaying on experimental approach of training prescription and to be able to manipulate the intensity of exercise program, quantifying the force-elongation of elastic material seems quiet to be critical.

2.5 Initial elongation of elastic resistance devices

Scientists believe prescribing resistance training in contribution of elastic device without recognition of force-elongation properties of Thera-Bands or Tubing can make contraindicating result in rehabilitation and athletic setting (Newsam, Leese and Fernandez-Silva, 2005; Page and Ellenbecker, 2003; Patterson *et al.*, 2001). A number of previous investigators have warned about the consequences of inappropriate external resistance selection in clinical setting. The unpleasant aspects of selecting an inappropriate magnitude of resistance has been manifested as either 1) inflammation and deformity of musculoskeletal organ due to carrying out intensive training and putting extra stress on the injured limb; 2) inability to approach threshold of adaptation due to inadequate external resistance. Consequently, overtraining and detraining have been enumerated as the results of wrong external resistance selection. In advocate of this concept, Simoneau and colleagues (2001) notified that recognition of resistance generated by elastic device (tensile force) in conjunction with amount of deformation (strain) is the key component in achieving optimal training intensity.

Failure in providing high tension development in initial segments of range of motion (beginning of concentric phase) has been the major concern of athletes and sport instructor in utilizing elastic resistance. Baechle and Earle, (2000) stated that "…development of strength may be retarded under training conditions that do not allow high tension development in the early part of range of motion". On this basis, most of the recent studies using elastic resistance for developing athletic performance, concentrated on combining traditional free weight and heavy elastic bands to administer sufficient stress on the muscle at the beginning of concentric phase (Anderson *et al.,* 2008; Cronin *et al.,* 2003 ; Ebben and Jensen, 2002; Ghigiarelli, 2006; Wallace *et al.,* 2006).

In these investigations, varies percentages of weight plates have been replaced by heavy elastic bands. For example, Wallace *et al.,* (2006) replaced 20 % and 35 % of total weight in smith machine with elastic bands. Despite a significant increase was reported for peak force, peak power and rate of force development after combining elastic material and free weights, several limitations was manifested for the method. Additional cost of equipment, additional time required for setup and remove of the bands, and time required for precise calculation of percentage of the weight and bands are the issues that depreciate the time and effort efficiency of this mode of exercise.

As mentioned earlier, the magnitude of tensile force in elastic device is a function of thickness of material and percentage of deformation during the trial (Hughes *et al.*, 1999; Patterson *et al.*, 2001; Simoneau *et al.*, 2001). Therefore, changing the color code of elastic device and using higher resistive elastic unit is the method recommended for improving the provided external resistance. However another key factor for enhancing the tensile force of elastic device has been highlighted as the initial elongation or percentage of strain before executing the main stretching. “Resting length” and “initial elongation” of elastic device are the two terminologies which are always used alternatively to address the starting length or percentage of deformation in elastic material prior to main stretching.

Simoneau and colleague (2001) have defined resting length as “… the length of the material with the slack taken out but with no stretch applied”. Another definition which has been propounded in therapeutic research community identifies the resting elongation as the length of elastic device equal to length of lever arm (Hughes *et al.*, 1999; Matheson *et al.*, 2001; Page and Ellenbecker, 2003). For instance, Hintermeister *et al.*, (1998) have defined the initial length of elastic material within performing leg press exercises “…the elastic resistance device was taut with subject`s knee and hip at maximal flexion”. Based on this method of determining the initial length, elastic resistance doesn’t provide any external moment of force exactly at the beginning of range of motion and consequently the prime movers wouldn't be properly activated to create any neuromuscular adaptation (Hodges, 2006).

In addition, selecting the resting elongation equal to length of lever arm (seems to be more insisted in clinical setting) delimits the percentage of deformation from 0% to 100% from beginning to the end of ROM (Hodges, 2006; Simoneau *et al.,* 2001). Despite the fact that, force-elongation values obtained from various percentage of deformation was reported from 0% to 250% of Thera-Band by Hughes *et al.,* (1999) and Simoneau *et al.,* (2001) . Therefore, 0% to 100% of deformation for different color-codes of elastic band induce a very low to moderate moment of force which is manifested as resistance suitable for primary rehabilitation programs for individuals after injury or surgery (Page and Ellenbecker, 2003; Simoneau *et al.,* 2001).

For example, maximum tensile force provided by various color codes of Thera-Band elastic devices at 100% of elongation has been reported from less than 7 N for yellow to less than 50 N for silver color elastic material. In conclusion, selecting unstretched initial length (0%) for the beginning of ROM could be indicated as a limitation in using elastic device, particularly if this mode of training is used for developing physical performance in athletic setting.

Reviewing the prior documented literature reveals that there are various methods for selecting the initial elongation of elastic material. For instance, the blue color of elastic tubing (Flex Cord) with 188.82 cm (6 feet) initial length has been selected by Hopkins *et al.,* (1999) for practicing close chain exercises for rehabilitation of knee. They mentioned that this color code of the tubing represent the medium tension. However, since utilizing other color code of elastic material with shorter length also can elicit the same magnitude of force, they have not elaborated why this long of device was selected for the study.

In a study by Herman and colleagues (2008), a leg extension task by ER device was assigned to be performed at 60 % of MVIC. This magnitude of tensile force was arranged to be achieved when elastic material was at 100 % of elongation. To materialize the overload progression regulation, the level of resistance was increased by 10 % (adding elastic units to the current unit of elastic device) when subject was able to meet the appointed repetition for each set without compromising the correct technique.

Matheson *et al.*, (2001) reported that, according to Thera-Band lower body instruction manual (Hygienic Corporation), the length of elastic device was determined as a looped piece of tubing with 32 centimeter in diameter. This length has been justified in an attempt to supply similar external moment to that of the ankle weight and Inertia Exercise Trainer load used in their study. Selecting this starting length and color code of elastic band (32 centimeter of blue color) for all the 52 participants has ignored distinctive personal anatomical and torque generating capabilities in different subjects.

Treiber and colleagues (1998) selected the elastic tubing color code which cause fatigue by the 20^{th} repetition (20 RM) without compromise the true techniques of internal and external rotation and horizontal shoulder abduction exercises. They announced that the length of elastic device was sufficient to make the participant feel fatigue at the end of each set without compromising the form of exercise; although, no further details were provided regarding the initial or percentage elongation of elastic device during each mode of exercise. However, they have notified that the tensile force was increased by changing the bands color code of elastic material (red, to green, to blue). They also notified that using the next grade of elastic material (stronger colour code) resulted in increasing 25% of external force. The internal and external rotation and horizontal shoulder abduction exercises have been focused in their research because initially, they had thought these particular exercises have usually been using in clinical setting for rotator cuff strength development.

As previously mentioned in this chapter, selecting the resting elongation equal to length of lever arm (or longer) delimits the percentage of deformation from 0% to 100% from beginning to the end of ROM and provide a very low to moderate moment of force (P. Page and Ellenbecker, 2003; Simoneau *et al.,* 2001). On this basis, a number of scientists have recently speculated about reducing the initial length of elastic material. This method is an approach to increase provided tensile force of elastic device and consequently enhance the muscular stimulation at the initial segment of ROM (Hodges, 2006; Simoneau *et al.*, 2001). In accordance with this strategy, Wallace *et al.,* (2006) recommended selecting the initial elongation of the elastic resistance in the way that there is still slight tension on the band at the end of eccentric motion. They reported that if the bands are taut at the end of eccentric phase, extra muscle stimulation is required to move the segment at the end of eccentric and beginning of concentric phases.

In a study by Hodges (2006), an intra-elastic-device alteration has been scrutinized to overcome drawback of elastic resistance training mode. Intra-elastic-device alteration was defined as changing initial length of elastic band. In opposite to clinical approach that recommends selecting the resting elongation of elastic device equal as length of lever arm, (Page and Ellenbacker, 2003), this investigator examined the effects of shorter initial length of elastic tubing. He evaluated the impact of 30% reducing in length of elastic material on resultant joint moment (RJM) within performing internal and external shoulder rotation. He reported that changing elastic strain strategy from 0 to 30 % increased amount of applied load to the joint up to 272 % in the concentric and 430 % in the eccentric phase. This increase in elastic moment may overcome the weakness of elastic resistance exercises in providing required neuromuscular stimulation.

He also notified that in this case, using the term “*resting elongation”* doesn’t make sense any longer; because, the band or tubing is already elongated and it provides some tension prior to any further deformation. In this situation, the muscle produces an isometric force at beginning of range of motion. Thus, initial elongation is another terminology which could be used in any situation to have a better understanding about starting length of elastic material. It is however worth mentioned that, based on Page and Ellenbacker (2003), reducing the initial elongation of elastic material (less than the length of the lever arm) may cause some changes in the strength curve or torque generating pattern of the appointed muscle.

Now, based on the method of shortening the initial length of elastic material, some might thought the concerns are resolved in terms of muscle activation level at the beginning of concentric phase. However, the results provided by Hodges (2006) indicated that even shortened elastic tubing provides less average resistance and consequently lower neuromuscular adaptation than the free weight at this particular segment of ROM. These findings necessitate extra investigations to elaborate the actual effects of reducing initial length of elastic device on level of muscle stimulation.

Simoneau and colleagues (2001) have discussed about the importance of the initial and final deformation of the elastic material in providing resistance torque during elbow internal and external rotation. They examined green color of tubing material in 3 different initial elongations comprises of 2 elastic device longer than length of lever arm (0.78 m and 1.56 m) and 1 elastic device shorter than length of lever arm (0.39 m). The length of lever arm was 0.58 m. Then, each elastic device was stretch 0.58 m. The elastic materials elongated 74.4% (for 0.78 m band from 0% initial deformation), 36.7 % (for 1.56 m band from 0%initial deformation) and 148 % (for 0.39 m band from 100 % initial deformation). They elaborated the effects of various initial elongation of elastic device in torque generating capabilities of internal and external shoulder rotator muscles in different segment of range of motion. A considerable increase in the peak and average torque generation have been observed following utilizing the bands with 100% initial elongation (pre-stretched) compare with 0% initial elongation. Regarding the significant role of initial deformation in resistance provided by elastic device, they notified that the color of elastic material shouldn`t be the sole parameter of prescribing the ER training in clinical and fitness setting.

However, further analyses by Hughes *et al.*, (1999) reveals that the highest possible rate of provided resistance by standard elastic material is 80 N (silver color at 250% elongation) which seem not to be enough for trained athletes. So, despite decreasing the initial elongation of elastic device, the provided tensile force might not be sufficient for leading the muscle to threshold of adaptation in athletic setting. Therefore, the question that arises regarding the present data is “how can we equip ER device to provide higher force for athletic application”?

This issue could be resolved by doubling various color codes of elastic material. Kraemer *et al.*, (2000) suggested that greater tensile force could be achieved either by using thicker band or by adding up less resistive bands to the initial unit to meet the necessary amount of tension to maintain the target number of repetition (repetition maximum zone ± 1 rep). However, to best of our knowledge, there is no documented investigation which has examined the effects of adding extra units to the current unit in magnitude of external resistance as well as pattern of torque generating capability.

2.6 Fatigue in elastic material

Attenuation of tensile force in elastic material over the times of utilization is known as fatigue. Fatigue has been focused as one of the most important physical properties of elastic material which should be considered in exercise prescription. Page and Ellenbacker, (2003) have warned clinicians to be careful about the losing resistance of elastic material which must not be mistaken by strength enhancement in patients. Although quality of material is the vital parameter in maintaining the tensile force of elastic device, amount of attenuation in resistive force has been attributed to the rate of mechanical deformations (number and percentage of stretch cycles which elastic material exposed with).

Research studies which quantified the rate of resistance attenuation following mechanical deformation of elastic material indicated that "… *the more often the material elongated the more the material lose its ability to generate tension*"(Simoneau *et al.*, 2001). In order to test the reliability and to determine the resistance properties of the elastic tubing, Matheson *et al.*, (2001) suggested stretching a looped piece of tubing in series with the load cell 25 to 250 % of its original length. The average value of load cell for five trials at each percentage of elongation were taken as the moment of resistance for given deformation. This procedure was completed before and after an experiment including 501 times stretching of elastic materials 100 % of the initial elongation. Nine to 12% attenuation in resistance of the Thera-Bands was observed following the experiment. Naturally, this value has been raised up 10 - 15 % when the tubing and band material was stretched to 200 % for the same number of mechanical elongation.

It is worth mentioned that initial 50 stretch cycles created the highest decrease in tension. Based on this finding, clinicians and sport instructors have been recommended to select the resting length of elastic device in the way that it would not get stretched higher than 200 % within each repetition. Otherwise, the elastic device will lose its tensile force faster and needs to be substituted with a new device. In this case, for increasing the external force provided by elastic device adding more units in parallel of the current unit has been recommended.

2.7 Normalizing moment of force between ER and DB

It is well known that to study the biomechanical and physiological effects of two modes of resistance exercises, first, we need to equalize the external magnitude of force between the two modes of contraction. By equalizing the magnitude of force between to modes of exercise, any subsequent results could be attributed to the mode of contraction (pattern of provided external resistance) rather than simply the magnitude of force. Based on this concept, balancing the magnitude of weight in traditional free weights and recoil force in elastic resistance device (by adjusting the initial elongation and color code elastic material) has been subject of some research studies which intended to compare physiological and biomechanical parameters (EMG, torque production, neuromuscular fatigue, etc) between the two modes of exercise.

Previous research studies proposed different methods of normalizing the external moment of the force between elastic resistance and traditional weight training. For instance, in clinical setting, some scientists recommended equating force between ER and DB based on the magnitude of resistance in elastic material at the middle of ROM. However, in athletic setting, it has been suggested to calculate the average resistance provided by elastic device throughout the whole ROM (Anderson *et al.,* 2008; Wallace *et al.,* 2006)

Simoneau and colleagues (2001) compared the resistance torque generation capability of subjects during elbow internal and external rotation using a green Thera-band elastic material and a 17.75-N (1.81 kg) hand held weigh. In this study, the resting length of Thera-band was 0.78 m and it was elongated 74.4 % of its resting length. On the basis of the regression equation suggested for calculating tensile force of elastic material, a green Thera-band with aforementioned resting length and percentage of elongating can generate 19 to 23.3 N resistances. The data indicate that the magnitude of elastic force is very close to the hand held weight at the beginning of ROM. However, the resistance of elastic device increases 50% higher than hand held weight at the end of range of motion. No explanation has been provided by the researcher regarding the possible distinction in magnitude of torque production in favor of ER device due to higher external force at the end of concentric phase.

In another research by Muhitch (2006), a 10 pound dumbbell and a black Thera-Band elastic resistance device were used to comparing the average and peak muscle activation during 3 shoulder rehabilitation exercises. Since this research was held based on rehabilitational purposes selecting relatively low external loading is completely justifiable. They notified that black Thera-Band was used to create close resistance to the 10 pound dumbbell. The resting length of elastic material was personalized for every subject and measured from hand (the spot of gabbing the band) in full arm extension to the origin of the band under subject`s foot. They stated that after full flexion, the band was approximately doubled in length (100% stretches in elastic material in full flexion). For both shoulder abduction and shoulder flexion exercises, the length of the arm and the distance from hand to ground were relatively the same. Therefore, the resting length of elastic device was completely in line with the clinical recommendation (Page and Ellenbacker, 2003). However, in terms of biceps curl, since the distance from hand to ground is definitely longer that the length of resistance arm (hand to elbow), elastic resistance could not have been elongated 100 percent. Based on this information black color Thera-Band couldn't have provided equal external load than 10 pond dumbbell.

However, opposing to the research by Muhitch (2006) which the length of elastic material was personalized based on participants anatomical features, in a research study by Matheson *et al.,* (2001) the length of elastic device was determined as a looped piece of tubing with 32 centimeter in diameter. This length has been justified in an attempt to supply similar external moment to that of the ankle weight and Inertia Exercise Trainer load used in their study. Selecting this starting length and color code of elastic band (32 centimeter of blue color) for all the 52 participants has ignored distinctive personal anatomical and torque generating capabilities in different subjects.

Among all of the documented investigation, Lim and Chew (1998) employed Repetition Maximum based (RM) or fatigue-limited method as a novel technique to equalize the magnitude of external force between elastic resistance and weight training exercises during performing 10 RM and 20 RM biceps curl motion. In fact, in this approach the limiting factor in determining the magnitude of external resistance was the fatigue induced by training. Therefore, the external load was added or removed to exactly meet the number of required RM.

Treiber and colleagues (1998) also employed the repetition maximum strategy for selecting external elastic force. They reported that the length and color of elastic material (resistance) was selected to make the participant feel fatigue at the end of each set without compromising the form of exercise. In this situation, no specific equalization is necessary between two modes of exercise. Based on this technique, the other parameter also could be compared including:

1) Resistive profile of each exercise mode.
2) Magnitude of external force in various phases of ROM.
3) External force / rate of muscle activation ratio.
4) External force / number of possible RM in each mode of exercise.

2.8 Loading profile differentiation

In order to prescribe an efficient training program and achieve desire athletic performance, recognition of the loading characteristics of employed resistance exercise is quite critical. In the other word, understanding the strength curve of the acting muscle and resistance curve of the training apparatus may facilitate optimal exercise prescription. Based on this school of thought, the loading profile of various resistance apparatuses and torque generating characteristics of different muscle groups have been analyzed in clinical and sport setting (Welsch, Bird and Mayhew, 2005). Lim and Chow (1998) devoted a research study to elaborate the loading profile of elbow flexors within performing biceps curl by ER and DB. They have also measured mean EMG muscle activation to compare muscle tension in different segment of exercise cycle. They selected the first 5 repetitions (during carrying out 10-RM and 20-RM) and divided each repetition to 6 phases (3 concentric and 3 eccentric). For this purpose they used a goniometer to make sure that all phases comprised of similar angle of ROM. the mean EMG in each phase has been calculated and compared with analogous phase in the other mode of resistance exercise. The results demonstrated that elbow flexors exerted higher muscle force during the early ascending and late descending phase of biceps curl exercise with DB training; however, force production in ER was greater in late ascending and early descending phase of contraction. Later, this ascending resistance profile of elastic device was taken to demonstrate that this mode of exercise could be an ideal mode of contraction for those muscle groups which require higher external force at the end of concentric phase. In the other word, ER exercise can approach muscles to their adaptive threshold in exercises such as bench press and leg squat because the provided resistance profile by ER is completely compatible with strength generating capability of the corresponding muscles.

However Lim and Chow`s investigation was confined to EMG data collected and no torque resistance generation has been quantified and compared within performing elastic resistance and traditional free weight exercise. Furthermore, since recent studies reveal the role of change in exercise velocity in alteration of the loading profile of muscle during whole range of motion (Hodges, 2006), lack of denoting the angular acceleration during the exercises in analyzing and interpretation of the data make the result of the research doubtful.

In another research by Hodges (2006) the resultant joint moment was measure during shoulder internal rotation exercise by elastic resistances. For this purpose, every repetition of internal rotation was segmented to four phases (P1, P2, P3, and P4) and the instantaneous loading characteristics during elastic resistance exercises have been elaborated. He calculated the relationship between angular acceleration, moment of inertia in the upper limb segment and moment of elastic force. The data in his research has advocated the findings of Lim and Chow (1998) about efficiency of elastic material in providing more tension at the end of concentric and beginning of eccentric phase of exercise cycle in low velocity of contraction. However, in fast cadence of movement the story is completely opposite. Because, he has shown that in fast velocity of contraction, increase the acceleration of movement at the initial part of internal rotation (P1) created a moment of force that shifted to the end of concentric phase and resulted in less tension requirement in this phase (P2). In addition, increase acceleration of movement at early eccentric phase resulted in reducing the tension on the muscle at in this phase (P3) because the vector of movement and of tensile elastic force (pulling back) is at the same direction. Consequently, the created moment of force at the early eccentric phase would have shifted to the end of eccentric and required an additional muscle tension to stop the movement at this phase (P4). Based on these results, he has concluded that in addition to recoil force of elastic resistance, the velocity of contraction and weight of the limb segment has directly impact on all moments acting about a joint.

However, more research studies are required to expand the finding of this investigation because: 1) comparisons in this research are all intra-elastic resistance device and no comparison have been made with any other training apparatus. 2) No Electromyographic data collection has been conducted to support the idea by demonstrating the alterations of neural activation pattern of the muscles in various segment of motion.

Overall, based on this background, it could be indicated that progressively increasing the external resistance of the elastic material at the end of the concentric phase decrease the deceleration phase and extend the amount of time to fully accelerate the muscle through the range of motion. Furthermore, Increase tensile force especially at the end of eccentric phase due to pulling down features of elastic material result in higher eccentric velocity and ultimately greater force requirement to stop the momentum of action. Nevertheless, comparing the mean EMG level muscle activation of agonist and antagonist muscles during elastic resistance and weight training protocol can elaborate loading pattern of muscles following these two modes of training.

2.9 Strength development

Documented studies which specifically measured the effects of elastic training in developing muscle strength are very scarce. To best of our knowledge, the investigation conducted by Mikesky *et al.*, (1994) is the only case in this regard. In this study the effects of 12-week home-based progressive elastic training program has been investigated on older adults. For this purpose, sixty-two subjects (mean age, 71.2 years old) were randomly assigned to either the exercise (E) (n = 31) or non-exercise (NE) group (n = 31). The training protocol for E group comprised of 12 elastic resistance exercises that performed 1-3 sets of 10-12 repetitions. This program completed three times a week and involved muscles of both the lower and upper body. The NE group continued their normal lifestyle. The results have demonstrated that the magnitude of elastic resistances employed during workouts increased significantly (82%). After completion of training protocol also the E group demonstrated a significant increase in isokinetic eccentric knee extension (12%) and flexion (10%) strength. No other significant changes were observed between E and NE groups. These results suggested that home-based resistance training programs utilizing elastic tubing can serve as a practical and effective means of eliciting strength gains in adults over the age of 65.

In addition, we are unaware of any documented research study which quantified and compared muscle strength and muscle endurance improvement following absolute elastic training and conventional weight training. However, there are documented investigations in literature which have studded the strength development following bungee-weight training programs (combination of heavy elastic bands and free weight) known as Combined Training (CT). The predominant ideology of adding up the elastic material to the traditional free weight bar is referring to this concern that absolute elastic device cannot provide sufficient external force to approach the muscles to its threshold of adaptation. In such a case, further strength development would not happen, particularly in larger muscle groups such as knee extensor or chest muscles (Anderson *et al.,* 2008; Cronin *et al.,* 2003 ; Ebben and Jensen, 2002; Wallace *et al.*, 2006).

In a study by Cronin *et al.,* (2003) forty male subjects volunteered to participate in10 weeks of ballistic weight training in the form of bungee and non-bungee squat exercises. Participants have been assigned in 2 experimental and one control group. Experimental groups separated in non-bungy jump squat and bungy jump squat groups which completed a protocol of 2 weeks preconditioning and 8 weeks training program in contribution of supine squat isoinertia machine. Various muscle function and functional performance tests such as electromyographic analyze, kinetic and kinematic values, strength, power, agility, single leg jump, and lunge test has been tested to compare the effect of these two modes of contraction. Both experimental groups demonstrated improvement in several strength and power measures. In addition, as far as training stimuli concern, both mode of contraction have offered similar rate of training stimulus. However, the higher peak velocity and EMG activity have been observed in later stage on eccentric contraction in bungee-weight training group.

Although both modes of contraction have shown to increase magnitude of maximal strength, relative strength, peak velocity and peak force, it has been hypothesized that higher velocity employed in bungee group might result in greater demand for force development (Cronin et al 2003). However more research studies are required to show the effects of absolute elastic material and weight training in non-ballistic resistance training. The results in the study of Cronin and colleagues must specifically be interpreted it its own context and is not extendable to absolute elastic device because:

1. The differences in position of squat exercise in supine isoinertia machine and standing squat method.
2. Different loading profile of bungee weight exercises compared with absolute elastic resistance exercises.
3. The ballistic technique carried out in this research may increase activation of the muscle in greater portion of the concentric phase and result in increase force production through entire range of motion.

These findings were supported with those of Wallace *et al.,* (2006) which demonstrated significant difference in peak force and peak power exerted during CT training in compared with traditional free weight. In this research, subjects performed back squat exercises with 60% and 85% of 1RM with and without using elastic band. In addition, two different elastic band conditions were examined at each of two resistances

(60% and 85% of 1RM). In fact, subjects performed back squat when one time 20% and another time 35% of the total load in barbell (in each exercise intensity) were replaced with elastic band. The data in this study demonstrated that using CT training device can demonstrate significantly higher peak force and peak power output compared with conventional free weights. As pointed out earlier (referring to biomechanical feature of elastic resistance), taking full advantage of length tension relationship of skeletal muscle result in optimize muscle activation through the range of motion in variable resistance exercises. However, the main reason that no significant difference observed between CT and conventional squat regarding strength and power enhancement has been attributed to small percentage of the overall load which was replaced by elastic material. In fact, perhaps if a greater percentage of total load (< 35%) had contributed by elastic material then significantly greater changes between two groups would be expected.

In another study by Anderson *et al.,* (2008), forty four trained male and female subjects randomly assigned in treatment and control groups which contributed in 7 weeks CR and FWR (Free Weight Resistance training) program respectively. They had hypothesized that CR training could provide better muscular stimulation to enhance strength, power and body composition following of 7 weeks of training protocol. Wave like progressive periodized training protocol comprises of 3-6 sets × 2-10 repetitions with 72-98% of 1-RM has been undertaken by the participants 3 sessions per week. The findings of this research supported its hypothesis and have demonstrated that using heavy elastic band resulted in greater gain in strength and power following 7 weeks training program, whereas the greater strength and power gain have been attributed to neural and muscular adaptations. The underlying neuromuscular adaptation for this result manifested as:

1. alteration in overall muscle recruitment pattern due to changes in loading profile of CR training.

2. greater type IIx muscle fiber recruitment due to approach the muscle closer to its maximal capacity in CR training group.

However the lack of measuring the EMG activity of the muscle in both mode of contraction left the component of this adaptation uncertain.

2.10 Possible underlying mechanism of strength development

2.10.1 Neural Adaptation

Resistance training is known as a physical activity that can lead to increase strength and force development measured by using dynamic (1 RM), isometric (MVIC) or explosive action (measuring the rate of force development). The underlying mechanisms of increasing strength following resistance training have been manifested as neuromuscular, hormonal and morphological adaptations (Folland and Williams,2007). However, what remained equivocal is that at what extent each mechanism contributes in increasing muscle strength. In other words, at what extend each neural adaptation or muscle hypertrophy may take responsibility for strength development.

It is well known that neuromuscular adaptations have major role of developing strength at the initial stage of carry out high intensity resistance training (2-8 weeks). Sale *et al.,* (1990) and McBride *et al.,* (2003) discussed about relatively disproportional increase in muscle strength compared with muscle hypertrophy, named as “increase muscle specific tension” and attributed this phenomenon to neural adaptation. Additional increase in muscle strength, happening in later phases by strength training, however has been associated with muscle hypertrophy (Behm, 1988; Hakkinen *et al.*, 1998; Kraemer *et al.*, 2002; Kraemer and Ratamess, 2004; Sale, D. Sale, 1988).

Ahtiainen and colleagues (2003) declared that the contribution of neuromuscular adaptation may become less accounted for strength development in athletes with a long training background. They stated that the muscular hypertrophy and strength development in trained athletes are correlated to hormonal regulations rather than neural adaptations. Before Ahtiainen et al., (2003), some investigators had propounded this idea when they found a greater acute increase in testosterone response following heavy resistance exercises in experienced athletes than unskilled weight trainer (Kraemer *et al.,* 1992, Hakkinen *et al.,* 2001).

Nonetheless, the supportive evidences for the concept of increasing muscle specific tension and neural adaptation include:

1. increase in strength without changes in muscle hypertrophy.
2. increase strength in contralateral untrained limb following training (cross-educational strength enhancement).
3. reduce integrated-EMG (IEMG) in a given load after resistance training program.

Further investigations elucidated the dominant neuromuscular responses that contribute in strength development following carrying out overloaded resistance training programs (Amiridis *et al.,* 1995; Hakkinen *et al.,* 1998; Sale, 1988). Among various possible mechanisms Behm (1995) emphasized on:

i. increase in neural drive which would result in increase motor unit recruitment.

ii. increase in selective recruitment of type II muscle fibers known as fast twitch muscle fibers (FT).

iii. increase rate of coding (MU firing frequency).

iv. motor unit synchronization.

v. reducing co-contraction of antagonist.

vi. increasing contribution of synergist.

vii. increase in reflex potentiation.

Among various proposed methods for evaluating possible neuromuscular adaptations (e.g. Increase in strength without changes in muscle hypertrophy and Cross-educational strength enhancement) surface electromyography (EMG) has been shown to be an acceptable method for measuring level of activation and changes in rate of muscle stimulation (Basmajian and Deluca, 1985; De Luca, 1997; Konrad, 2005). Hortobagyi *et al.,* (1996) and Maestu *et al.,* (2006) recommended surface electromyography as a viable method for quantifying the muscular activation potential and assessing the alteration in muscle tension with resistance training over a period of time (McBride *et al.,* 2003). In addition, EMG has been shown to be a reliable method for estimating muscle fatigue noninvasively (Ahmadi *et al.,* 2007; Komi and Tesch, 1979; Moritani *et al.,* 1982).

2.10.2 EMG

Surface electromyography has been introduced as a technique for recording physiological properties of active muscles at rest and during exercise (Basmajian and Deluca, 1985; De Luca, 1997; Konrad, 2005). Electromyographic signals monitor neuromuscular action potential comprised of two fundamental types of parameters:

frequency and amplitude. EMG signals directly reflect firing frequency and motor unit recruitment characteristic of the detected motor units within the interested muscles.

Konrad (2005) stated that typically bipolar electrode configuration and a differential amplification are utilized for kinesiological EMG testing. Depending on the spatial distance between electrodes, a monopolar action potential create a bipolar signal (depolarization-repolarization cycle) with a differential amplification. Regarding that a motor unit is consisted of many muscle fibers, a pair of surface electrode detects the magnitude of all innervated fibers within a motor units. Monitored signal in surface EMG process is the sum up of a triphasic motor unit action potential, which varies in form and size depending on the geometrical fiber orientation in ratio to the electrode site. In other words, the motor unit action potential of all motor units detectable under the surface electrode site is electrically observed as a bipolar signal.

Regarding the capability of EMG process in distinguishing between situations, McCaw and Friday (1994) proclaimed that a particular EMG system is more powerful when it can identify higher percentage of differentiation between two similar tasks. However, there are some external factors influencing the EMG signals which may distract researcher from the reality (Konrad, 2005). These parameters are tissue characteristics, physiological cross talk (especially ECG in upper body), changing the distance between electrode (detection surface) and muscle belly (signal origin), and external noise due to movements of leads, electrode and preamplifier. However, various techniques have been proposed to minimize the interference of these artifacts (Basmajian and Deluca, 1985; Hopkins *et al.*, 1999; Konrad, 2005).

Evaluating the electromyographic components such as amplitude, frequency; power spectrum, zero crossing, and area under the signals have been marked to demonstrate possible adaptation mechanism following a training program. Sale (1988) has attributed increase in EMG after resistance training (within performing maximal muscle action) to:

1. increase motor unit recruitment.
2. increase motor unit firing rate.
3. decrease in subcutaneous fat on the active muscle.
4. increase surface area of hypertrophied muscle fibers.

In line with these findings, Oliveira and Goncalves (2007) have hypothesized that the EMG amplitude and frequency can demonstrate training-related differences. More specifically, they have attributed increase in EMG amplitude of prime movers to motor learning characterised by increasing motor unit recruitment and motor units synchronization. These changes in magnitude and pattern of motor unit recruitment have been highlighted as the major adaptations which would culminate to strength gain. However, they did not rule out the probability of hypertrophic adaptation in increase EMG amplitude following 8 weeks dynamic training program.

However, some evidences demonstrating ability of subject to recruit all motor units before resistance training (Hortobagyi *et al.,* 1996; Caralon and Cafarelli, 1992; Jones and Rutheford, 1987). For instance, Caralon and Cafarelli (1992) reported that all subjects could activate all motor units at pretest stage and no increase in integrated EMG (IEMG) in agonist muscle has been reported after 8 weeks training program. They concluded that they couldn't find any evidence which support the idea of improving neural drive or force-generation capacity that would contribute to MVC force development after participating in resistance training. Thus, in one hand increase in integrated EMG and in the other hand lack of significant alteration in responsible pathway keep the underlying mechanism of increase in IEMG equivocal.

Despite that strength development has been accredited as a product of neural and structural adaptations (e.g. increase neural activation and the develop muscle CSA), McBride *et al.,* (2003) stated that "EMG value do not always change directly in accordance with changes in force production or strength, but do serve a general indication of changes in the amount of muscle activity present at any given point in time". In support of this concept, scientific evidences reveal that decrease or increase in electromyographic values could not positively be correlated with changes in force production (Hakkinen *et al.,* 1987). In addition, some other research studies also have demonstrated that time-course for EMG changes and changes in force production or strength value do not always coincide (Hakkinen *et al.,* 1998).

These evidences explicitly support the research outcomes reported by Higbie and colleagues (1996). They have described integrated EMG (IEMG) measurement as a way to assess degree of electrical excitability of the muscles. They have notified that IEMG could be affected by the number and size of motor unit recruited, frequency of stimulation and synchrony of firing. However, the changes in IEMG do not reflect other possible neural adaptation such as activation of stabilizers or antagonists. Thus EMG shouldn't be considered as a measurement of all neural adaptations.

Hopkins and colleagues (1999) have discussed about relationship between force production and IEMG values. They have notified that due to firing rate, recruitment patterns, muscle fiber type, muscle length, and contraction area, EMG neural activity may not be directly related to muscle and joint forces. However, they have suggested some experimental conditions which must be met to be able to interpret muscle force from electromyographic impulses. These criteria include:

1. Controlling the velocity or rate of action within performing exercise via utilizing a metronome.

2. Measuring the force production and EMG values of different phase of contraction independently (concentric and eccentric).

3. Having each participant complete each of the exercises without removing the electrodes in order to control the length-tension relationship of the muscle.

There are some studies in the literature utilized EMG testing for measuring the muscle activation during elastic resistance exercises; however, most of them are revolving around evaluating the muscle activation potential after injury or surgery (Hintermeister *et al.*, 1998; Schulthies *et al.*, 1998). In addition, we are completely unaware of any study which attempted to quantify the changes in EMG parameters following elastic resistance strength training program and compare it with other conventional strength training.

In addition to monitoring the changes in the amount of muscle activity, the surface electromyogram signals has been extensively used to study muscle fatigue (Kroon and Naeije, 1991). Muscle fatigue has been identified as "failure of the neuromuscular system to carry out a previous determined task" (Kroon and Naeije, 1988). Intensive muscle activities induce fatigue which reflects in deterioration of maximal force production, muscle endurance capacity and changes in various components of EMG signals. Arendt-Nielsen and Mills (1988) indicated that recording and analyzing various parameters of electromyographic signals may facilitate better understanding about the source of muscle fatigue.

Quantifying modifications in the EMG activity of the fatiguing muscles provides further insight about the time course of fatigue-related physiological processes. It is well known that exercises which conclude muscle fatigue would result in decrease strength and endurance output and reduce electromyographic activity measured from the muscle in the maximal voluntary contraction test (Arendt-Nielsen and Mills, 1988; Kroon and Naeije, 1988).

Some investigators have attributed the underlying mechanism of muscle fatigue to biochemical causes such as accumulation of byproducts such as lactate (Ahmadi *et al.*, 2007; Linnamo, Bottas and Komi, 2000; Oliveira and Gonçalves, 2008), decrease in intracellular pH (Arendt-Nielsen and Mills, 1988) and substrate depletion (Komi and Tesch, 1979). Central nervous system factors, the neuromuscular junction and failure of muscle fiber themselves have been the parameters that were manifested as underlying mechanism fatigue. Traditionally, three parameters which have been recommended to quantify the changes in the EMG during fatigue are:

1. muscle fiber conduction velocity.
2. mean power frequency of the EMG spectrum.
3. summated or integrated measure of overall EMG amplitude

Central fatigue is identified as an attenuation of muscle activity and force output due to a decrease ability of the central nervous system to elicit motor unit activation. (McCaulley *et al.*, 2009). Kroon and Naeije, (1988, 1991) approved that muscle fatigue could be evaluated through the changes in electromyogram signals of a muscle. They explained that carrying out heavy eccentric and concentric contractions would result in mechanical damage of muscle fiber identified as broadening or total disruption of the Z-bands. This muscle disruption would result in reduction of the K^+ gradient across the muscle fiber and affect the electrical excitability of the membrane. Consequently, this would result in decreasing muscle fiber conduction velocity and the shifting EMG power spectrum to lower frequency.

On the other hand, the other source of fatigue can be defined as peripheral which has been identified as the failure of force generation by the muscle, due to metabolic by-products accumulation and decrease excitation contraction coupling (Bigland-Ritchie, Furbush, and Woods, 1986). There are evidences in which supported similar pathway of affecting lactate accumulation on reducing frequency of EMG power spectrum. More specifically, increase H^+ and reducing PH in the muscle has shown to affect the excitation-contraction coupling process which ultimately results in reduction muscle fiber conduction velocity and shift of EMG power spectrum to lower frequencies.

This phenomenon together with recruitment and non-fatigued motor units and alteration in frequency discharge of motor units have been shown to gradually shift the EMG power spectrum to lower frequency during isometric contractions. The rate of reducing in frequency of EMG power spectrum has been correlated to the endurance capacity of the muscle and has been supported as an indicator of local muscle fatigue.

Among various components of EMG signals, Median frequency MDF is recommended variable for the study of muscle fatigue and damage (Ahmadi *et al.*, 2007; Komi and Tesch, 1979; Moritani *et al.*, 1982). The MDF is the point at which the spectral power is divided into equal low and high frequency halves. It has been shown that increase post exercise blood lactate shift EMG power spectrum to lower frequency via diminishing conduction velocity of the muscle fiber action potential (Kroon and Naeije, 1991). On this basis, estimation of changes in surface electromyogram signals such as median frequency has been recommended as a noninvasive method for determining muscle fatigue (Arendt-Nielsen and Mills, 1988). The MDF represents information about:

1. conduction velocity of the muscle fiber
2. shape of motor unit action potential
3. mean firing rate of individual motor units
4. the recruitment of MU.
5. the extent of superposition of action potential from concurrently active MUs.

However, the process of neuromuscular fatigue is known to be highly task-dependant (Bosco *et al.,* 2000). Previous studies have observed that the magnitude and source of fatigue may vary when different contraction type, intensity, repetitions speed, and rest period are incorporated into the resistance training protocols. Sale (1987) have advocated this idea and stated that those resistance exercise protocols arranged to develop muscle strength (very high intensity and low volume of repetitions) may result in greater fatigue due to central origins. However, hypertrophy type resistance exercise (moderate intensity and high volume of repetitions) may promote peripheral fatigue and increase strength through muscle morphology and cross sectional area changes (McCaulley *et al.,* 2009).

However, it has also been suggested that the rate of fatigue is likely to be different according to the morphological structure of the muscles involving during each exercise performed (Bosco *et al.,* 2000). More recently, Ullrich and Bruggemann (2008) also supported that muscle activity during fatigue depends on morphological properties of the fatiguing muscle such as cross sectional area and fiber-type distribution. Previous investigations demonstrated that fewer MUs carry out the lowering external resistance task. Therefore, more FT muscle fibers are selectively activated during eccentric phase of contraction. This situation makes the FT MUs susceptible to damage and fatigue due to excessive mechanical stress. Consequently, after muscle fiber disruption, a tendency towards more recruitment of ST muscle fibers have been stated (Ahmadi *et al.,* 2007) which explain the decline observed in mean amplitude of signal fallowing fatiguing contractions.

2.10.3 Hormonal adaptation (Testosterone and Growth Hormone)

Intensive prolong strength training is known to induce specific neuromuscular and hormonal adaptive responses in the human body (Bosco *et al.,* 2000; HÄkkinen *et al.,* 1985; HÄkkinen *et al.,* 1987 ; HÄkkinen *et al.,* 1988). Previous literature showed that heavy resistance training provides anabolic hormonal environment and plays a major role in reducing protein degradation and increase resynthesis of actin and myosin after a resistance training session (Kraemer and Ratamess, 2005). Thus, hormonal secretion has always been considered as one of the most important mechanisms in regulating adaptations during and after resistance training session. Measuring the hormonal concentration in the blood via blood sample drawn, although is only one part of the whole hormonal response puzzle, provides an indication of responses of endocrine system to training.

It has been shown that manipulating training variables such as intensity, volume, resting period, and type of resistance training play critical role in rate of acute and chronic hormonal response (Fleck and Kraemer, 2004). Kraemer (2000) stated that “Although resistance training is the only natural stimulus that cause increase in lean tissue mass, dramatic differences exist among resistance training programs in their ability to produce in muscle and connective tissue size”. Therefore, having a basic understanding about the hormonal responses to various types of resistance training has been considerably emphasized by many sport investigators (Fleck and Kraemer, 2004; Kraemer, 2000; Kraemer and Ratamess, 2005).

Anabolic hormones are vital prerequisites of musculoskeletal adaptation following resistance training. Different resistance training protocol have shown to influence the cute secretion of hormones such as testosterone, SHBG, LH, GH, Catecholamine, and Cortisol (Kraemer and Ratamess, 2005). The increase the level of anabolic hormones following intensive resistance training has shown to increase the probability of interaction between free hormones and receptors which ultimately would result in developing protein synthesis via various cellular mechanisms.

Scientists have notified that increase in basal and acute concentration of anabolic hormonal at the beginning of training program (preparatory phase) could be attributed to high stress (intensity and volume) of training program. Therefore, any decline in the volume or intensity of training can cause decrease in basal and acute hormonal concentration (Durand *et al.,* 2003; Häkkinen *et al.,* 1992; Raastad, *et al.,* 2000; Schwab *et al.,* 1993). Overall, the concentration of serum anabolic hormone has been shown to be dependent in following factors:

1. total amount of work.
2. amount of activated muscle mass
3. age of the subjects
4. resting period during the exercise

Resistance exercise has been shown to produce acute increases in serum levels of growth hormone (GH) and testosterone (T). These hormones have been shown to be sensitive to the stress of resistance exercise and are known to effect tissue in a variety of ways including stimulation of protein synthesis. Numerous investigations indicated that serum concentrations of T and GH are shown to increase during and to elevate for 0.5-1 hour after different protocols of strength exercises. (Kraemer *et al.,* 1990; Raastad *et al.,* 2000).

The effects of exercise induced increases in GH and T dependent on a wide variety factors including type of muscle contraction, rest period length, exercise intensity, exercise volume, and the amount of muscle mass activated during exercise (Durand *et al.,* 2003). Previous investigators stated that "although it is not clear weather acute increases in GH play a role in local skeletal muscle hypertrophy it is interesting to note that resistance exercises producing the greatest GH responses are typically hypertrophy protocols with high repetitions and short rest period; whereas, low repetition strength-training protocol with long rest period result in a lesser GH responses" (Ojasto and Häkkinen, 2009).

Exercise-induce acute increase in GH secretion is highly affected by high intensity and heavy resistance exercises. It has been shown that those factors which modulate the GH discharge are controlled from both central and peripheral sites. In fact, chemoreseptors activation of group III and IV nerve fibers mediates GH release by stimulating the hypothalamic-pituitary axis. Ahtiainen and colleagues (2003) advocated that this acute increase in level of GH could be due to the central stimuli and/or change in acid base balance of the muscles. The potential stimulators of exercise-induced GH discharge have been manifested as elevated H+ ions, lactate levels and oxygen availability (Durand *et al.,* 2003). In fact, the increase lactate resulting from tissue hypoxia can elevate GH significantly. In line with this concept, greater lactate accumulation in heavy and high volume resistance exercises has demonstrated that it might contribute to the greater GH response (Raastad *et al.,* 2000). However, it appears that the level of lactate must be elevated above a certain threshold for GH secretion to rise.

There is a debate whether except lactate and H+ there are other mechanisms which have a greater impact on GH release. The investigators considered that proprioceptive feedback to be a more important modulator of GH secretion than metabolites. Proprioceptive feedback through muscle spindles and Golgi tendon organs caused significant increase in bioassayable GH. Therefore it is possible that lactate, pH, and proprioceptive feedback all played a role in the different GH responses. (Durand *et al.,* 2003).

In an investigation by Linnamo *et al.,* (2005) the concentration of serum GH increased for both women and men following heavy resistance training. The underlying mechanisms for this increase in GH concentration have been attributed to decrease in blood PH due to increase in lactate production. In addition, a significant increase was observed level of GH following explosive exercise (40% 1-RM) and heavy resistance training (100% 1-RM) but not in submaximal resistance training group (70% 1-RM). These data was taken to indicate that the amount of muscle activated play the major role in rate of GH secretion. Similar equation is consistent for serum level of Testosterone whereby scientific evidences have demonstrated that high intensity resistance exercise can produce larger increase in lactate and circulating T concentration than high-volume, low intensity protocols (Durand *et al.,* 2003). In addition, the magnitude of lactate production has been attributed to rate of motor unit recruitment (Durand *et al.,* 2003).

However, the GH responses after strength exercise are difficult to measure from single blood samples because of the pulsatile secretion pattern and relatively short half-life of this hormone in blood (Raastad *et al.,* 2000). Thus, GH responses must be interpreted cautiously because a very large standard error of mean observed in the post-GH concentration which indicates a high interindividual variance of the response. In line with this concept, previous literature have warned of expounding GH responses throughout single blood sample after strength exercise because of its pulsatile secretion pattern (Kraemer *et al.,* 1998; Raastad *et al.,* 2000). However, a number of research studies found no significant acute changes in the level of serum GH during and after short period of very intensive resistance training in elite weight lifters (Häkkinen *et al.,* 1987; Häkkinen *et al.,* 1988).

HÄkkinen and colleague (1988) concluded that the magnitude of physiological stress during performing very intensive resistance training exercises determine the level of serum Testosterone concentration. In this investigation, serum total and free T have shown to increase during and immediately after two strength training sessions in morning and afternoon within one week training and testing protocol. The level of T exhibited a decline after termination of strength training session (every afternoon). They have attributed this T concentration decrement to some potential explanations such as:

1. diurnal decrease in serum T in the morning.
2. increase T consumption for remodeling muscle tissues.
3. increase in level of other hormones such as SHBG.

The basal anabolic hormonal concentration could be a major underlying mechanism for developing strength and muscular hypertrophy in athletes contributing to strength training programs. Scientist speculated that correlation observed between the changes in acute T response and the changes in muscle CSA suggest that training-induce changes in hormonal concentration, especially acute T response, may be an important factor for training induces muscle hypertrophy. Ahtianen *et al.*, (2003) found high correlation between muscle CSA and intrasession differences in acute T response observed before and after the 21-weeks training protocol. Based on these findings Increase in serum testosterone might be duo to:

1) increase gonadal secretion.
2) testosterone release by vasodilatation.
3) increase in LH pulsatility or production.
4) direct stimulatory effect of lactate on T secretion.

Overall, these data indicated that increase serum T in men can be mediated through the pituitary-testicular axis either by increase in secretion rate or by alteration in testicular blood flow.

Despite these findings, Ahtianen *et al.*, (2003) observed no significant changes in T, Free T, Cortisol concentration and T/C or FT/C ratio during a 21-week strength training period in untrained and strength athletes. They also found no significant differences in the blood lactate concentration before and after the experimental program in both trained and untrained athletes. In their investigation however, the magnitude of change in the maximal isometric force after 21 weeks of training has shown significant correlation ($r = 0.84$) with serum basal total T concentration and T/C ratio ($r = 0.88$) in strength trained athletes. This finding approved the major role of hormonal adaptation in development of strength and muscle cross section area of high resistance trained athletes. They also announced the average value of the 0, 7, 14 and 21 weeks of serum basal free T concentration correlated with maximal isometric values before and after the 21 weeks training period.

Ahtiainen and colleague (Ahtiainen *et al.,* 2003) notified that the influence of neuromuscular adaptation may become less accounted for strength development in athletes with a long training background. They announced that the muscular hypertrophy and strength development in trained athletes are correlated to hormonal regulations rather than neural adaptations.

Intensive prolong strength training is known to induce specific neuromuscular and hormonal adaptive responses in the human body. However little is known about hormonal changes that occur during single strength training session. Furthermore, less knowledge is available with respect to relative strength loss and hormonal changes during acute exercise with variable external resistance exercises (Bosco *et al.,* 2000). Therefore, it seems of interest to investigate hormonal changes following performing training protocol which is consisted of moderate intensity, short resting period, and large muscle mass and high volume of training.