CZECH TECNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING

Department of Biomedical Technology

Objective Assessment of Muscle Tonus

Master thesis

Study programme: Biomedical and Clinical Technology
Study branch: Biomedical Engineering

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Kladno, 18th 2018.

Thesis assignment – tied up assignment of master thesis – original with all signatures has to be in one version and scan copy of the assignment in second version of the master thesis

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Abstract

The aim of this study was to use a novel, non-invasive handheld device (MyotonPro) to quantify the biomechanical properties of the Gluteus Maximus (GM), Vastus Lateralis (VL) and Vastus Medialis (VM) muscles, and to assess the reliability of a novice user. MyotonPro device offers rapid, objective testing of mechanical parameters of muscle in clinical or sports settings. Twenty healthy participants (Age: 18 to 40 years) with two different groups (Sports active (S.A) and Sports Inactive (S.I)) were analyzed on the relaxing position before and after the squats (05) exercise by using MyotonPro device for all the three selected muscles for each side (Left and Right). All the data from the MyotonPro device were processed by using Matlab software 2017a version with one-way analysis of variance (anova1). As a result of this study, we found that most of the muscles for both the groups (S.A and S.I) were significantly different from each other with a certain anova1 difference (p) value. Vastus Lateralis Right side(VLR) and Vastus Medialis Right side (VMR) muscles were more stiff for the sport active (S.A) group than the sport inactive (S.I) group while both the sides (Left and Right) of the Gluteus Maximus (GM) muscle was less stiff for the sport active (S.A) group than the sport inactive (S.I) group. The results also show that Vastus Lateralis Right (VLR) and Vastus Medialis Right (VMR) have more muscle tone (Frequency) (Hz) than the rest of the side of the muscles. Both the groups (S.A and S.I) were significantly different for the Creep (D.n) and Decrement parameters. Frequency (Hz) was not significantly different for the Vastus Lateralis left (VLL) side muscle. Each side of the muscles was significantly different for the Relaxation Time (ms) except Vastus Lateralis (VL) muscle while Sti ness (N/m) was not significantly different for Gluteus Maximus (GM) muscles. The conclusion of the study shows that MyotonProdevice is rapid, novel and very precise to evaluate the biomechanical properties of the human body muscles.

Keywords: Myoton measurement, Myoton Technology, Muscles, Mechanical Properties.

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Acknowledgment

God has provided guidance, strength, patience and enabled to complete this thesis. I thankfully acknowledge the support and guidance of many, for the completion of this thesis. It is a pleasure to thank those who made this thesis worthwhile.

With a deep sense of gratitude, I thank my consultant Dr. Lenka Lhotska and my co-supervisor Iva Novotna for her kind help, encouragement and for providing a friendly working environment together with constructive criticism and advice throughout my dissertation.

I express my sincere thanks to my parents, my fiancee and my family members to become my strong backbone throughout my project.

I am very thankful to my all dear friends who are my colleagues and the ones who are not for their encouraging words, thoughtful criticism, time and attention during their busy schedule.

I am also thankful to the teaching and non-teaching staff of the faculty of Biomedical Engineering, Czech Technical University, Prague for assisting me with the task necessary for the completion of my Post-Graduation program.

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Chapter 1

Introduction

From the last thousand years, sports have been an important part of one's life. Sports must be taken seriously and should be made into a good habit. Most of young children' s knowledge and development depends on their interest and participation in sports and games, and this same dedication to sports as adults can lead to happier, healthier and more productive lives.

The benefits of sports and games in children' s development are quite obvious and also well stated. According to an Ad Hoc Committee, the signs of development and benefits in children as well as youngsters are well developed and also other various skills such as managing skills, mental strength and both improved health and sport-specific fitness. This is both beneficial for an average youngster as well as physically and mentally challenged youngsters or children in different ways. Playing indoor games such as board games and mind games also help children to develop certain abilities to make strategies and getting along with adults and their experience. [26]

According to some Medical Experts and Diseases prevention center, adults need at least One hundred and fifty minutes of a medium intensity of some physical or aerobic workout including some light warm-ups and exercises on daily basis. For accomplishing such kind of activities, one should play normal sports such as racquetball, squash, badminton, lawn tennis, etc. which can help in keeping one fit and also one can have a hint of competition with fitness and fun. Taking part in the indoor game such as chess and other board games with family and close friends help in increasing social awareness and also helps to relieve the stress of day to day life if played on a daily basis. [26]

Putting undue pressure on youngsters to win at all costs and to not make mistakes can take a potentially wonderful experience and turn it into injuries. These injuries might be lethal sometime. So much attention to care is required to recover for that kind of injuries. We have to diagnose the injury level in minimum time cost. This reason motivates researchers to develop new devices in the field of medical technology which can be very beneficial for the society in crucial time. This medical device needs to be portable, easy to handle, painless and accurate in measurements. MyotonPro device is one of the latest technology invented in recent time for the monetary (Measurement of muscles parameter) in the field of medical technology. further development in research of this MyotonPro device for the betterment of accuracy in measurements is still going on which leads many research area.

The Human muscular system is a setup which supports athletic movements in muscles of an athlete for sports-related movement of body and energy produced for competitions related to sports and games. With the specialized characteristics of contraction muscles support a body for movement.While contraction muscles produce energy which gets converted into heat and that helps in maintaining the body temperature which is an important aspect for human body functionality. Movements such as moving an arm, leg, or breathing and also they can help in highly coordinated skills, such as swimming or throwing a ball. Muscles are very important part of a body to maintain body posture and position (refer figure: 1.1). Muscles are part of almost all the physical activities performed by a human which includes activities like standing as well as supporting spine while lifting heavy weights as well as while sleeping.

Figure 1.1: Human body Muscles diagram.
[27]

The brain and the nervous systems are the supporters of Muscles by conducting important signals to the body at the right time and the right direction which is very well used by the athletes while playing sports. As time passes skills are ought to be more precise as the whole system get used to as a particular skill set. The Human muscular system does not work individually as this system works with the linkage of the respiratory system as well as a cardiovascular system which helps in the long lasting stamina and accuracy for an athlete. They function in groups to generate efficient movement. For example, while the biceps contract when performing a certain type of skill is known as agonists, the triceps extensions known as antagonists. A synergist supports a larger agonist to work efficiently. Synergists provide external support to stabilize muscles.

For a human body to perform one movement, it needs many muscles to work simultaneously. For just a simple movement of walking takes about two hundred muscles to work together while it takes forty muscles to work for raising a single leg. Thus it is very important for an athlete who needs to train harder to get the whole body and all the muscles of the body to work in coordination for specific skills to perform. For performing a specific skill it is very important for the system to get used to that particular skill performed by the athlete. As the human muscular system build a specific type of process which is better for a repeated activity performed.

For being sports athletics, we must know about their muscles strong and how fast their muscles can recover from serious injuries so they can start their training again. To know about the recovery ability of the different muscles, first, they must know about their muscles Bio-mechanical parameters. Every muscle is different in their Bio-mechanical properties. They are many different approaches for the measurement of the Bio-mechanical parameters of the muscles but most of them are less effective, non-consistent and time-consuming. We need a novel approach for the measurement of Bio-mechanical parameters which should be more effective, consistent and not time-consuming. If we can find out the novel approach for muscle parameter measurement, it will be a great contribution to the field of medical science and sports.

1.1 Muscles Anatomy

The muscular system is responsible for the movement of the human body as half of the body weight of any person is because of the muscles. Most of the muscles are attached to bones and other skeletal parts of the human body which is one of the main reason for movement in a human body. Each muscle tissue consists of various tissues namely skeletal muscle tissue, blood vessels, tendons, and nerves. Muscle tissues are found at many important places in a human body which are heard, blood vessels and the digestive system where the help human body to move substances as necessary throughout the body. There are three types of muscle tissue: (1) Visceral muscles: They are found inside of important body organs such as the stomach, small intestine, large intestine and blood vessels. It is the weakest muscle tissue of all muscle tissues, they make organs contraction and help to move substances inside of the organ. The main reason for its functionality is that it is controlled by the unconscious part of the brain, a that is why it is known as involuntary muscle. (2) Cardiac muscles: These muscles are also called involuntary muscles. These are a most specific type of muscles as they are found in heart and they are also responsible for the process of pumping blood in and out of the heart and to the other body parts. (3) Skeletal muscles: These are the only voluntary muscle tissues in the human body which are controlled consciously. They are mainly found in a cerebral region of the human body which includes brain and other parts.

All the physical activities which are performed knowingly such as walking, standing, throwing, etc. are performed by the skeletal muscle tissues. This is done by the simple process of muscle contraction to the bones in the important parts of the body. Skeletal muscles are generally attached between the two bones across a joint and so these muscles help to move parts with the bones closer to each other. Formation of skeletal muscle cells occurs when smaller original cells join themselves together to form a long, straight, and multinucleated fibers. Similar to those of cardiac muscle fibers, these skeletal muscle fibers are also very strong. These muscle fibers got there name from where they are found, which is mainly inside the skeletal region of a human body as illustrated in Figure:1.2.

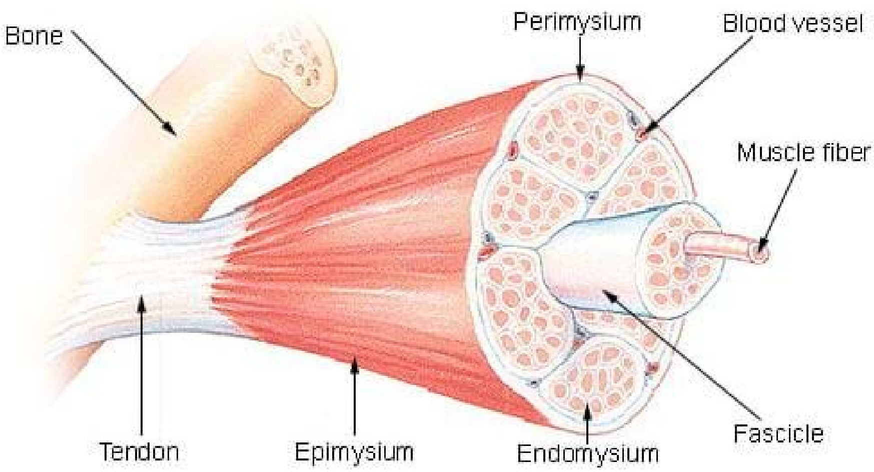

Figure 1.2: Skeletal Muscle formation.
[30]

Structural changes in skeletal muscle can occur with injury and chronic pain causing abnormal function. These changes may lead to altered elasticity and increased risk of injury Preliminary observations suggest that muscular injuries have unique stiffness properties that can be characterized with novel measurement techniques. Measurement of tissue stiffness affords an opportunity to progress the understanding of muscle structural deficits that may be related to injury. [1]

Physical appearance is the most obvious difference between a sport active and sport inactive person. Sport active types tend to have more muscles and less body fat than more sedentary people. The physical capabilities of sport active person may exceed those who don't regularly engage in exercise, and active sports people also tend to have fewer health problems.

Athletes' heart rates tend to be lower than heart rates of non-athletes. A low resting heart rate is generally a sign of good cardiovascular fitness and efficiency. A well-trained athlete may have a normal resting heart rate of only 40 beats per minute, compared with the average heart rate that ranges from 60 to 100 beats a minute. [22] Athletic types may have better overall health and be less apt to develop certain diseases. Regular exercise boosts your immune system and lowers the risk of serious health conditions such as cancer and heart disease. Physical activity can also reduce the risk of type 2 diabetes and osteoporosis while helping to manage cholesterol levels and blood pressure. You gain about two hours of additional life expectancy for each hour of regular exercise, according to the American Heart Association. [22] Athletes may have better mental clarity and focus than non-athletes. Exercise increases the flow of oxygen, produce more enzymes (Myosin ATPase) and reduce the ROS (Reactive Oxygen Species) which has a direct impact on muscles contraction and brain function, explains the American Heart Association. Exercise can help improve your memory and reduce negative feelings, such as anger, tension, anxiety, and depression. We can also found some between sport active person and sport inactive person. [21] During high-intensity exercise, large changes in metabolites and ions are observed within the working muscles. Disturbances in the concentration of muscle lactate, hydrogen (H+), potassium (K+), and calcium (Ca2+) ions are linked with fatigue and thus ionic regulation becomes critical for muscle membrane excitation, contraction, and energy metabolism. [21]

Skeletal muscle is a fascinating biological tissue able to transform chemical energy into mechanical energy. The biomechanical parameters of the muscles changes during the muscle contraction. The muscle contraction can be explained by the theory of the sliding filament theory. Muscle contraction is the basis of all skeletal movements. Skeletal muscles are composed of muscles fibers which in turns are made of repetitive functional units of sarcomeres. Each sarcomere contains many parallels, overlapping thin (Actin) and thick (Myosin) filament. The muscles contact when these filaments slide past each other, resulting in a shortening of the sarcomeres and thus a muscle. This is known as sliding filament theory. Cross –bridge cycling forms the molecular basis for these sliding movements. Muscles contraction is initiated when muscle fibers are stimulated by a nerve impulse and Calcium ions are released. The troponin units on the actin myofilaments are bound by calcium ions. The binding displaces tropomyosin along the myofilaments, which in turns to exposes the myosin binding sites. At this stage, the head of each myosin unit is bound to an ADP (Adenosine diphosphate) and phosphate molecule remaining from the previous muscle contraction. The myosin head releases these phosphates and bind to the actin myofilaments via the newly exposed myosin binding sites. The two myofilaments glide past one another, propelled by headfirst movement of the myosin units powered by the chemical energy stored in their heads. As these units move, they release ADP molecules bound o their heads. The gliding motion is halted when ATP (Adenosine triphosphate) molecules bind to the myosin heads, thus serving the bonds between actin and myosin. The ATP (Adenosine triphosphate) molecules are now decomposed into ADP (Adenosine diphosphate) and a phosphate molecule, with the energy released by this reaction stored in the myosin heads, ready to be used in the next cycle of movement. The myosin heads resume their starting positions along the actin myofilament, and can now begin a new sequence of actin binding.

The presence of further calcium ions triggers a new cycle. [20]

1.2 Experimental Exercise

We choose the squat exercise in our present study because squat exercise has so many benefits in our daily life. The squat is a fundamental movement pattern. It is very hard to imagine getting through the day without doing at least a few squats. Standing up out of a chair, getting in and out of your car and even sitting on the toilet are all movements involving squats. In addition to being such a regular movement for most people, squats are also an important and beneficial leg exercise used by bodybuilders, weightlifters and other athletes and exercisers looking to develop high levels of fitness, strength, and performance.

The squat is a compound exercise, meaning it targets several different joints and hence, muscle groups at once. We usually use the squat to train our lower body, as well as our core. [31]

Core

Core muscles: These muscles describe themselves in their name itself. Core muscles are muscles that support the human spine. Specifically speaking it supports human back parts such as rectus abdominis, erector spinae, obliques and transversus abdominis. While performing heavy weight squats and heavyweight lifting these muscles take care of the spine and ensure that spinal cord is at right position and lower back does not round for a severe injury. Thus it is very important to make your core ready before performing heavy squats or such activities as it prevents you from fatal injuries.
. [31]

Hamstrings

Hamstring: These muscles are found behind the thighs. Hamstrings control the movement of the center part from the base of the pelvis to just below the behind of knees while running. Hamstrings are responsible for controlling extension of hips while doing squats. Hamstrings are made up of these three type of muscle tissues: namely biceps femoris, semimembranosus, and semitendinosus. When they perform together while descending during squats and then extremely contract for the extension of your hips and help to stand back up. Flexible hamstrings are as important as strength as very tight hamstring also resist the free-flowing movement of the legs while doing squats. [31]

Gluteus Maximus

Gluteus Maximus(refer to figure:1.4)is one of the most strong parts of the muscles which leads an important role while performing squats. It coordinates with hamstrings and also controls the hips. Similarly to hamstrings gluteus maximus also helps in descent and get back up while completing squats. Thus, Squats are one of the most effective butt-building exercises. [31]

Quadriceps

Quadriceps: They are located in the front of thighs and continued from hip to below your knee. Quadriceps are considered to be the knee extensor muscles also Known as the quads. As per the name, four muscles make up your quadriceps namely: rectus femoris, vastus intermedius, **vastus lateralis and vastus medialis** (refer to figure:1.3). After a high rep of squats, these muscles are to considered to be affected the most. [31]

Additional Muscles

Without supporting role no work is possible. Thus while squatting these additional muscles help to get it done. These muscles are located on the inside and outside of your butt and thighs mainly known as adductors and abductors. These mainly work to keep balanced knees while sit-ups and keep track of it that they don't misplace inward or outward while doing squats. While performing squats, the upper body also has a main role in supporting the body for balance which also depends on front or back squats. Therefore we can see that while performing squats it is not only the leg muscles that are taking part in the exercise but also there are many secondary muscles which performs an important role in completing one squat. [31]

The Vastus Medialis(VM) and Vastus lateralis (VL) (Figure: 1.3) muscles are part of the extensor apparatus of the knee joint. Both muscles are situated close to each other on the anterior and medial aspect of the femur. The VM and VL work together with the other components of the quadriceps muscle group (rectus femoris, Vastus Intermedius, and tensor) Vastus lateralis to produce knee extension torque when knee joint action is performed. However, anatomical properties such as muscle volume, the origin of the muscle and fiber-type composition seem to be inconsistent among the components of this muscle group. These variations may be attributed to different functional roles or contributions among synergists of the extensor apparatus of the knee joint. [3]

The human Gluteus Maximus(GM) (to refer figure:1.4) is anatomically distinctive compared to other non-human primates in several respects, notably in its overall enlargement, in the expansion of its cranial portion and in the loss of its caudal portion. Since Cuvier, anatomists have speculated that the distinctive human GM is an adaptation for either walking or maintaining upright posture, but electromyography (EMG) studies have shown that the GM has little or no activity in walking or normal upright standing. Instead, the human GM is primarily active during climbing, as well as running and other activities that involve stabilizing the trunk against flexion. [4]

Biomechanical properties of the musculoskeletal system are challenging to assess because of the complex active and passive tissues that comprise them.

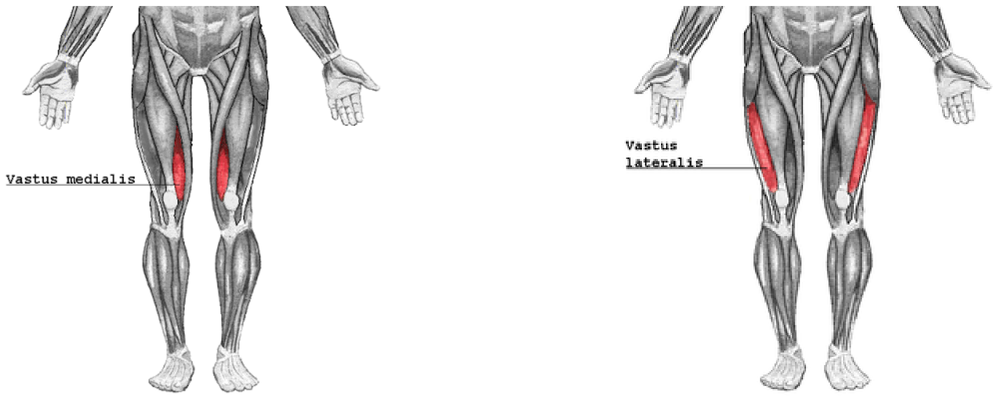

Figure 1.3: Vastus Medialismuscle and Vastus lateralis muscle.
[28]

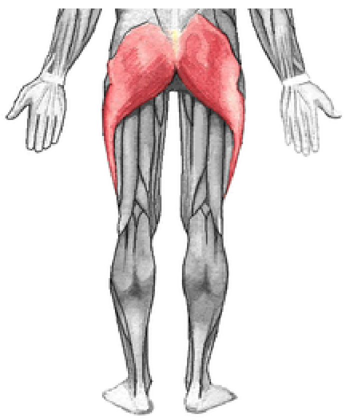

Figure 1.4: Gluteus Maximusmuscle.
[29]

1.3 Bio-mechanical Analysis

According to recent developments in medical science, the elastic nature of a skeletal muscle is been focused mainly because of the injuries due to stiffness in hamstrings. Various techniques for estimating muscle bio-mechanical parameters have been proposed among them some are listed below with very brief information.

1. **EMG (Electromyography)**

   EMG signal-based control system research is going on mainly for recovering of muscles. EMG is all about experiments on measuring and recording the amount of electrical data that is emitted from the muscles. These EMG signals are formed due to physiological differences in any state of muscle fibers. In muscle physiology, the major factor depends on the ascent in muscle fibers by means of neural control. While in EMG mostly the signals are based on the activity in the muscle membrane which leads to process from depolarization to repolarization.
   In detecting and recording EMG signals, there are two main issues of concern that influence the fidelity of the signals;

   1. the signal-to-noise ratio
   2. noise signal

   In the first case, the ratio of energy emitted from EMG signals to the energy of noise signals is examined. The electrical signals which are not part of the EMG signals are defined as Noise signals. The second issue is discussed in the next section below: [23].

2. **USE (Ultrasound Elastography)**

   Development in the application of Ultrasound Elastography to the skeletal muscle is going on with large scale. Supersonic shear wave imaging (SSI) is one of the latest technology developed in ultrasound elastography. In this technology, stress is applied on soft tissue through the noise radiating force in large amount which is focused on ultrasound beams or ultrasound pulses which produce a wave that is observed by high frame pulse-echo ultrasound imaging. Then the time difference of the ultrasound echo is used to evaluate deformation which depends on the displacement of the shear wave tissue. Shear wave elastography is a method used for the measurement of the shear wave velocity for estimation of properties of elasticity in vivo. Let us consider tissue to be elastic and homogeneous and then the shear modulus (μ, kPa) is calculated using the following equation: $\mu = \rho V2$, where ρ is the density of the tissue (kg.$m^{-}3$) and V the shear wave velocity (m.s^{1}). Young's modulus (E) can be calculated from the shear modulus by considering isotropic as locally homogeneous and quasi-in compressible biological tissues using the following equation: E = 3μ. While many recent experiments have stated muscle mechanical properties with SSI, and this method was also used to know the perfect length of Achilles tendon while performing stretches of the ankle. Although measurements start deducing at relatively low tension levels according to the latter studies (20° in plantar flexion during passive stretching) because of the high shear wave velocity observed in stiff tissues like tendon, feasibility, and accuracy in the measurement of the slack length with SSI was shown. As stated the muscle and tendon slack lengths are corresponding to different angles of ankles, in the latter study the major interaction between muscles and Achilles tendon during passive motion of lower limbs are also highlighted. [25].

3. **SWE (Supersonic Imagine shear wave elastography)**

   Supersonic Imagine shear wave elastography (SWE) accessible approach to objectively quantify the biomechanical stiffness of muscle. SWE uses focused ultrasound radiation forces, causing a wave to travel horizontally to the point of application through tissue, to estimate material properties. The measurement estimates Young's modulus, as a surrogate for stiffness, based on the shear wave velocity of ultrasound propagation. Previous studies have found SWE measures to be highly reliable across a wide variety of muscle groups. Previous studies have also reported a strong linear relationship between muscle stiffness and muscle force. A limitation of SWE is the relative cost per unit to employ in a clinic setting [5].

4. **MAS (Modified Ashworth Scale)**

   The Modified Ashworth Scale (MAS) is a subjective technique, assessing muscular resistance to passive movements and is the most commonly used method for determining the tone of a muscle group, i.e. hypotonic or hypertonic. However, MAS results lack objective grading and reliability and are not well correlated with muscle stiffness after stroke [5].

5. **TMG (Tensiomyography) Functional Muscle Strain Diagnostics assessment**

   TMG Functional Muscle Strain Diagnostics assessment helps to determine the depth and extent of the injury caused to muscles and also check the functionality of the remaining muscle tissues. These comparisons between the affected muscles and the unaffected help in early recovering of tissues and also helpful in planning rehabilitation. Regular TMG Functional Muscle Strain Diagnostics measurements help in determining the functionality of the muscles accurate which helps in properly administrate the recovery. Conventional imaging locates the lesion; TMG Functional Muscle Strain Diagnostics gives information about the way muscle functions are damaged or affected and also helps to know which safety measurements to apply in recovery. [24].

Examining the tone, biomechanical and viscoelastic properties of individual superficial skeletal muscles is proposed to be a complementary, non-invasive and cost-effective technology that enables real-time assessment of muscle. Changes in muscle tone and properties could be used to assess the effects of pathology, sport-related injury or therapeutic intervention. Such assessments could be performed at regular intervals to monitor the stage of the pathological processes of muscles and for assessing the efficacy of therapeutic interventions.

To meet this need, a novel approach, myometric measurement, has been introduced showing reliable, objective and user-independent measurements for healthy adults as well as for various patient populations, including Parkinson's disease and stroke patients. As well as being used to evaluate the tone and biomechanical properties of muscles and tendons (e.g. Frequency (Hz), Stiffness (N/m) and Elasticity), myometric measurements have also shown an almost linear relationship with electromyographic (EMG) activity and therefore provide an indirect measure of changes in the muscle force-generating capacity.

Within space science, an approach is required that allows non-invasive, time-efficient and easy-to-use assessment of muscle health and quality for research purposes, as well as for health monitoring, providing an objective analysis of the deconditioning of muscle under prolonged unloading, as occurs during weightlessness in microgravity environments. A study of Myoton technology in an extreme environment is necessary before it could be considered for use in space [7].

1.4 MyotonPro Device

MyotonPro device is also known as MyotonPro Digital Palpation Device which is a very unique, reliable and accurate instrument for very objective measurements which mainly includes measuring of superficial skeletal muscles. None the less they also allow us to measure not only muscles but also tendons, ligaments, and also other soft biological tissues such as skin. Thus we can say that MyotonPro will become one of the best devices in the future for everyday diagnostics and as a monitoring tool in upcoming medical science. The major use of application of myoton technology is obtaining invaluable information on the muscle's condition in many fields of sports and activities. Thus we can say that the myoton gives an ocean of information for understanding the relationship between the Tone, stiffness or elasticity to the health of the muscle and physical strength. All this latest set of information allows us to support the efficiency of different discoveries, physical exercises, injuries or even aging. It has potential that it could help to detect disease in muscles at a very early stage so important medical steps are taken to prevent it beforehand.

1.4.1 Types of tissue

1. Single superficial skeletal muscles tissue.

2. Tendons, ligaments, other superficial biological soft tissues.

1.4.2 Advantages of MyotonPro device

1. We can measure the muscle parameters in different body positions.
2. We can measure the muscle parameters at different angles (360°).
3. We can measure the muscle parameters in Earth's gravity as well as in zero gravity.
4. The MyotonPro provide the results with reproducibly and repeatedly and independently.
5. The MyotonPro device is small enough so it gives us portably.
6. The MyotonPro device measures the muscle parameters non-invasively and painlessly.
7. The MyotonPro device is cost-effective and quick for the muscles measurement.

1.4.3 Areas of application

MyotonPro can be used for both clinical and non-clinical purposes, to assess superficial skeletal Muscles or other soft biological tissues.

Following are the examples of possible applications of the MyotonPro device are:

in sports medicine:

1. Observation of the effects of training on Muscles.
2. Identifying causes of Muscle over-training.
3. Determining optimal physical training load for Muscles.
4. Prevention of Muscle and tendon injuries.

in clinical medicine:

1. Monitoring the changes in the muscles parameter caused by Muscle disorders.
2. Obtaining supplementary information about the muscles when diagnosing Muscle diseases.
3. Evaluation of the benefits of applied interventions.
4. Evaluation of the benefits of rehabilitative treatments.

in occupational health care:

1. Prevention of trauma caused by Muscle overload due to uncomfortable positions assumed when working over a prolonged period.

2. Monitoring the changes to Muscle condition due to uncomfortable working positions assumed over a prolonged period.

3. Obtaining supplementary information when diagnosing Muscle diseases.

in veterinary medicine:

1. Prevention of Muscle and tendon injuries.

2. Identifying causes of Muscle over-training.

3. Evaluation of the benefits of applied interventions or treatments.

1.4.4 Method for measuring using MyotonPro device

The essence of the MyotonPro method of measuring consists of the recording the damped natural oscillation of soft biological tissue in the form of an acceleration graph and the subsequent simultaneous computation of the parameters associated with the tissue being measured, including its state of tension, as well as biomechanical and viscoelastic properties. The method of myometry is objective, safe, non-invasive, painless, quickly applicable and cost-effective. [32]

1.4.5 The measuring process

The measuring process of the muscle (Figure:1.5) by MyotonPro device consists of the steps.

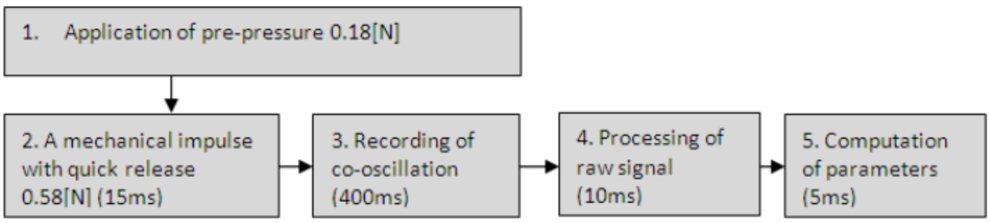

Figure 1.5: Flow diagram for the MyotonPro device.

1. Constant Pre-pressure is applied to the skin surface above the Muscle being measured, thereby slightly compressing the subcutaneous superficial tissues.

2. On the Muscle located under the subcutaneous compressed tissues, a light, a quick-release mechanical impulse is exerted by the Device at constant mechanical force.

3. The Muscle responds to the exterior mechanical impulse by a damped natural oscillation. The Co-oscillation of the:

a. Muscle being measured.
b. Compressed subcutaneous superficial tissues above it.
c. Probe.

are recorded by an accelerometer in the form of an acceleration graph.

4. From the raw signal obtained above in step 3, the low and high frequencies that are not characteristic of soft biological tissue's natural oscillation are then filtered out.

5. On the basis of the processed oscillation signal, numerical values showing the tension of the Muscle as well as its biomechanical and viscoelastic properties are then calculated.

The mechanical impulse applied on the Muscle is of short duration (15ms) and involves minimal mechanical force (Pre-load 0.18 + impulse 0.40 = 0,58[N]) hence, it does not cause residual mechanical deformation to nor neurological reaction of the Object being evaluated.

1.4.6 Recording the Muscle's natural oscillations

Recording the Muscle's natural oscillations through the subcutaneous superficial tissues located on top of it is possible, as:

1. During the measuring process, the subcutaneous superficial tissues are compressed by means of the probe at constant Pre-pressure.

2. The oscillating mass of the Muscle being measured is larger than the oscillating mass of the superficial tissues on top.

3. In general, the accumulation and recuperation of mechanical energy in the Muscles and Tissues is higher than subcutaneous superficial tissues.

1.4.7 Limitations of the MyotonPro device

1. The MyotonPro device cannot measure the parameters from Muscle groups.

2. MyotonPro device cannot measure the parameters of the muscles with a small mass (<20 g).

3. Not possible to measure with Un-palpable Muscles.

4. Not possible to measure for deep Muscles located under layers of other Muscles.

5. Not possible to measure with the tissues that are not categorized as soft biological tissue.

6. Not possible to measure with the tissues that are not categorized as soft biological tissue.

1.4.8 The formulas and legend of the Acceleration Graph.

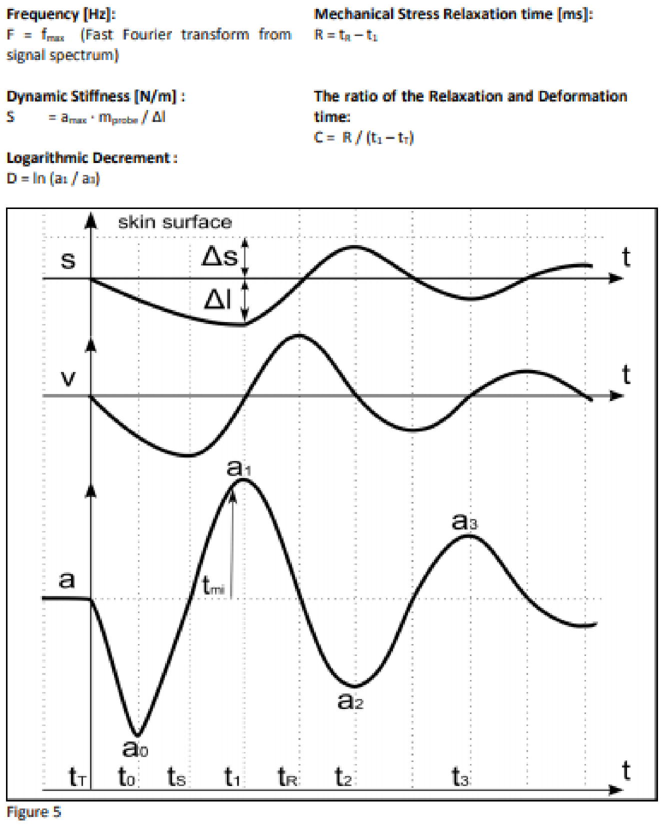

Figure 1.6: MyotonPro Acceleration Curve.
[32]

1.4.9 Experimental Parameters

The mechanical properties of tissues show two distinct phases: the elastic one, reflecting tissue extensibility without triggering rupture, and the plastic one, where structural tissue failures are found. When a skeletal muscle is passively tensioned without triggering contraction, a measurable strength can be obtained. This behavior has been named muscle stiffness, elasticity, extensibility or passive muscle tonus. The musculotendinous complex presents distinct structural components responsible for supporting tensional loads avoiding potential ruptures. Tendon, fascia, fascicles, contractile and cytoarchitectural proteins represent a set of structures offering resistance to external strengths. These strengths are able to change the format and size of a muscle, and are directly influenced by tissue temperature, amount and duration of employed strength.

There are several biomechanical properties of skeletal muscle's. From these, the following five Bio-mechanical properties can be analyzed by using a MyotonPro device.

1) Oscillation frequency [Hz]

Oscillation frequency indicates the tone (i.e. intrinsic tension) of a muscle in its resting state, which can be at rest without any voluntary contraction (EMG silent) or contract. The higher the value, the higher the tone. Hypertonia and respectively increased intramuscular pressure cause reduced blood supply, which brings on worse muscle recovery and quicker muscle fatigue. Oscillation Frequency in the contracted state indicates the tension of a muscle. [7]

F - Natural oscillation frequency [Hz] characterizing Muscle Tone.

$$\mathrm{F} = f_{max}$$

2) S: Dynamic stiffness [N/m]

Dynamic stiffness is the biomechanical property of a muscle that characterizes the resistance to a contraction or to an external force that deforms its initial shape. The higher the value, the higher the stiffness. Greater effort is required from the muscle to extend the muscle with high stiffness, which leads to an inefficient economy of the movement. The inverse of Stiffness is Compliance. [7]

S - Dynamic Stiffness [N/m].

$$\mathrm{S} = a_{max} * m_{probe}/\Delta \mathrm{I}$$

$$a_{max} = \text{a1 max displacement.}$$
$$m_{probe} = \text{probe mass.}$$

3) D: Logarithmic Decrement

The logarithmic decrement of a muscle's natural oscillation indicates the muscle's elasticity and dissipation of mechanical energy when tissue recovers its shape from being deformed. Elasticity is the biomechanical property of a muscle that characterizes the ability to recover its initial shape after a contraction or removal of an external force. The higher the value of logarithmic decrement, the lower the elasticity and the higher the dissipation of mechanical energy, as the tissue recovers its shape. Elasticity is inversely proportional to the decrement. In theory, a decrement of 0 (Zero) represents absolute elasticity. The opposite of the Elasticity is Plasticity. [7]

D - Logarithmic Decrement of natural oscillation, characterizing Elasticity.

$$\mathrm{D} = \ln\,(a_1/a_3)$$

4) R: Mechanical stress Relaxation Time [ms]

Mechanical stress relaxation time is the time for a muscle to restore its shape from deformation after a voluntary contraction or an external force is removed. The higher the value, the longer the time of recovery from maximum deformation to full recovery of the shape. Mechanical Stress Relaxation Time is the time between maximum deformation and zero deformation. [7]

R - Mechanical Stress Relaxation time [ms]

$$C = R - (t_1 - t_T)$$

5) C: Indication of Creep [Deborah number]

Creep is the gradual elongation of a muscle over time when placed under a constant tensile stress. This is the ratio of the relaxation and deformation time of the muscle. The smaller the difference between relaxation and deformation time, the higher the value of the C parameter indicating the creep. Younger and healthier muscles have a smaller value of the C parameter. Creep is the ratio between the Mechanical Stress Relaxation time R and deformation time t(1) and t(T). [7]

C - The ratio of relaxation time to deformation time, characterizing Creep (Deborah number).

$$R = t_R - t_1$$

1.5 Statistical Analysis

An ANOVA test is a way to find out if survey or experiment results are significant. In other words, they help you to figure out if you need to reject the null hypothesis or accept the alternate hypothesis. Basically, you're testing groups to see if there's a difference between them.

One-way (Anova1) or two-way (Anova2) refers to the number of independent variables (IVs) in your analysis of variance test. One-way has one independent variable (with 2 levels) and two-way has two independent variables (can have multiple levels). For example, a one-way analysis of variance could have one IV (brand of cereal) and a two-way analysis of variance has two IVs (brand of cereal, calories).

There are two main types: one-way and two-way. Two-way tests can be with or without replication.

1. **One-way ANOVA between groups**: used when you want to test two groups to see if there's a difference between them.
2. **Two way ANOVA without replication**: used when you have one group and you're double-testing that same group. For example, you're testing one set of individuals before and after they take a medication to see if it works or not.
3. **Two-way ANOVA with replication**: Two groups and the members of those groups are doing more than one thing. For example, two groups of patients from different hospitals trying two different therapies.

1.5.1 One Way Analysis of the variance

The one-way analysis of variance also known as ANOVA is mainly used in determining if there are any statistical related differences between three or more groups which are independent or unrelated to each other.

The one-way ANOVA helps in comparing the data between the selected groups according to your selection and also determines if any of these groups as different from each other or not. Specifically speaking it examines the null hypothesis as stated below: (H_0):

$$H_0{:}\mu_1{=}\mu_2{=}\mu_3.....{=}\mu_k$$

where μ = mean of the groups and k = number of groups. Anyhow if the one-way ANOVA returns a statistically significant result, then we have to accept the alternative hypothesis (H_A), which states that at least there are two groups which are statically significant different from each other .

In this case, it is important to accept that the one-way ANOVA can only test statistics but not tell if there is any significant statistical difference between the groups.

p = anova1(X) performs balanced one-way analysis of variance (anova1) for comparing the means of two or more columns of data in the matrix X, where each column represents an independent sample containing mutually independent observations. The function returns the p-value under the null hypothesis that all samples in X are drawn from populations with the same mean. [33]

If p is near zero, it casts doubt on the null hypothesis and suggests that at least one sample mean is significantly different than the other sample means. Common significance levels are 0.05 or 0.01.

The anova1 function displays two figures, the standard ANOVA table and a box plot of the columns of X. [33]

The standard ANOVA table divides the variability of the data into two parts:

1. Variability due to the differences among the column means (variability between groups).

2. Variability due to the differences between the data in each column and the column mean (variability within groups).

The standard ANOVA table has six columns:

1. The source of the variability.

2. The sum of squares (SS) due to each source.

3. The degrees of freedom (df) associated with each source.

4. The mean squares (MS) for each source, which is the ratio SS/df.

5. The F-statistic, which is the ratio of the mean squares.

6. The p-value, which is derived from the CDF of F.

The box plot of the columns of X suggests the size of the F-statistic and the p-value. Large differences in the center lines of the boxes correspond to large values of F and correspondingly small values of p.

anova1 treats NaN values as missing and disregards them.

p = anova1(X,group) performs ANOVA by group.

Supposing if X is a matrix then anova1 treats each column as a separate group and evaluates if they are equal by means of statistics or not. This type of ANOVA is appropriate when every group has the same number of data also known as balanced ANOVA. A group can contain arrays such as character array or cell array of strings including one row per column of the matrix X which contains group names. It is also valid if no group name is entered and for doing that an empty array ([ ]) can be entered or also that argument can be omitted.

Supposing if X is a vector then a group must be considered as a categorical variable, vector, string array, or cell array of strings and each and every element of X is given a name. All the values of X are placed in the same group as per the names. Thus, this form of ANOVA1 is correct when all the groups have a different number of elements (unbalanced ANOVA).

If a group is empty or null set or contains no-value cells then the respective observations in Group X are not valid or disregarded.

Assumptions

The anova test makes the following assumptions about the data in X:

1. All sample populations are normally distributed.
2. All sample populations have equal variance.
3. All observations are mutually independent.

The ANOVA test is known to be robust with respect to modest violations of the first two assumptions.

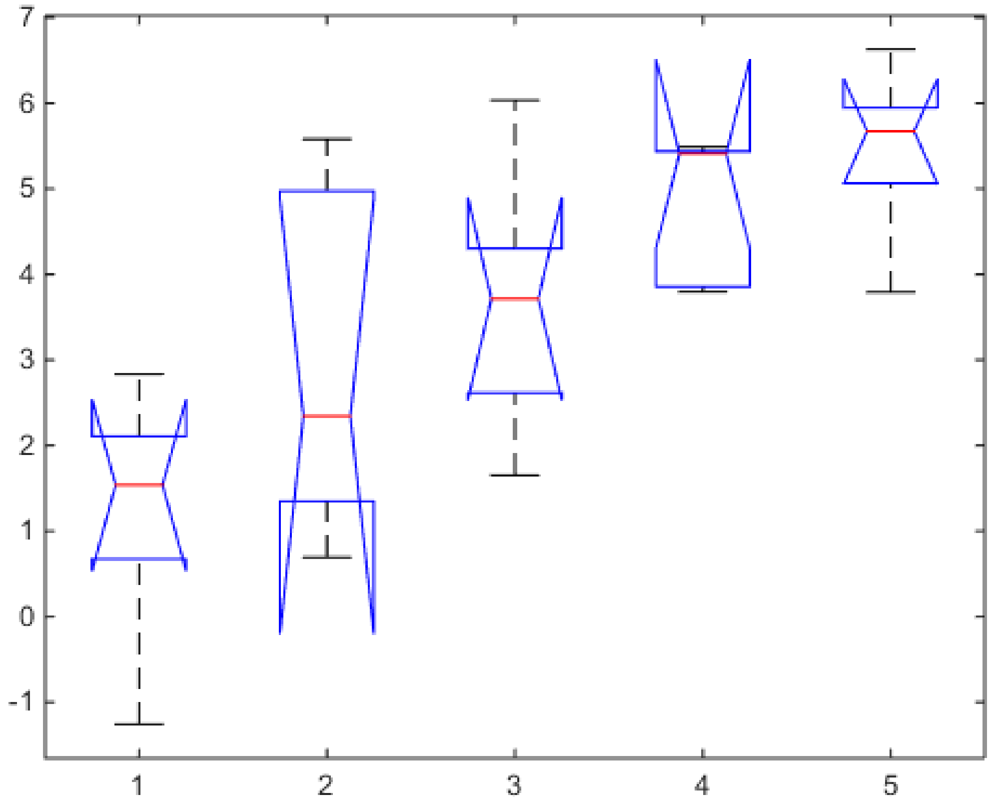

Figure 1.7: Different types p values probability in the anova1 analysis. [33]

Here in the above figure:1.7, X-axis belongs to the different types of p values we can have during our ANOVA1 analysis while Y-axis belongs to the specific parameter value like Stiffness (N/m) or Frequency (Hz) for both the groups. The small p-value indicates that differences between column means are significant. The probability of this outcome under the null hypothesis (H_0) (that samples drawn from the same population would have means differing by the amounts seen in X) is equal to the p-value.

Chapter 2

Review and Literature

The MyotonPro device is a new portable device for measuring muscle mechanical properties (Frequency, Creep, R.Time, Decrement, and Stiffness) and its reliability has yet to be established. Many Researchers have been measured the muscles parameters by using the MyotonPro device to find out its reliability and its feasibility to use with the different types of muscles. Little is known about the between-limb symmetry of mechanical properties in healthy older people, despite symmetry often being used as a measure of unilateral abnormalities in clinical assessment. Since quadriceps is important for mobility, it was selected for the present study. Reliability of using prototypes of Myoton devices has generally been good but varied with the muscle studied. When compared with TMG, the MyotonPro device was more reliable on repeated testing and more valid for detecting changes in muscle parameters at different muscle lengths. Reliability of novice user is important to examine, not only to reflect the clinical situation but as it may influence the likely uptake of the technique by clinicians if it is found to be easy to use.

Here below are the example of some research work have been done by the researcher by using the MyotonPro device in their study to understand the mechanical properties of the different muscles in the human body.

I have reviewed the article of the Joseph P. Kelly and I found that he and his colleagues were studied measurement methods of tissue stiffness using ultrasound shear wave elastography (SWE) and superficial mechanical deformation (MyotonPRO) in 30 healthy participants in the infraspinatus, erector spinae, and gastrocnemius muscles. They found significant ($r=0.23$ to 0.71, $p < 0.05$), and strongest in the gastrocnemius correlation between two methods in the three muscle regions. They found excellent (ICC >0.93), reliability with MyotonPRO and it demonstrates the ability to discriminate between the three levels of muscle contraction. While SWE (Shear wave elastography) demonstrated only good reliability in the resting condition (ICC >0.88), but lower reliability during the 2 (40 % and 80 %) MVIC conditions. They found that the SWE method cannot discriminate between 40 % and 80 % MVIC. So its use is limited to the MVIC conditions [4].

Wai Leung Ambrose Lo and his colleagues investigated the device's between-days intra-rater reliability for acute stroke participants (n=5, Age: 40 to 80 years) who were within 1 month of their first stroke occurrence. They studied Muscle tone of biceps brachii, brachioradialis, rectus femoris, and tibialis anterior and recorded on two consecutive days. They used different methods like intraclass correlation coefficient (ICC), standard error of measurement (SEM), the smallest real difference (SRD), and the Bland-Altman limits of agreement for assessment of Reliability. Results of this study show excellent reliability between days intra-rater reliability (ICC >0.75), SEM and SRD show small differences between measurements while the Bland-Altman analysis shows a tendency of overestimation of the rectus femoris. MyotonPRO represents acceptable reliability when it is used in a ward setting in those patients with acute stroke [5].

Wai Leung Ambrose Lo his colleagues studied the within-session relative and absolute interrater reliability of MyotonPRO device with participants (n=29, Age:40 to 80) who were within 1 month of the first occurrence of stroke. They were recorded mechanical properties of biceps brachii, brachioradialis, rectus femoris, and tibialis anterior. The intraclass correlation coefficient (ICC), standard error of measurement (SEM), the smallest real difference (SRD), and the Bland-Altman 95% limits of agreement were used for assessment of the relative and absolute reliability. ICCs of all studied muscles indicates excellent (0.63 to 0.97) results. The SEM of all muscles ranged from 0.30–0.88 Hz for muscle tone, 0.07 to 0.19 for decrement, 6.42 to 20.20 N/m for stiffness, and 0.04 to 0.07 for creep. The SRD of all muscles ranged from 0.70 to 2.05 Hz for tone, 0.16 to 0.45 for decrement, 14.98 to 47.15 N/m for stiffness, and 0.09 to 0.17 for creep. This study shows MyotonPro provide acceptable relative and absolute reliability for patients with acute stroke [6].

Sahand Sohirad and his colleagues examined the stiffness and other properties of ballistics gel in comparison with an external materials testing system (PCB electronics), the same properties of avian Achilles tendons before and after the removal of the overlying skin and subcutaneous tissue and the stiffness of the Achilles tendon was measured before and after competitive running races of varying distances (10, 21 and 42 km, Total number of athletes analyzed (n) = 66) by using MyotonPRO digital palpation device. The results from the MyotonPro device indicates good consistency when ballistics gel tested with known viscoelastic properties while the presence of skin overlying the avian Achilles tendon had a significant impact on stiffness ($p < 0.01$). For the adults who have normal BMI, the reliability of stiffness values was excellent both for the patellar tendon (ICC - 0.96) and the Achilles tendon (ICC = 0.96). Overall the results of the study demonstrated that men had stiffer tendons than women ($p < 0.05$), and the stiffness of the Achilles tendon tended to increase following running ($p = 0.052$) [7].

Sarah Orner and his colleagues were studied the quantitative tissue properties (Frequency [Hz], Decrement, Stiffness [N/m], Creep and Relaxation Time [ms]) of the Achilles tendon (Total: 207, Male: 87, Female: 120) and plantar fascia (Total:176, Male:73, Female:103) by using a handheld, non-invasive MyotonPro device, to obtain normal values and examine the biomechanical relationship of both structures. The correlation of the tissue parameters from the Achilles tendon and plantar fascia showed a significant correlation between all the parameters on the left as well as on the right side of the healthy participants. They indicated that MyotonPro is a feasible device for easy measurement of passive tissue properties of the Achilles tendon and plantar fascia in a clinical use [8].

Seung Kyu Park and his colleagues studied and analyzed the mechanical properties [Muscle tone (Hz), Stiffness (N/m), and Elasticity (log decrement)] of the upper cervical muscles in patients with a cervicogenic headache to identify effective methods of treatment and diagnosis. A total of 40 subjects were selected including 20 healthy individuals and 20 patients with a cervicogenic headache to measure the Muscle tone (Hz), Stiffness (N/m), and Elasticity (log decrement) of the suboccipital muscles and upper trapezius of the subjects by using MyotonPro palpation device for this study. Results from these study demonstrated that there was no significant difference between the 2 groups in the elasticity of the suboccipital muscles and upper trapezius while there was a statistically significant difference in tone and stiffness. They found some conclusion that the muscle tone and muscle stiffness of the suboccipital muscles and upper trapezius in patients with a cervicogenic headache had increased in compared to healthy subjects [9].

Stefan Schneider and his colleagues studied and tested the possibility of using myometric measurements to monitor the mechanical properties (Frequency, Decrement, Stiffness, Relaxation time and Creep) of skeletal muscles and tendons in weightlessness during parabolic flights. They assessed the mechanical properties of the m. gastrocnemius, m. erector spinae and Achilles tendon by using the handheld MyotonPro device for the 11 healthy participants (aged 47 ± 9 years) in normal gravity as well as in microgravity during two parabolic flight campaigns. The results from these study indicate significant ($p < 0.05$ to 0.001) changes in all mechanical properties of both muscles and the Achilles tendon. They concluded that myometric measurements are a feasible, easy-to-use and non-invasive approach to monitor muscle health in extreme conditions in comparison to other methods. Results also show that Real-time assessment of the quality of a muscle being exposed to the negative effect of microgravity and also the positive effects of muscular training could be achieved by using MyotonPro technology [10].

Elizabeth C. Pruyn and her colleagues compared the validity and reliability of 3 in vivo methods of stiffness measurement by using 1 cohort of participants. To measure inter-day reliability, they assessed 15 female for stiffness twice within one week using unilateral hopping (vertical stiffness), free oscillations of the calf, and myometry of various muscles of the triceps surae. Results from their study revealed that vertical stiffness produced moderate to high reliability and myometry presented moderate to very high reliability while the free oscillation technique displayed low to moderate reliability. For squat jump vertical stiffness represent a significant correlation with the rate of force development, while myometer stiffness measurements from 3 sites in the lower limb revealed significant correlations with the isometric rate of force development. At the end of the study, they conclude that vertical stiffness and myometry are valid and reliable methods for assessing stiffness while free oscillation technique is not because there were no such relationships were established between the free oscillation technique and any of the performance measurements. [11]

Lucy Aird and her colleagues investigated the between-day intra-rater reliability of a novice user of MyotonPro and between side symmetry of mechanical properties of quadriceps in older males. They studied 20 healthy, community-dwelling, right-lower-limb-dominant males (mean age 71.7, range 65 to 82 years) for this experiment. They conducted this study on two occasions at the same time and day of the week, one week apart in which the participants in a relaxed supine lying to measure the mechanical properties. The study results demonstrate that repeated measurements had very high within-day (intraclass correlation coefficient, ICC 3, 1 >0.90) and high between-day (ICC 3, 2 >0.70; mean of two measurement sets) reliability while there was no statistically significant difference between muscle mechanical properties of the dominant and nondominant muscles (<2.5 % difference; p >0.05) which indicate symmetry of the muscles. [12]

Li-Ling Chuang and his colleagues investigated relative and absolute reliabilities of the myotonometer in 61 participants. They calculated Intraclass correlation coefficient, a relative reliability index for 3 muscular properties (Muscle tone, stiffness and elasticity) for each muscle to examine the degree of consistency and agreement by using absolute reliability indices, including the SEM, smallest real difference, and Bland-Altman limits of agreement to quantify measurement errors and check systematic biases of the 2 test sessions. The study results show that intraclass correlation coefficients were 0.83 to 0.95 for all muscle properties of all muscle groups, the SEM and the smallest real difference of muscle tone, elasticity, and stiffness of the biceps were the smallest among the 6 muscles tested while the Bland-Altman analyses showed no systematic bias between most of the repeated measurements. They concluded that the myotonometer reliably measures muscular properties, with a good relative and absolute reliabilities. [13]

Li-ling Chuang and his colleagues assessed the metric properties of a myotonometer (N=67). They measured muscle tone, elasticity, and stiffness of relaxed extensor digitorum, flexor carpi radialis, and flexor carpi ulnaris by using the myotonometer. The results demonstrated high test-retest reliability for muscle properties in three muscles, significant correlations between the tone and stiffness of the three muscles and palmar pinch strength, between those of the flexor carpi muscles and lateral pinch strength, and between those of the flexor carpi radialis and the ARAT at post-treatment. It also indicated that Muscle stiffness was more responsive than tone and elasticity in all three muscles. At the end of the study, they concluded that Myotonometry can be a reliable, valid, and responsive outcome measure for assessing muscle properties after stroke rehabilitation. [14]

Damian Janecki and his colleagues studied the protective adaptation after eccentric exercise affects changes in passive stiffness of the biceps brachii muscle. Total 14 volunteers (Age: 20 to 24 years) took part in this study. To compare changes in passive muscle stiffness after eccentric exercise between the first and second bouts separated by 2-3 weeks, they design within-group repeated measures and measured maximal isometric torque, passive muscle stiffness and soreness on the right elbow flexors in 14 untrained male volunteers before, immediately after, 24, 48 and 120 h following each bout of eccentric exercise that consisted of 30 repetitions of lowering a dumbbell adjusted to 75 % of each individual's maximal isometric torque. The study results demonstrated that maximal isometric torque reduced immediately after the first bout by 24 $\pm$ 11 % (mean $\pm$ SD; $P < 0.05$) and remained decreased for the next 120 h (23 %) while passive muscle stiffness immediately increased from 223 ± 19 N/m to 254 ± 22 N/m (P <0.05) and remained higher for 120 h. it also indicates that after the second bout maximal isometric torque decreased 21 ± 13 %, and 48 h later recovered to pre-exercise level (P <0.05). they also concluded that smaller increases in passive muscle stiffness and soreness, and faster maximal isometric torque recovery after the second bout of eccentric exercise could result from adaptation process that occurred after the first bout. [15]

Jarosław Marusiak and colleagues have conducted a study to assess muscle passive stiffness in medicated Parkinson's disease patients using myotonometry. They measured the passive stiffness of relaxed biceps brachii (BB) muscle by using myotonometry in total 18 participants (10 healthy and 08 Patients). They also recorded surface electromyographic and mechanomyographic signals from the muscle at rest, while the amplitude of those signals was analyzed offline. The study results revealed that the values of BB muscle passive stiffness were significantly (P_.004) higher in PD than in the controls, with a statistically significant influence of parkinsonian rigidity score (Unified Parkinson's Disease Rating Scale) on intergroup differences (P_.001) while Spearman correlation coefficient value showed a significant (P_.005) positive relationship (0.866) between the parkinsonian rigidity score and passive stiffness values of BB in PD. The groups were not different significantly in the electromyogram amplitude (P_.631) and mechanomyogram amplitude (P_.593) of the BB muscle, and values of these parameters did not correlate significantly with rigidity score (P_.555, P_.745, respectively) in the patients. This study concluded that Myotonometer is a sensitive enough tool to show that PD patients have higher muscle passive stiffness than healthy controls. [16]

Jarosław Marusiak was studied to assess medication-induced changes in resting muscle stiffness in PD patients using myometry. They measured resting muscle stiffness by myometry and recorded a surface electromyogram of relaxed biceps brachii, brachioradialis and triceps brachii muscles in 10 patients with PD (Age: 51–80 years; Hoehn and Yahr stage: 2.5–4) during medication on-phase and medication off-phase (12 h after withdrawal of the medication). The results from their study indicated that patients had significantly lower myometric stiffness and electromyogram amplitude in all tested muscles, and also lower clinical rigidity scores during the medication on-phase compared with the medication off-phase. They also concluded that Myometry revealed that anti-parkinsonian medication decreases not only rigidity in PD, but also rigidity-related stiffness in resting skeletal muscles in PD patients. These findings show that myometry can enrich neurological practice, by allowing objective and reliable assessment of parkinsonian rigidity treatment effectiveness. [17]

James Mullix and his colleagues studied a novel, non-invasive handheld device (MyotonPro) to quantify ratios of relative non-neural tone and mechanical properties of the rectus femoris (RF) and biceps femoris (BF) muscles and assess the reliability of a novice user (n = 21, Age: 20 to 35 years). They obtain relaxed muscle parameters of RF and BF using the MyotonPro and Data were collected on two days, one week apart. The mean (± SD) RF: BF ratios for resting muscle were: frequency 1:0.96 (± 0.05), decrement 1:1.10 (± 0.17) and stiffness 1:0.95 (± 0.07) for their study. They found the excellent reliability of all three parameters within-sessions (ICCs 3, 2 >0.99) and good between-days (ICCs 3, 1, 0.72 to 0.87). They concluded that the relative resting tone and mechanical properties of RF and BF have been characterized in young males, with ratios close to 1:1. They indicated that the MyotonPRO has the potential for assessing changes in muscle properties objectively over time. They also concluded that the relative tone and mechanical properties of RF and BF could potentially be used as a rapid method for assessing the risk of injury is sporting populations and presence of an abnormality in musculoskeletal and neurological conditions, once normal values have been established in relevant groups. [18]

The Simon Krašna and his colleague conducted a study to evaluate a novel approach to measuring neck muscle load and activity in vehicle collision conditions. A series of sled tests were performed on 10 healthy volunteers at three severity levels to simulate low-severity frontal impacts. They measured Electrical activity, electromyography (EMG) and mechanical tension bilaterally on the upper trapezius. A mechanical contraction (MC) sensor was used to measure the tension on the muscle surface. The neck extensor loads were estimated based on the inverse dynamics approach. The results of the study showed a strong linear correlation (Pearson's coefficient $p = 0.821$) between the estimated neck muscle load and the muscle tension measured with the MC sensor. The peak of the estimated neck muscle force delayed 0.2 ± 30.6 ms on average vs. the peak MC sensor signal compared to the average delay of 61.8 ± 37.4 ms vs. the peak EMG signal. The observed differences in EMG and MC sensor collected signals indicate that the MC sensor offers an additional insight into the analysis of the neck muscle load and activity in impact conditions. [34]

T.Finni and his colleague conducted a study to evaluate the validity, reliability, and feasibility of this new product to measure averaged rectified EMG. They tested validity by comparing the signals from bipolar textile electrodes (42 cm^2) and traditional bipolar surface electrodes (1.32 cm^2) during bilateral isometric knee extension exercise with two electrode locations (A: both electrodes located in the same place, B: traditional electrodes placed on the individual muscles according to SENIAM, n=10 persons for each). They calculated Within-session repeatability (coefficient of variation CV %, n=10) from 5 repetitions of 60 % maximum voluntary contraction (MVC). Day-to-day repeatability (n=8) was assessed by measuring three different isometric force levels in five consecutive days. They assessed the feasibility of the textile electrodes in field conditions during maximal treadmill test (n=28). The results of the study (Bland-Altman plots) showed a good agreement with 2SD between the textile and traditional electrodes demonstrating that the textile electrodes provide similar information on the EMG signal amplitude as the traditional electrodes. The within-session CV ranged from 13 to 21 % in both the textile and traditional electrodes. The day-to-day CV was smaller ranging from 4 to11 % for the textile electrodes. A similar relationship (r^2=0.5) was found between muscle strength and EMG of traditional and textile electrodes. The results of the study showed that the textile electrode technique can potentially make EMG measurements very easy in the field conditions. This study concluded that the textile electrodes embedded into shorts is a valid and feasible method for assessing the average rectified value of EMG. [35]

Anne Heizelmann and his colleague were used virtual touch imaging quantification (VTIQ) technology for the first time to conduct measurements of the trapezius and erector spinae muscles in a large study population. The various influencing factors, such as age and sex, were examined during the study. Total 278 subjects took part in the study. The Siemens Acuson S3000 and VTIQ technology were used for measurements of the trapezius and erector spinae muscles (Siemens Healthcare, Erlangen, Germany). As a results of the study, mean values ± standard deviation were calculated: left trapezius: males 2.89 ± 0.38 m/s, females 2.71 ± 0.37 m/s; right trapezius: males 2.84 ± 0.41 m/s, females 2.70 ± 0.38 m/s; left erector spinae: males 2. 97 ± 0.50 m/s, females 2.81 ± 0.57 m/s; right erector spinae: males 3.00 ± 0.52 m/s, females 2.77 ± 0.59 m/s. A significant difference between male and female subjects was demonstrated both for the shear wave velocities of the trapezius and erector spinae as well as for the thickness of the trapezius muscle ($p < 0.05$). There was also a significant difference in muscle elasticity between subjects over 60 years of age and those under 60 ($p < 0.05$). The results of the study indicate that regular physical activity has an effect on muscle elasticity. [36]

Chapter 3

Method

3.1 Device and It's features

The MyotonPro device has been designed for the non-invasive measurement of any single superficial skeletal muscle (hereafter "Muscle") and other biological soft tissue (hereafter "Tissue"), either in the relaxed or in the contracted state. The Device contains a system which allows measurements to be taken in any orientation in relation to Earth gravity vector as well as in zero gravity. [4]

Figure 3.1: MyotonPro Device.
[32]

3.2 Participants

The study was designed on the random trial base and conducted at the building of CIIRS, Czech Technical University, Prague, Czech Republic. MyotonPro device was used to measure muscles parameter for Vastus Medialis(VM) and Vastus lateralis (VL) and Gulteas maximum (GM) muscles in the healthy participants. All subjects in this study met the inclusion criteria (no chronic diseases affecting the musculoskeletal system such as diabetes mellitus, osteoporosis or rheumatism; no surgery or injuries of the lower limb and the foot; no skin lesions above the measuring sites; no intake of anabolic or other drugs affecting the musculoskeletal system). The study sample population for the measurements of the muscles parameter included 20 healthy subjects (10 males with active in the sports and 10 males with no sports activity) divided into two different groups one is sport active (S.A) and second is sport inactive (S.I) according to their sport activity from last six months. For these subjects, the mean age was 24.3 years (SD= 4.43) and the mean body mass index mean was 22.8 kg/m2 (SD= 2.5) as illustrated in the Table:3.1 and Table:3.2.

Table 3.1: Demographic Data of Sport active (S.A) group participants .

Characteristics	**Sport Active**	
	Mean	$\pm SD$
Age(Years)	23.50	3.20
Mass(kg)	69.20	13.13
BMI(Kg/M^2)	22.62	2.40
Height(cm)	174.90	2.88
Sex	Male	

Table 3.2: Demographic Data of Sport inactive (S.I) group participants.

Characteristics	**Sport Inactive**	
	Mean	± SD
Age(Years)	25.10	5.40
Mass(kg)	70.90	12.43
BMI(Kg/M^2)	23.02	2.50
Height(cm)	175.50	4.94
Sex	Male	

3.3 Experimental Procedure

All subjects were informed about the whole study and followed the same procedures for the study. At the start of the procedure, all the subjects were checked to fulfill the required criteria for the study (Age, Body Mass Index, Sports activity (Football, Cricket, Basketball)). After fulfillment of the study requirement and before the exercise, subjects were marked on the body part of desired muscles for repetition of the muscle measurement location by using special marker pen which was available with the MyotonPro device (refer figure:3.6) and measured the muscle parameters for the desired muscles (Gluteus Maximus(GM) (refer figure:3.8), Vastus Lateralis (VL) (refer figure:3.9) and Vastus Medialis(VM) (refer figure:3.10) one by one at each side of the body by using MyotonPro device at the relaxed lying position as illustrated in the figure:3.5.

Later, subjects did five full squats (refer figure: 3.7) to stretch the thigh muscles and then measured the muscles parameter again for the same muscles at the same place by using the MyotonPro device in the same relaxed lying position. They (subjects) repeated this procedure until twenty full squats consisting of five squats per set. After the squats were completed, then measured the muscles parameter every two minutes till ten of minutes in total to check the difference biomechanical parameters of muscles.

All the measured parameters were recorded in MyotonPro device and data was downloaded to MyotonPro software then the data was processed with Matlab software 2017a. The muscles parameter were evaluated by using different function and tools of Matlab and the significant difference in muscles parameters of two different groups was analyzed by using one-way analysis of variance (anova1) tool in the Matlab 2017a software. The flow chart for the experimental procedure is illustrated in figure 3.4. The results of the present study are discussed further.

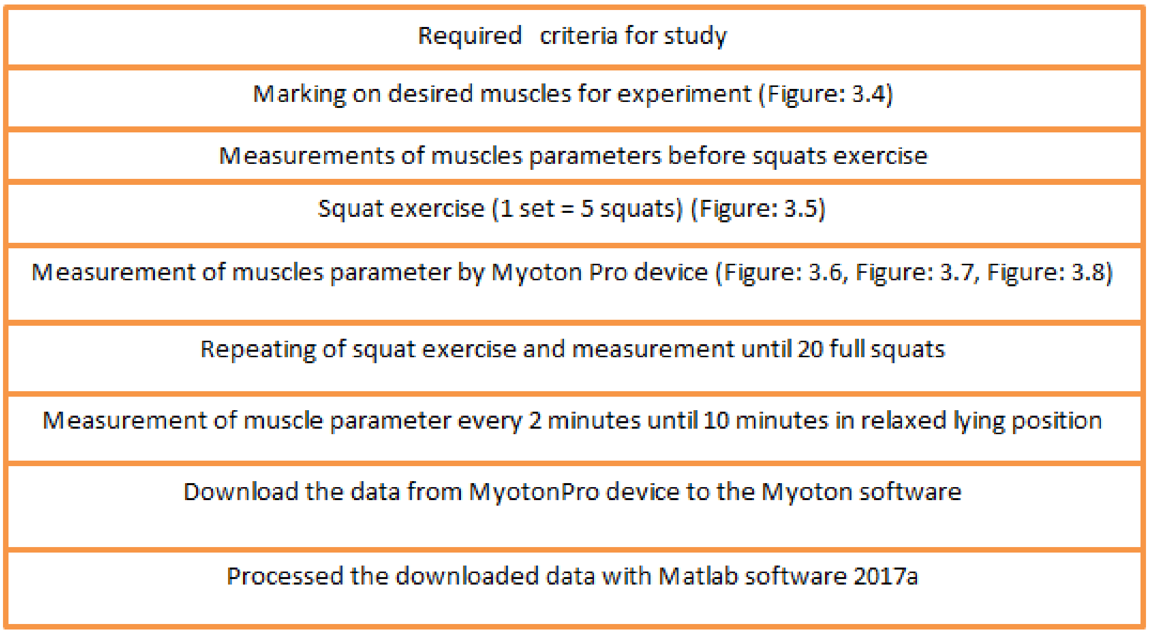

Figure 3.2: Flow chart of the experimental procedure for the present study.

Figure 3.3: Relaxing Position for the parameters measurement by using MyotonPro device.

Figure 3.4: Marking the muscles for the parameter measurement by using MyotonPro device.

Figure 3.5: Squat exercise for the muscles parameter measurement by using MyotonPro device.

Figure 3.6: Measurement of the parameters from Gluteus Maximus(GM) Muscle by using MyotonPro device.

Figure 3.7: Measurement of the parameters from Vastus Medialis(VM) Muscle by using MyotonPro device.

Figure 3.8: Measurement of the parameters from Vastus Lateralis (VL) Muscle by using MyotonPro device.

3.4 Data Analysis

Data were downloaded from MyotonPro device in the form of.CSV file and processed by using Matlab 2017a software. MyotonPro device use five shock wave mechanism to produce an authentic data and give us the mean values with a standard deviation of each set of the data. After the data was downloaded from the MyotonPro device by using MyotonPro software, Matlab function (Mean, SD and RMS (Root Mean square)) were generated for each participants using Matlab 2017a software which were used for further statistic analysis (anova1) of the data.

RMS (Root Mean Square) and One-way analysis of variance (Anova1) test are the important tools for the statistical analysis of the group.

RMS value of a set of values (or a continuous-time waveform) is the square root of the arithmetic mean of the squares of the values, or the square of the function that defines the continuous waveform. The RMS over all time of a periodic function is equal to the RMS of one period of the function. The RMS value of a continuous function or signal can be approximated by taking the RMS of a sequence of equally spaced samples. Additionally, the RMS value of various waveforms can also be determined without calculus, as shown by Cartwright.

In the case of the RMS statistic of a random process, the expected value is used instead of the mean.

Here below is an example of the plot for the RMS (Root Mean Value) values of the stiffness (N/m) for the Vastus Lateralis Right (VLL) muscle of the sport inactive group.

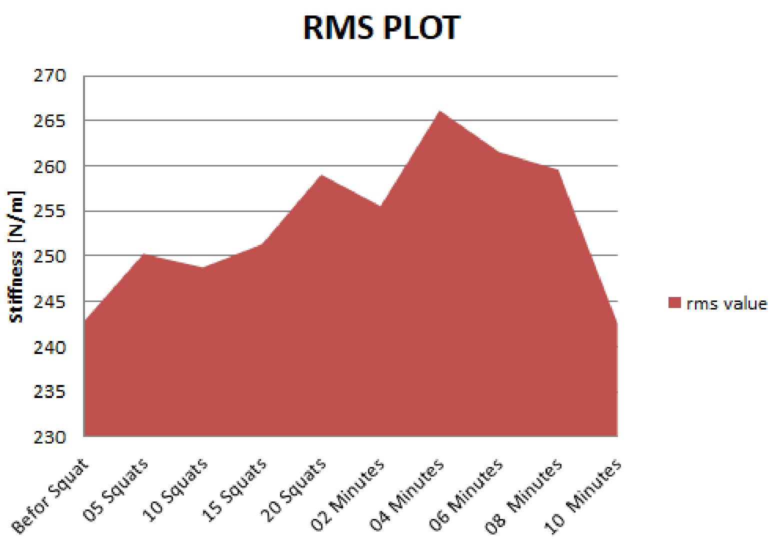

Figure 3.9: RMS values of the stiffness (N/m) parameter for the VLL muscle of the sport inactive group.

3.5 Statistical Analysis

In the present study, we were applied null hypothesis (H_0) of the one way analysis of the variance (ANOVA) between the mean values of RMS (Root Mean Square) of the different parameters (Frequency (Hz), Creep (D.n), Decrement, R.Time (ms) and Stiffness (N/m)) of the sport active (S.A) group and the mean value of RMS (Root Mean Square) of the different parameters (Frequency (Hz), Creep (D.n), Decrement, R.Time (ms) and Stiffness (N/m)) of the sport inactive (S.I) group. If the ANOVA gives the statistically significant results, we accept the alternative (H_A) hypothesis, which state that there are at least two group means that are statistically significantly different from each other.

In the statistical analysis of the variance, the common significance levels were 0.05 to 0.01. if the value of the p is near zero (0), it produces doubt on the null hypothesis (H_0). If the value of the p is within the common levels, it shows the significant difference between the sport active (S.A) group and sport inactive (S.I) group. If the value of p is not within the common levels, it shows that there is no significant difference between sports active (S.A) and sports inactive (S.I) groups.

Chapter 4

Results and Discussion

A total of 20 healthy subjects were measured using MyotonPro device during this measurement which is illustrated in Table:2.1 and Table:2.2. Descriptive statistics of the myotonometric measurements are reported in below tables. The values of muscle bio-mechanical properties were within the upper and lower limits of measurements. The results of the experiment show the significant difference in the RMS (Root Mean Square) values of muscles parameters between the two groups of subjects (Sports Active (S.A) and Sports Inactive (S.I)). Among the five different parameters of the muscles, Muscle Tone (Frequency (Hz)), Relaxation Time (ms) and Stiffness (N/m) are the most important parameters which define biomechanical properties of the muscles. Muscle tone indicates the intrinsic tension of the muscle in its testing position. Relaxation Time shows the time required to come at the normal state after each starching of the muscle while Stiffness shows how stiff the muscle is? Along with these three major parameters, other two parameters Decrement, and Creep (D.n) also define the biomechanical properties of the muscles.

4.1 Analysis for a single person:

Table:4.1 and Table:4.2 reports the mean values ± SD for the different parameters for the Gluteus MaximusLeft (GML) side of the sport active group single person and sport inactive group single person simultaneously. The table comprises the mean values ± SD of parameters before squat exercise and after each set of the squats exercise. Figure:4.1 and Figure:4.2 reports the mean values of frequency (Hz) parameter for the single person of the sport active group and sport inactive group. From both the tables and plot, we can clearly see the difference in the frequency (Hz) parameter. Sport active group is more consistent than sport inactive group for the frequency (Hz) parameter after squats exercise. The maximum value for the sport active group person is 12.82 ± 0.083 at 04 ± 01 minute while the maximum value for the sport inactive group person is 11.68 ± 0.268 after 05 squats. This kind of data is used for the person to person analysis of different biomechanical parameters to evaluate the muscles properties. By using this kind of person to person data analysis, we can calculate the Mean values for the frequency (Hz) parameter for the whole group to find some similarities and differences between sports active and sports inactive group. We can calculate and plot the other parameters by repeating the Matlab function for each side of muscle for every healthy subject who took part in the study.

Table 4.1: Mean ± SD values of Different Parameters for Gluteus MaximusLeft (GML) side for single person of the sport active group by using MyotonPro.

Mode	**Frequency(Hz)**	**Creep(D.n)**	**Decrement**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	11.42 ± 0.044	1.352 ± 0.010	0.956 ± 0.024	26.52 ± 0.376	141.6 ± 01.816
08 minutes	11.30 ± 0.070	1.290 ± 0.086	0.762 ± 0.049	26.26 ± 0.733	127.0 ± 04.636
06 minutes	11.38 ± 0.130	1.218 ± 0.027	0.890 ± 0.053	25.76 ± 0.207	124.8 ± 03.962
04 minutes	12.82 ± 0.083	1.396 ± 0.011	0.922 ± 0.037	23.76 ± 0.114	189.2 ± 01.303
02 minutes	11.46 ± 0.054	1.260 ± 0.072	0.942 ± 0.019	25.42 ± 0.601	135.0 ± 03.535
20 Squats	12.42 ± 0.535	1.386 ± 0.125	0.876 ± 0.085	24.98 ± 0.887	171.2 ± 24.681
15 Squats	11.62 ± 0.109	1.220 ± 0.219	0.830 ± 0.036	25.00 ± 1.713	135.4 ± 16.562
10 Squats	12.28 ± 0.083	1.260 ± 0.242	0.830 ± 0.023	24.06 ± 1.930	153.8 ± 19.816
05 Squats	12.14 ± 0.054	1.160 ± 0.190	0.906 ± 0.008	23.24 ± 1.556	149.8 ± 13.590
Before Squat	12.58 ± 0.476	1.436 ± 0.051	1.092 ± 0.048	24.66 ± 0.844	192.0 ± 07.615

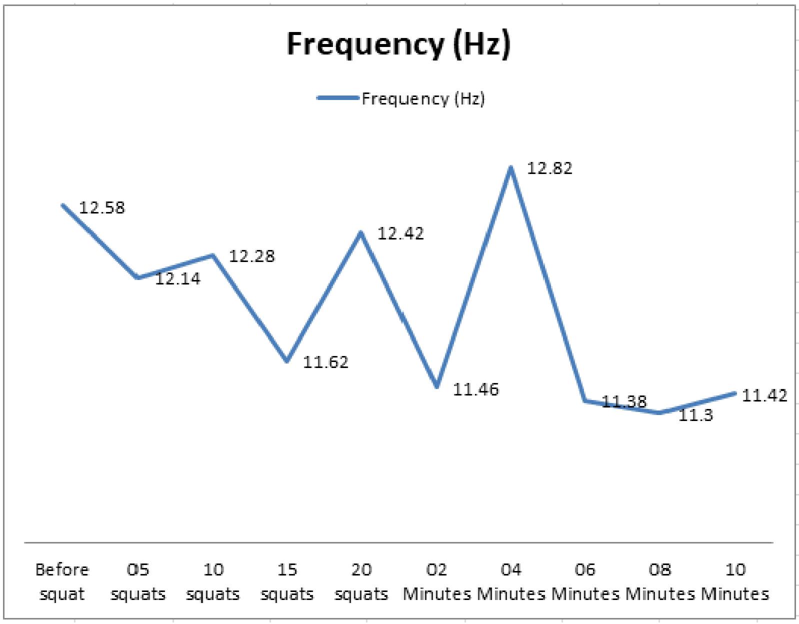

Figure 4.1: Mean value of Frequency (Hz) parameter for the single person of the sport active group.

Table 4.2: Mean ± SD values of Different Parameters for Gluteus MaximusLeft (GML) side for single person of the sport inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Creep(D.n)**	**Decrement**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	11.54 ± 0.181	1.588 ± 0.223	1.032 ± 0.042	29.26 ± 1.683	148.0 ± 14.713
08 minutes	10.68 ± 0.083	1.784 ± 0.055	1.270 ± 0.038	32.02 ± 0.311	155.0 ± 03.741
06 minutes	10.84 ± 0.207	1.720 ± 0.169	0.960 ± 0.041	30.90 ± 1.337	149.8 ± 13.700
04 minutes	11.20 ± 0.187	1.736 ± 0.175	1.032 ± 0.059	31.06 ± 1.339	151.2 ± 13.255
02 minutes	11.38 ± 0.130	1.526 ± 0.247	1.092 ± 0.051	29.08 ± 1.652	138.8 ± 18.939
20 Squats	11.30 ± 0.291	1.824 ± 0.024	1.230 ± 0.073	31.06 ± 0.270	166.6 ± 02.302
15 Squats	10.62 ± 0.148	1.984 ± 0.020	1.186 ± 0.053	33.66 ± 0.207	160.8 ± 01.303
10 Squats	11.68 ± 0.044	1.712 ± 0.013	1.126 ± 0.037	29.54 ± 0.151	166.4 ± 00.547
05 Squats	11.38 ± 0.268	1.690 ± 0.113	1.070 ± 0.060	29.82 ± 1.287	161.0 ± 03.316
Before Squat	10.86 ± 0.089	1.804 ± 0.016	1.014 ± 0.044	31.26 ± 0.240	154.0 ± 02.000

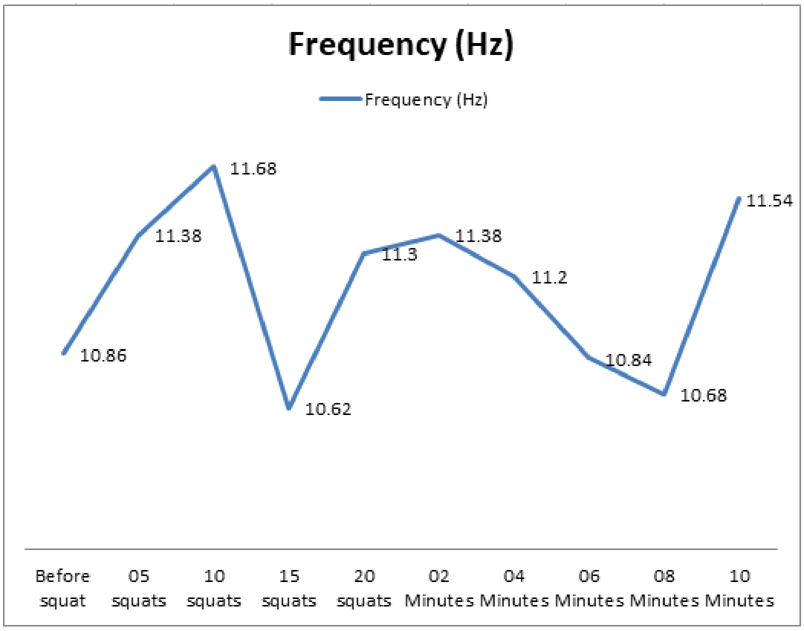

Figure 4.2: Mean value of Frequency (Hz) parameter for the single person of the sport inactive group.

4.2 Mean value analysis:

Approximate mean value analysis (MVA) is a popular technique for analyzing queueing networks because of the efficiency and accuracy that it affords. The results of MVA give us the clear idea about the large network behavior with some pattern. we can use these result to compare with the results of other data to produce some graph pattern.

4.2.1 Gluteus Maximus

The Gluteus Maximusmuscle is located in the buttocks and is regarded as one of the strongest muscles in the human body. It is connected to the coccyx, or tailbone, as well as other surrounding bones. The Gluteus Maximusmuscle is responsible for the movement of the hip and thigh. Standing up from a sitting position, climbing stairs, and staying in an erect position are all aided by the gluteus maximus. It is very important to know the biomechanical properties of the Gluteus Maximusmuscles with each side.

Table:4.3 and Table:4.4 shows the mean values ± SD values of different parameters for Gluteus Maximusleft (GML) side muscles while Table:4.5 and Table:4.6 shows the mean values ± SD values of different parameters for Gluteus MaximusRight side muscles for both the groups simultaneously. The mean values ± SD value of Relaxation Time(ms) and Stiffness(N/m) of the Sport Active group are significantly low in comparison to Sport Inactive group for both the side of the muscle. Less time is required for relaxation of muscle for Sport Active group while Sport Inactive group take more time to recover its original position before squat. After each set of squats(05 squats) exercise, both the sides of muscles take almost same time for relaxation of both the groups. The Left and Right sides of the muscle take around 04 ± 01 minutes to recover its original state as before squat exercise for Sport active group and sport inactive group. The stiffness values of both the sides of the muscles indicates that Gluteus Maximusmuscle is less stiff in the Sport active group while Sport inactive group has more stiff muscle. The values of Decrement and Creep are slightly less while the value of the Oscillation Frequency (Hz) is high for the sport active group than sport inactive group for both the side of the muscles.

Table 4.3: Mean Values ± SD values of Different Parameters for Gluteus MaximusLeft (GML) side for the Sport Active group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 Minutes	15.888 ± 0.302	1.126 ± 0.013	1.554 ± 0.034	23.538 ± 0.400	162.200 ± 1.844
08 Minutes	15.996 ± 0.169	1.017 ± 0.039	1.446 ± 0.058	22.694 ± 0.481	149.020 ± 3.872
06 Minutes	16.236 ± 0.878	1.110 ± 0.029	1.478 ± 0.112	22.630 ± 0.147	153.780 ± 6.853
04 Minutes	16.062 ± 0.291	1.085 ± 0.013	1.463 ± 0.031	21.776 ± 0.467	177.080 ± 2.707
02 Minutes	16.552 ± 0.278	1.076 ± 0.021	1.461 ± 0.026	21.928 ± 0.229	158.780 ± 1.541
20 Squats	17.272 ± 0.502	1.038 ± 0.054	1.427 ± 0.095	20.968 ± 0.779	171.020 ± 9.109
15 Squats	16.400 ± 0.341	1.141 ± 0.045	1.519 ± 0.078	22.840 ± 0.639	161.180 ± 5.661
10 Squats	15.742 ± 0.249	1.128 ± 0.069	1.444 ± 0.090	22.334 ± 0.738	161.300 ± 7.222
05 Squats	15.754 ± 0.446	1.048 ± 0.018	1.487 ± 0.078	22.850 ± 0.573	164.380 ± 5.509
Before Squat	16.782 ± 0.461	1.069 ± 0.021	1.484 ± 0.053	21.734 ± 0.392	172.540 ± 2.795

Table 4.4: Mean Values ± SD of Different Parameters for Gluteus MaximusLeft (GML) side for the Sport Inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	12.746 ± 0.199	1.383 ± 0.022	1.746 ± 0.063	29.970 ± 0.491	168.260 ± 4.125
08 minutes	12.810 ± 0.161	1.349 ± 0.060	1.692 ± 0.034	29.176 ± 0.429	159.080 ± 2.32
06 minutes	13.368 ± 0.605	1.342 ± 0.032	1.597 ± 0.084	26.842 ± 0.452	166.380 ± 6.184
04 minutes	13.380 ± 0.262	1.459 ± 0.020	1.685 ± 0.048	27.558 ± 0.378	172.400 ± 3.493
02 minutes	12.614 ± 0.101	1.488 ± 0.054	1.763 ± 0.095	29.258 ± 0.666	161.590 ± 6.351
20 Squats	13.684 ± 0.496	1.505 ± 0.025	1.769 ± 0.087	27.688 ± 0.511	177.680 ± 6.861
15 Squats	12.840 ± 0.113	1.444 ± 0.025	1.736 ± 0.057	28.494 ± 0.556	167.860 ± 2.155
10 Squats	13.616 ± 0.405	1.396 ± 0.028	1.563 ± 0.033	25.770 ± 0.562	183.220 ± 2.741
05 Squats	13.316 ± 0.102	1.458 ± 0.030	1.642 ± 0.036	27.056 ± 0.517	172.560 ± 1.654
Before Squat	13.182 ± 0.426	1.288 ± 0.025	1.604 ± 0.062	28.806 ± 0.474	163.620 ± 2.692

Table 4.5: Mean Values ± SD Values of Different Parameters for Gluteus MaximusRight (GMR) side for both the Sport Acive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	16.180 ± 0.395	1.162 ± 0.022	1.431 ± 0.055	21.392 ± 0.374	178.140 ± 4.241
08 minutes	16.072 ± 0.438	1.110 ± 0.027	1.482 ± 0.076	22.500 ± 0.575	164.080 ± 3.608
06 minutes	16.034 ± 0.531	1.170 ± 0.016	1.495 ± 0.056	21.768 ± 0.201	163.920 ± 2.184
04 minutes	16.566 ± 0.199	1.095 ± 0.064	1.474 ± 0.025	22.868 ± 0.253	168.380 ± 4.661
02 minutes	15.988 ± 0.617	1.268 ± 0.020	1.499 ± 0.092	22.578 ± 0.747	170.120 ± 3.099
20 Squats	16.506 ± 0.335	1.076 ± 0.021	1.407 ± 0.051	21.168 ± 0.455	172.780 ± 6.434
15 Squats	16.228 ± 0.583	1.141 ± 0.018	1.412 ± 0.072	21.520 ± 0.575	171.640 ± 2.746
10 Squats	16.306 ± 0.170	1.145 ± 0.076	1.487 ± 0.017	22.002 ± 0.328	177.240 ± 5.869
05 Squats	16.400 ± 0.183	1.109 ± 0.023	1.461 ± 0.035	21.868 ± 0.277	174.440 ± 5.266
Before Squat	16.170 ± 0.314	1.186 ± 0.022	1.466 ± 0.020	21.878 ± 0.217	176.640 ± 4.385

Table 4.6: Mean Values ± SD Values of Different Parameters for Gluteus MaximusRight (GMR) side for both the Sport Inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	12.748 ± 0.296	1.494 ± 0.026	1.828 ± 0.052	29.476 ± 0.327	171.600 ± 2.587
08 minutes	13.084 ± 0.123	1.405 ± 0.027	1.778 ± 0.069	28.938 ± 0.679	167.620 ± 4.720
06 minutes	12.602 ± 0.333	1.546 ± 0.016	1.873 ± 0.081	30.334 ± 0.435	167.040 ± 2.264
04 minutes	13.230 ± 0.158	1.550 ± 0.013	1.761 ± 0.034	27.860 ± 0.264	180.720 ± 4.085
02 minutes	12.906 ± 0.625	1.490 ± 0.025	1.829 ± 0.076	29.446 ± 0.275	175.260 ± 5.232
20 Squats	13.352 ± 0.071	1.459 ± 0.044	1.728 ± 0.066	28.124 ± 0.429	175.080 ± 4.764
15 Squats	13.182 ± 0.273	1.448 ± 0.035	1.801 ± 0.033	29.014 ± 0.529	173.720 ± 2.566
10 Squats	13.262 ± 0.111	1.468 ± 0.023	1.702 ± 0.049	27.718 ± 0.524	175.900 ± 6.817
05 Squats	13.478 ± 0.113	1.477 ± 0.040	1.770 ± 0.077	28.428 ± 0.516	176.860 ± 2.423
Before Squat	13.012 ± 0.138	1.406 ± 0.035	1.637 ± 0.046	27.628 ± 0.481	167.340 ± 3.971

4.2.2 Vastus Lateralis

The vastus lateralis muscle is located on the side of the thigh. This muscle is the largest of the quadriceps group (often called quads) which also includes the rectus femoris, the vastus intermedius, and the vastus medialis. Collectively, the quadriceps muscle is the largest in the human body and its purpose is to extend the knee. The specific task of the vastus lateralis muscle is to extend the lower leg and allow the body to rise up from a squatting position. Any kind of injuries with this muscles lead to a big problem in the life of athlete's. It is very important to an analysis of the injury level with this muscle in a very short time with proper care.

Table:4.7 and Table:4.8 reports the mean values± SD for the Vastus Lateralis left (VLL) side muscles and Table:4.9 and Table:4.10 reports the mean value± SD value of the different parameter of the Vastus Lateralis Right (VLR) side of muscle for both the groups. The Relaxation Time (ms) values for the left side of the muscles is slightly high for the sport active group while for the right side of the muscle, the value is slightly low for the sport active group in comparison to sport inactive group. The left side of the Vastus Lateralis muscle of sport active group take almost 02 ± 01 minutes while right side of the muscle take almost 08 ± 01 minutes to recover its original state for the Sport Active group while left and right side of the muscle of Sport Inactive group take around 04 ± 01 minutes to recover its original position. The value of stiffness for both the sides of the muscles is higher for the Sport Active group than the sport Inactive group. The stiffness value of both the sides of the Vastus Lateralis muscle is significantly higher than both the sides of the Gluteus Maximusmuscles. This higher values indicate that the Vastus lateralis muscle is more involved in the squat exercise. The mean values of Decrement and Creep are slightly less for the Sport Active group than the Sport Inactive group for both the side of the Vastus Lateralis muscle. While the Oscillation frequency values are almost similar for both the groups at both the side of the muscle.

Table 4.7: Mean Values ± SD Values of Different Parameters for Vastus Lateralis Left (VLL) side for both the Sport Active group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	16.066 ± 0.268	1.379 ± 0.310	0.973 ± 0.016	18.422 ± 1.228	353.920 ± 10.531
08 minutes	16.238 ± 0.192	1.296 ± 0.040	1.023 ± 0.008	18.056 ± 0.136	345.440 ± 5.369
06 minutes	15.798 ± 0.191	1.221 ± 0.022	1.027 ± 0.004	18.274 ± 0.072	335.320 ± 3.428
04 minutes	16.636 ± 0.109	1.280 ± 0.030	0.961 ± 0.005	17.442 ± 0.069	360.120 ± 2.036
02 minutes	16.216 ± 0.108	1.293 ± 0.039	0.971 ± 0.008	17.986 ± 0.122	352.600 ± 5.201
20 Squats	16.968 ± 0.145	1.212 ± 0.012	0.935 ± 0.004	17.118 ± 0.111	368.620 ± 1.767
15 Squats	17.772 ± 0.112	1.300 ± 0.038	0.912 ± 0.009	16.262 ± 0.119	373.680 ± 4.967
10 Squats	16.924 ± 0.061	1.286 ± 0.014	0.982 ± 0.005	17.340 ± 0.096	351.840 ± 2.922
05 Squats	16.620 ± 0.170	1.212 ± 0.039	0.889 ± 0.007	17.280 ± 0.283	391.840 ± 10.484
Before Squat	18.084 ± 0.158	1.317 ± 0.026	0.909 ± 0.009	16.090 ± 0.108	379.160 ± 5.226

Table 4.8: Mean Values ± SD Values of Different Parameters for Vastus Lateralis Left (VLL) side for both the Sport Inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	16.842 ± 0.156	1.504 ± 0.041	1.065 ± 0.009	17.666 ± 0.147	333.780 ± 5.923
08 minutes	16.506 ± 0.058	1.325 ± 0.025	1.064 ± 0.006	17.896 ± 0.103	331.320 ± 1.596
06 minutes	16.486 ± 0.128	1.468 ± 0.013	1.081 ± 0.007	17.956 ± 0.106	325.760 ± 1.902
04 minutes	16.542 ± 0.103	1.421 ± 0.033	1.119 ± 0.013	18.548 ± 0.131	322.800 ± 1.255
02 minutes	18.146 ± 0.087	1.420 ± 0.031	1.020 ± 0.012	16.906 ± 0.157	364.640 ± 2.604
20 Squats	17.628 ± 0.094	1.442 ± 0.024	1.069 ± 0.010	17.538 ± 0.155	342.520 ± 7.159
15 Squats	16.632 ± 0.085	1.451 ± 0.027	1.065 ± 0.003	17.674 ± 0.065	328.140 ± 1.82
10 Squats	17.284 ± 0.159	1.504 ± 0.017	1.085 ± 0.007	17.830 ± 0.154	337.780 ± 11.172
05 Squats	17.028 ± 0.213	1.517 ± 0.054	1.053 ± 0.007	17.640 ± 0.107	366.080 ± 3.782
Before Squat	17.348 ± 0.171	1.503 ± 0.005	1.056 ± 0.008	17.462 ± 0.099	333.580 ± 2.494

Table 4.9: Mean Values ± SD Values of Different Parameters for Vastus Lateralis Right (VLR) side for the Sport Active group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	15.878 ± 0.226	1.274 ± 0.039	0.914 ± 0.013	17.756 ± 0.453	379.580 ± 10.209
08 minutes	16.122 ± 0.195	1.227 ± 0.030	0.940 ± 0.009	17.844 ± 0.625	369.480 ± 8.514
06 minutes	16.628 ± 0.213	1.777 ± 0.034	0.923 ± 0.009	17.258 ± 0.072	375.940 ± 11.019
04 minutes	16.420 ± 0.114	1.203 ± 0.031	0.897 ± 0.007	17.166 ± 0.296	375.220 ± 5.577
02 minutes	16.610 ± 0.083	1.261 ± 0.022	0.939 ± 0.005	17.238 ± 0.126	374.260 ± 2.608
20 Squats	16.814 ± 0.323	1.199 ± 0.044	0.904 ± 0.017	16.732 ± 0.413	376.420 ± 8.320
15 Squats	16.258 ± 0.159	1.197 ± 0.027	0.920 ± 0.011	17.398 ± 0.110	378.360 ± 7.800
10 Squats	16.918 ± 0.126	1.208 ± 0.040	0.913 ± 0.007	16.792 ± 0.088	376.260 ± 4.020
05 Squats	16.274 ± 0.253	1.173 ± 0.042	0.893 ± 0.014	17.230 ± 0.232	379.840 ± 10.163
Before Squat	16.120 ± 0.284	1.263 ± 0.046	0.908 ± 0.010	17.674 ± 0.315	390.100 ± 10.060

Table 4.10: Mean Values ± SD Values of Different Parameters for Vastus Lateralis Right (VLR) side for the Sport Inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	16.890 ± 0.082	1.252 ± 0.018	1.042 ± 0.004	17.518 ± 0.104	322.320 ± 7.699
08 minutes	17.002 ± 0.075	1.341 ± 0.027	1.058 ± 0.010	17.448 ± 0.123	322.800 ± 5.497
06 minutes	17.134 ± 0.252	1.240 ± 0.037	1.053 ± 0.004	17.394 ± 0.116	324.740 ± 6.631
04 minutes	16.974 ± 0.207	1.254 ± 0.026	1.016 ± 0.011	17.178 ± 0.169	322.820 ± 5.315
02 minutes	16.096 ± 0.474	1.347 ± 0.040	1.112 ± 0.060	18.368 ± 0.821	306.780 ± 3.148
20 Squats	17.140 ± 0.306	1.334 ± 0.022	1.031 ± 0.006	17.226 ± 0.079	324.940 ± 4.568
15 Squats	17.748 ± 0.111	1.269 ± 0.018	0.984 ± 0.006	16.296 ± 0.122	332.800 ± 5.900
10 Squats	17.132 ± 0.095	1.354 ± 0.013	1.048 ± 0.013	17.538 ± 0.144	329.680 ± 5.230
05 Squats	17.106 ± 0.172	1.371 ± 0.027	1.027 ± 0.011	17.358 ± 0.157	331.420 ± 4.905
Before Squats	17.658 ± 0.122	1.406 ± 0.038	1.022 ± 0.005	17.072 ± 0.120	340.780 ± 8.601

4.2.3 Vastus Medialis

The Vastus Medialis muscle is a part of the quadriceps muscle group, located on the front of the thigh. It is the most medial, or inner, of the quadriceps muscles. It extends the entire length of the thigh. The portion of the muscle that is just above the knee is sometimes referred to as the vastus medialis obliquus, or VMO. This muscle is used to extend the leg at the knee and to stabilize the patella, which is also known as the kneecap. Injuries with this muscles lead problem with the running and walking. So it is very important to acquire the detail information of the injury with the muscle.

Table: 4.11 with Table: 4.12 and Table:4.13 with Table:4.14 summarized the mean value± SD value of different parameters for the Vastus Medialis left (VML) and right (VMR) sides muscles. The Relaxation time (ms) for both the side of the muscle are significantly lower for the sport active group than the sport inactive group. The left side of the muscle takes 06 ± 01 minutes time for the sport active group and 02 ± 01 minutes time for the sport inactive group for returning its original state. The right side of the muscle takes 02 ± 01 minutes time to recover its initial state for sport active group and 08 ± 01 minutes for sport inactive group. While the stiffness value is higher for the Sport Active group for both the side of the muscles. The Decrement (D.n) and Creep values remain the same for both the group of both the sides. The oscillation frequency (Hz) values are higher for Sport active groups in both the side of the muscles. These results indicate that the Vastus Medialis is less involved during the squat exercise than the Vastus Lateralis muscles.

Table 4.11: Mean Values ± SD Values of Different Parameters for Vastus Medialis Left (VML) side for the Sport Active group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	15.960 ± 0.031	1.146 ± 0.012	1.313 ± 0.010	19.612 ± 0.167	236.240 ± 1.698
08 minutes	16.496 ± 0.054	1.134 ± 0.036	1.284 ± 0.006	18.938 ± 0.080	245.900 ± 2.023
06 minutes	16.062 ± 0.077	1.167 ± 0.005	1.303 ± 0.005	19.458 ± 0.066	241.820 ± 2.844
04 minutes	16.208 ± 0.107	1.134 ± 0.016	1.194 ± 0.011	18.574 ± 0.158	261.920 ± 3.414
02 minutes	16.484 ± 0.049	1.115 ± 0.020	1.222 ± 0.010	18.362 ± 0.134	253.200 ± 2.379
20 Squats	16.212 ± 0.121	1.094 ± 0.027	1.228 ± 0.007	18.714 ± 0.141	243.100 ± 2.842
15 Squats	16.228 ± 0.178	1.105 ± 0.018	1.242 ± 0.019	18.806 ± 0.428	241.280 ± 4.436
10 Squats	16.054 ± 0.133	1.151 ± 0.014	1.284 ± 0.011	19.344 ± 0.222	245.500 ± 1.578
05 Squats	16.158 ± 0.110	1.099 ± 0.009	1.252 ± 0.020	18.942 ± 0.254	240.100 ± 1.105
Before Squat	16.032 ± 0.216	1.113 ± 0.013	1.269 ± 0.022	19.196 ± 0.397	243.460 ± 3.616

Table 4.12: Mean Values ± SD Values of Different Parameters for Vastus Medialis Left (VML) side for the Sport Inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	13.722 ± 0.058	1.223 ± 0.017	1.397 ± 0.016	22.600 ± 0.106	219.720 ± 1.612
08 minutes	13.884 ± 0.036	1.176 ± 0.013	1.377 ± 0.009	22.438 ± 0.076	219.560 ± 1.713
06 minutes	13.626 ± 0.028	1.141 ± 0.012	1.378 ± 0.012	22.660 ± 0.074	214.400 ± 1.456
04 minutes	13.810 ± 0.053	1.195 ± 0.008	1.384 ± 0.006	22.432 ± 0.059	221.380 ± 1.438
02 minutes	13.786 ± 0.051	1.172 ± 0.006	1.367 ± 0.006	22.396 ± 0.133	224.200 ± 1.150
20 Squats	13.776 ± 0.052	1.221 ± 0.013	1.399 ± 0.005	22.612 ± 0.074	225.280 ± 1.924
15 Squats	13.776 ± 0.101	1.140 ± 0.038	1.365 ± 0.011	22.380 ± 0.146	218.640 ± 1.737
10 Squats	13.612 ± 0.061	1.218 ± 0.012	1.393 ± 0.012	22.754 ± 0.076	219.080 ± 2.454
05 Squats	13.362 ± 0.036	1.185 ± 0.010	1.437 ± 0.016	23.462 ± 0.137	212.440 ± 0.861
Before Squats	14.156 ± 0.391	1.180 ± 0.008	1.340 ± 0.013	21.936 ± 0.116	228.880 ± 1.861

Table 4.13: Mean Values ± SD Values of Different Parameters for Vastus Medialis Right (VMR) side for the Sport Active group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	15.770 ± 0.066	1.076 ± 0.019	1.270 ± 0.007	19.586 ± 0.067	240.760 ± 1.699
08 minutes	15.634 ± 0.175	1.044 ± 0.022	1.231 ± 0.021	19.286 ± 0.115	257.620 ± 0.916
06 minutes	15.546 ± 0.079	1.028 ± 0.013	1.209 ± 0.006	19.188 ± 0.126	259.140 ± 1.775
04 minutes	15.806 ± 0.300	1.069 ± 0.050	1.203 ± 0.017	19.136 ± 0.286	262.980 ± 8.101
02 minutes	15.538 ± 0.158	1.034 ± 0.051	1.246 ± 0.012	19.508 ± 0.084	252.480 ± 2.298
20 Squats	15.794 ± 0.065	0.995 ± 0.071	1.208 ± 0.004	18.990 ± 0.052	255.960 ± 1.134
15 Squats	15.370 ± 0.059	1.014 ± 0.012	1.231 ± 0.005	19.576 ± 0.056	249.520 ± 1.501
10 Squats	16.102 ± 0.073	1.053 ± 0.011	1.241 ± 0.005	18.880 ± 0.085	247.060 ± 1.515
05 Squats	15.340 ± 0.120	1.051 ± 0.020	1.232 ± 0.006	19.512 ± 0.098	249.200 ± 2.632
Before Squat	15.842 ± 0.067	1.063 ± 0.022	1.299 ± 0.006	19.678 ± 0.108	240.880 ± 1.545

Table 4.14: Mean Values ± SD Values of Different Parameters for Vastus Medialis Right (VMR) side for the Sport Inactive group by using MyotonPro.

Mode	**Frequency(Hz)**	**Decrement**	**Creep(D.n)**	**R.Time(ms)**	**Stiffness(N/m)**
10 minutes	13.948 ± 0.070	1.080 ± 0.018	1.349 ± 0.013	22.136 ± 0.111	215.680 ± 1.548
08 minutes	13.580 ± 0.188	1.134 ± 0.010	1.397 ± 0.020	22.742 ± 0.092	214.420 ± 2.311
06 minutes	14.012 ± 0.048	1.093 ± 0.014	1.350 ± 0.013	21.992 ± 0.128	220.980 ± 2.290
04 minutes	13.448 ± 0.057	1.083 ± 0.016	1.439 ± 0.005	23.386 ± 0.106	210.460 ± 2.521
02 minutes	14.042 ± 0.075	1.203 ± 0.009	1.368 ± 0.009	22.162 ± 0.075	227.140 ± 2.078
20 Squats	13.534 ± 0.078	1.141 ± 0.023	1.423 ± 0.011	22.958 ± 0.117	212.560 ± 1.906
15 Squats	13.680 ± 0.059	1.111 ± 0.012	1.381 ± 0.011	22.590 ± 0.126	222.040 ± 2.177
10 Squats	13.443 ± 0.096	1.187 ± 0.017	1.427 ± 0.006	23.146 ± 0.110	216.440 ± 1.527
05 Squats	13.284 ± 0.132	1.132 ± 0.016	1.393 ± 0.007	22.960 ± 0.070	220.760 ± 1.631
Before Squat	13.432 ± 0.064	1.161 ± 0.027	1.409 ± 0.005	22.954 ± 0.061	218.180 ± 0.994

4.2.4 Root Mean Square analysis:

In data processing which is time-dependent, a data is viewed as a function of time. The term "size of a data" is used to represent "strength of the data". RMS (Root Mean Square) value of a data (x(t)) is calculated as the square root of the average of the squared value of the data.

Following tables (Table:4.15 to Table:4.21) contain the RMS (Root Mean Square) values of the different biomechanical parameters for each side of the muscles for both the groups (sport active and sport inactive) which were derived from the mean value analysis (MVA) of the each healthy subject who took part in the present study. This data helps us with the value which is time independent so we can be more sure with the biomechanical properties of each side of muscle for each patient at a particular time. With the help of this RMS (Root Mean Square) data, we can find the significant difference between the two groups by applying the one-way analysis (anova1).In the present study, we used one-way analysis rather than two-way analysis because to analyzed the groups with only one different variable within it. By applying one-way analysis, groups were analyzed for H_{0B} hypothesis which means all samples from factor B (i.e., all row-samples in X) are drawn from the same population.

Table 4.15: RMS (Root Mean Square) values from mean values of Different Parameters for Gluteus MaximusLeft (GML) side for both the groups by using MyotonPro.

Patients	**Frequency(Hz)**		**Creep(D.n)**		**Decrement**		**R.Time(ms)**		**Stiffness(N/m)**	
	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I
Patient 01	18.205	14.364	1.503	1.617	1.082	1.346	22.947	27.435	174.475	166.048
Patient 02	17.027	14.340	1.517	1.649	1.085	1.547	24.145	27.597	165.232	174.436
Patient 03	16.973	14.363	1.466	1.571	1.213	1.452	23.593	26.313	163.427	186.978
Patient 04	17.908	14.109	1.537	1.745	1.210	1.511	24.155	29.173	162.906	169.880
Patient 05	18.602	14.682	1.435	1.714	1.080	1.605	22.017	28.275	173.976	179.623
Patient 06	18.138	13.994	1.476	1.771	1.103	1.564	23.138	29.944	160.905	163.895
Patient 07	17.255	14.586	1.484	1.693	1.117	1.527	22.818	28.167	178.399	174.542
Patient 08	17.854	14.506	1.492	1.611	1.159	1.410	23.831	27.518	155.927	169.885
Patient 09	17.449	13.547	1.466	1.703	1.063	1.385	24.027	29.864	151.366	162.554
Patient 10	17.358	13.806	1.573	1.756	1.155	1.442	24.852	29.598	164.017	170.144

Table 4.16: RMS (Root Mean Square) values from mean values of Different Parameters for Gluteus MaximusRight (GMR) side for both the groups by using MyotonPro.

Patients	**Frequency(Hz)**		**Creep(D.n)**		**Decrement**		**R.Time(ms)**		**Stiffness(N/m)**	
	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I
Patient 01	17.374	13.874	1.485	1.655	1.232	1.471	23.081	28.232	179.018	169.982
Patient 02	17.792	14.617	1.482	1.775	1.144	1.573	23.065	29.120	177.338	178.276
Patient 03	17.595	14.219	1.507	1.710	1.165	1.557	23.146	28.287	178.324	177.748
Patient 04	17.453	14.213	1.435	1.809	1.177	1.522	22.706	29.747	174.045	175.163
Patient 05	17.807	14.425	1.425	1.740	1.104	1.517	22.260	28.811	176.233	176.991
Patient 06	17.263	13.934	1.518	1.837	1.157	1.567	23.774	30.200	171.514	176.514
Patient 07	18.117	14.693	1.507	1.777	1.131	1.603	23.232	28.734	170.139	182.168
Patient 08	17.557	13.902	1.519	1.880	1.205	1.626	24.111	31.058	166.471	168.407
Patient 09	17.551	14.359	1.501	1.786	1.145	1.494	23.679	29.555	166.187	169.462
Patient 10	17.389	13.945	1.461	1.835	1.221	1.599	22.630	30.155	181.233	172.823

Table 4.17: RMS (Root Mean Square) values from mean values of Different Parameters for Vastus Lateralis Left (VLL) side for both the groups by using MyotonPro.

Patient	**Frequency(Hz)**		**Creep(D.n)**		**Decrement**		**R.Time(ms)**		**Stiffness(N/m)**	
	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I
Patient 01	18.356	17.523	0.918	1.080	1.330	1.534	16.396	17.871	381.309	338.918
Patient 02	17.028	17.363	0.905	1.081	1.226	1.555	17.829	18.111	398.598	342.910
Patient 03	17.054	17.688	0.990	1.123	1.310	1.522	17.516	18.458	353.993	349.579
Patient 04	17.948	16.774	0.915	1.088	1.311	1.500	16.493	18.052	374.584	332.001
Patient 05	17.158	18.027	0.941	1.108	1.222	1.469	17.371	18.207	370.696	354.862
Patient 06	16.394	18.620	0.981	1.071	1.323	1.454	18.283	17.748	355.810	379.865
Patient 07	16.783	16.785	0.966	1.151	1.292	1.453	17.667	19.064	361.830	332.445
Patient 08	15.893	16.673	1.037	1.102	1.237	1.507	18.385	18.292	337.515	330.033
Patient 09	16.372	16.724	1.034	1.090	1.306	1.361	18.217	18.306	348.385	338.368
Patient 10	16.254	17.121	0.984	1.094	1.431	1.518	18.703	18.168	358.307	340.650

Table 4.18: RMS (Root Mean Square) values from mean values of Different Parameters for Vastus Lateralis Right (VLR) side for both the groups by using MyotonPro.

Patient	**Frequency(Hz)**		**Creep(D.n)**		**Decrement**		**R.Time(ms)**		**Stiffness(N/m)**	
	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I
Patient 01	16.483	18.018	0.928	1.041	1.269	1.423	18.092	17.748	396.468	347.648
Patient 02	16.570	17.345	0.904	1.050	1.180	1.377	17.580	17.781	383.623	335.832
Patient 03	17.163	17.335	0.920	1.078	1.214	1.364	17.064	18.026	377.650	333.466
Patient 04	16.535	17.859	0.932	0.985	1.212	1.278	17.757	16.511	374.132	335.468
Patient 05	17.044	17.329	0.911	1.059	1.211	1.347	17.018	16.694	373.721	329.489
Patient 06	16.890	16.210	0.954	1.139	1.270	1.360	17.599	18.811	377.877	311.992
Patient 07	16.718	17.154	0.907	1.037	1.204	1.271	17.534	17.553	382.778	327.251
Patient 08	16.926	17.283	0.937	1.078	1.190	1.241	17.624	17.788	379.901	327.919
Patient 09	16.366	17.147	0.951	1.084	1.250	1.352	18.253	17.862	373.624	326.378
Patient 10	16.215	17.099	0.930	1.072	1.289	1.267	18.271	18.007	384.595	328.086

Table 4.19: RMS (Root Mean Square) values from mean values of Different Parameters for Vastus Medialis Left (VML) side for both the groups by using MyotonPro.

Patient	**Frequency(Hz)**		**Creep(D.n)**		**Decrement**		**R.Time(ms)**		**Stiffness(N/m)**	
	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I
Patient 01	16.369	14.435	1.275	1.356	1.123	1.200	19.602	22.421	244.342	232.678
Patient 02	16.488	13.650	1.258	1.445	1.116	1.197	19.342	23.812	241.569	213.354
Patient 03	16.391	13.870	1.296	1.404	1.175	1.226	19.355	23.119	247.021	220.542
Patient 04	16.531	14.047	1.250	1.385	1.124	1.164	19.190	22.848	242.135	219.557
Patient 05	16.487	14.023	1.235	1.410	1.114	1.233	19.082	22.967	243.987	226.561
Patient 06	16.744	14.047	1.227	1.380	1.139	1.181	18.669	22.788	244.596	227.067
Patient 07	16.433	14.131	1.203	1.394	1.146	1.203	18.832	22.805	264.060	222.840
Patient 08	16.431	13.943	1.312	1.388	1.178	1.155	19.946	23.036	243.014	216.723
Patient 09	16.869	14.161	1.290	1.384	1.145	1.190	19.347	22.759	247.377	221.359
Patient 10	16.388	14.052	1.323	1.405	1.155	1.230	20.141	22.978	237.376	221.629

Table 4.20: RMS (Root Mean Square) values from mean values of Different Parameters for Vastus Medialis Right (VMR) side for both the groups by using MyotonPro.

Patient	**Frequency(Hz)**		**Creep(D.n)**		**Decrement**		**R.Time(ms)**		**Stiffness(N/m)**	
	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I	S.A	S.I
Patient 01	16.219	13.723	1.315	1.424	1.072	1.176	20.302	23.410	242.861	219.365
Patient 02	15.523	13.501	1.238	1.408	1.061	1.179	19.777	23.348	250.293	222.505
Patient 03	16.379	13.839	1.246	1.443	1.068	1.208	19.207	23.701	248.764	218.742
Patient 04	15.560	13.910	1.240	1.391	1.029	1.121	19.904	22.940	251.364	223.426
Patient 05	16.056	13.914	1.217	1.439	1.004	1.147	19.283	23.460	259.057	213.810
Patient 06	15.807	14.416	1.264	1.391	1.051	1.226	20.006	22.741	255.566	230.364
Patient 07	16.040	13.776	1.214	1.459	1.079	1.094	19.406	23.936	266.152	211.900
Patient 08	15.754	14.299	1.219	1.366	1.036	1.110	19.443	22.402	261.572	221.701
Patient 09	15.884	13.914	1.242	1.414	1.056	1.157	19.608	23.246	259.574	216.074
Patient 10	16.090	14.302	1.279	1.373	1.081	1.098	19.494	22.726	242.591	217.642

4.2.5 One Way Analysis OF Variance (anova1)

The one-way analysis of the variance (anova1) from the RMS values of the both the groups gave as the difference value (p) between the two group (Sport active and Sport inactive) for each side of the muscles (GM,VL, and VM). Table: 4.21 reports the p values derived from the anova1 Matlab function. The following figures (Figure:4.3 to Figure:4.9) contains the information about the anova1 difference (p) between two groups. Five different figures of each parameter for a single muscle side (like GML) makes one figure, which shows the significant difference (p) for single muscle side (Left and Right). For Gluteus Maximusmuscles (GML and GMR) Frequency (Hz), Creep (D.n), Decrement and Relaxation Time (ms) were significantly different while Stiffness (N/m) was not significantly different from sport active (S.A) and sport inactive (S.I) group (Figure:4.1 and Figure:4.2). For Vastus Lateralis left (VLL) side of the muscle Stiffness (N/m), Creep (D.n) and Decrement was significantly different while Frequency (Hz) and Relaxation Time (ms) were not significantly different (Figure:4.3) for both the groups. Vastus Lateralis right (VLR) side muscle was significantly different for all the biomechanical parameters except Relaxation Time (ms) (Figure:4.4) for both the groups. In both the groups (S.A and S.I), for Vastus Medialis left (VML) and Vastus Mediailis Right (VMR) muscles, all the biomechanical parameters were significantly different from each other (Figure:4.5 and Figure:4.6). The results from the anova1 function from Matlab gives a clear idea about the muscles bio-mechanical properties for both sports active and sports inactive group. Both the groups (sports active and sports inactive) are significantly different for the majority of the muscle parameters which shows that MyotonPro device is significantly useful to isolate the muscles parameters with the minimum error. it also shows that MyotonPro device can be used for the various purpose to evaluate the muscles data in short-time with no pain to the patient.

Table 4.21: One way analysis of variance (anova1) difference value(p) between the RMS values of three different muscles with each sides.

Parameters	**Glutus Maximus**		**Vastus Letralis**		**Vastus Medialis**	
	Left	Right	Left	Right	Left	Right
Frequency	$2.20 * e^{-}12$	$5.24 * e^{-}16$	0.212	0.0046	$8.53 * e^{-}17$	$7.27 * e^{-}12$
Creep	$5.57 * e^{-}07$	$2.18 * e^{-}10$	$3.06 * e^{-}07$	$4.98 * e^{-}09$	$5.16 * e^{-}08$	$7.57 * e^{-}10$
Decrement	$1.78 * e^{-}09$	$3.05 * e^{-}13$	$1.16 * e^{-}16$	0.0003	$8.64 * e^{-}05$	$1.21 * e^{-}05$
R.Time	$4.88 * e^{-}09$	$4.59 * e^{-}13$	0.0603	0.6302	$3.12 * e^{-}13$	$3.85 * e^{-}13$
Stiffness	0.0746	0.7515	0.0126	$4.83 * e^{-}11$	$1.81 * e^{-}07$	$1.23 * e^{-}09$

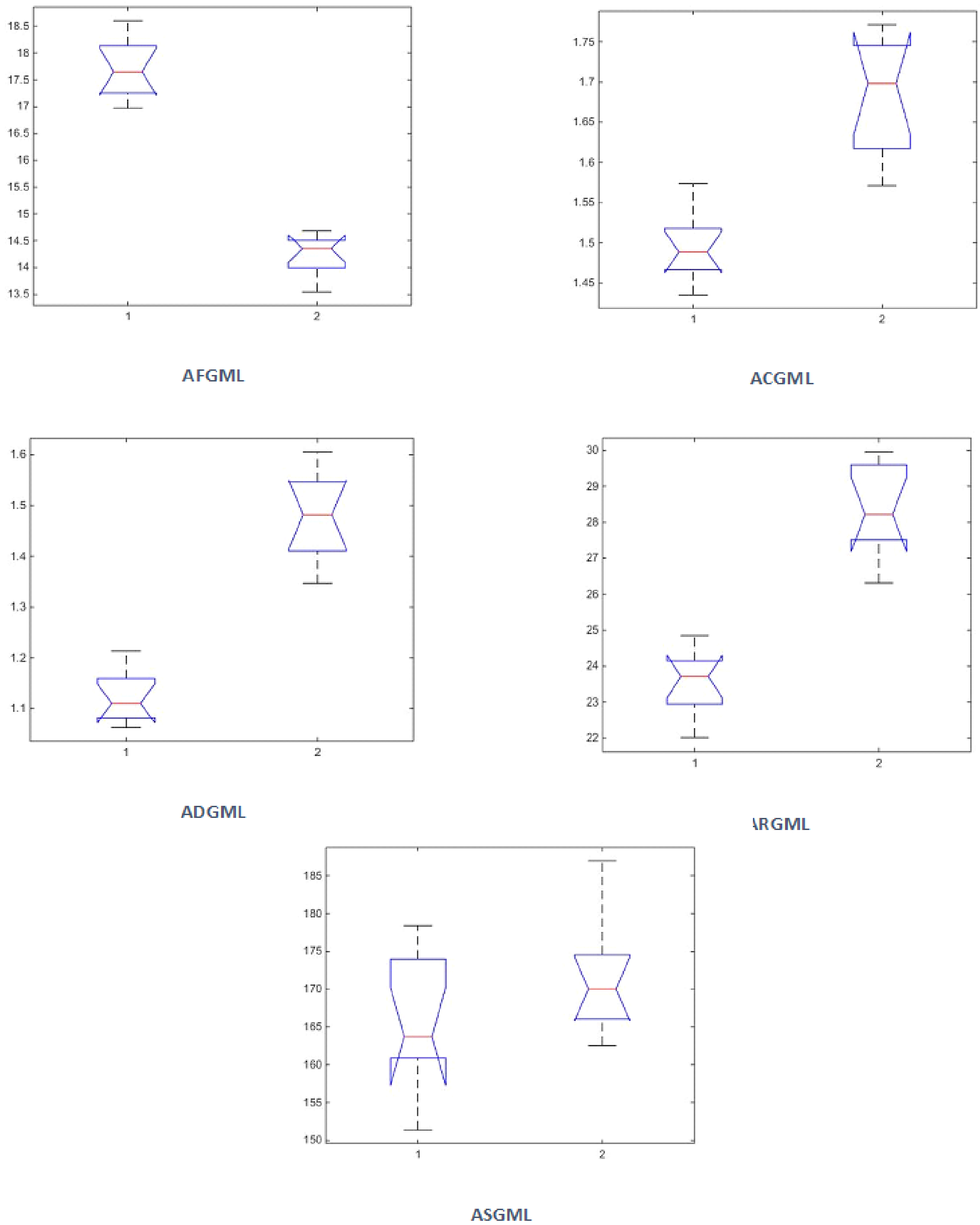

Figure 4.3: One way analysis of variance (anova1) difference of RMS values between two groups for the Gluteus MaximusLeft (GML) side muscle.

[**AFGML**: ANOVA Frequency Gluteus Maximum Left side muscle, **ACGML**: ANOVA Creep Gluteus Maximum Left side muscle, **ADGML**: ANOVA Decrement Gluteus Maximum Left side muscle, **ARGML**: ANOVA R.Time Gluteus Maximum Left side muscle, **ASGML**: ANOVA Stiffness Gluteus Maximum Left side muscle.]

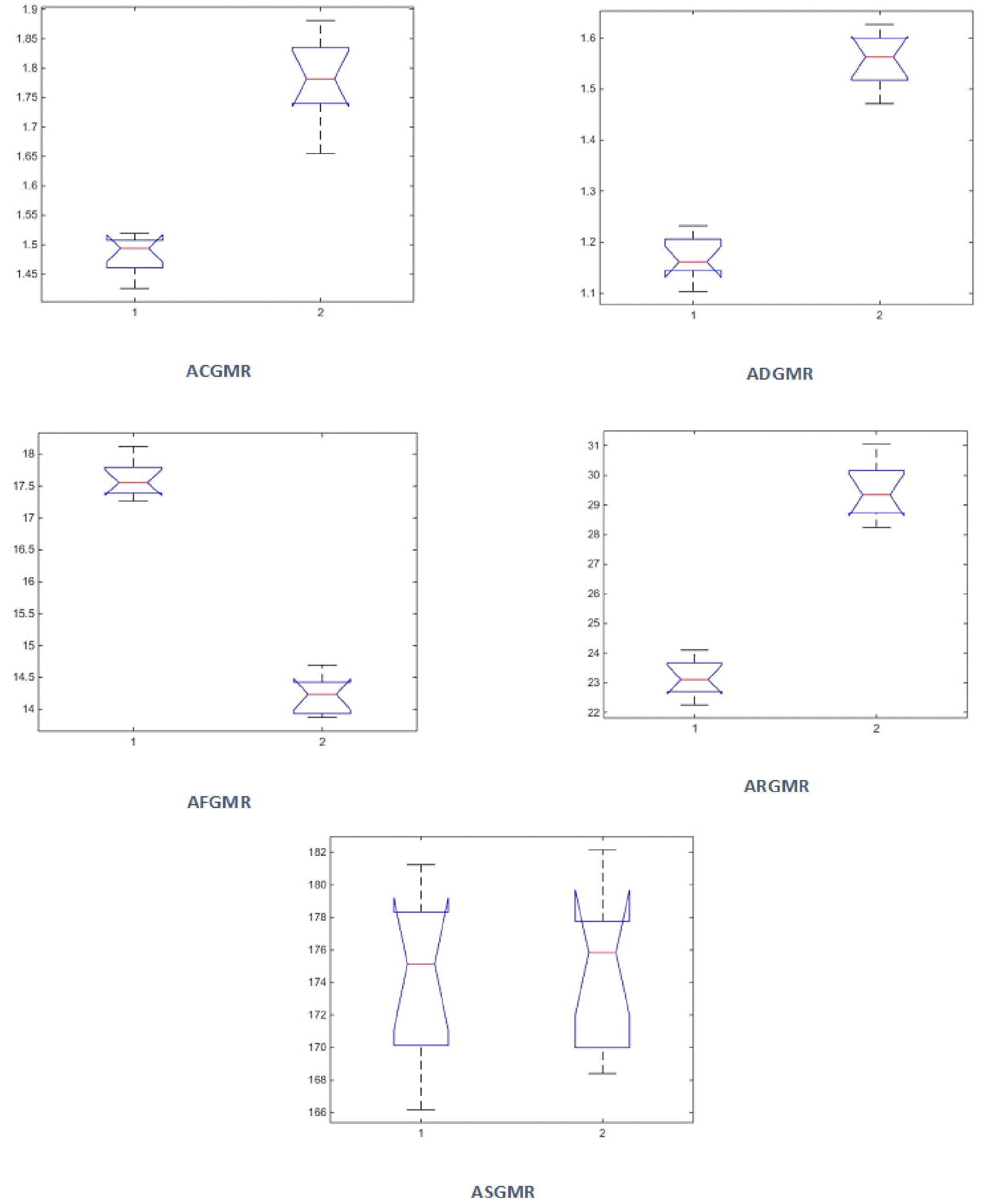

Figure 4.4: One way analysis of variance (anova1) difference of RMS values between two groups for the Gluteus MaximusRight (GMR) side muscle.

[**AFGMR**: ANOVA Frequency Gluteus Maximum Right side muscle, **ACGMR**: ANOVA Creep Gluteus Maximum Right side muscle, **ADGMR**: ANOVA Decrement Gluteus Maximum Right side muscle, **ARGMR**: ANOVA R.Time Gluteus Maximum Right side muscle, **ASGMR**: ANOVA Stiffness Gluteus Maximum Right side muscle.]

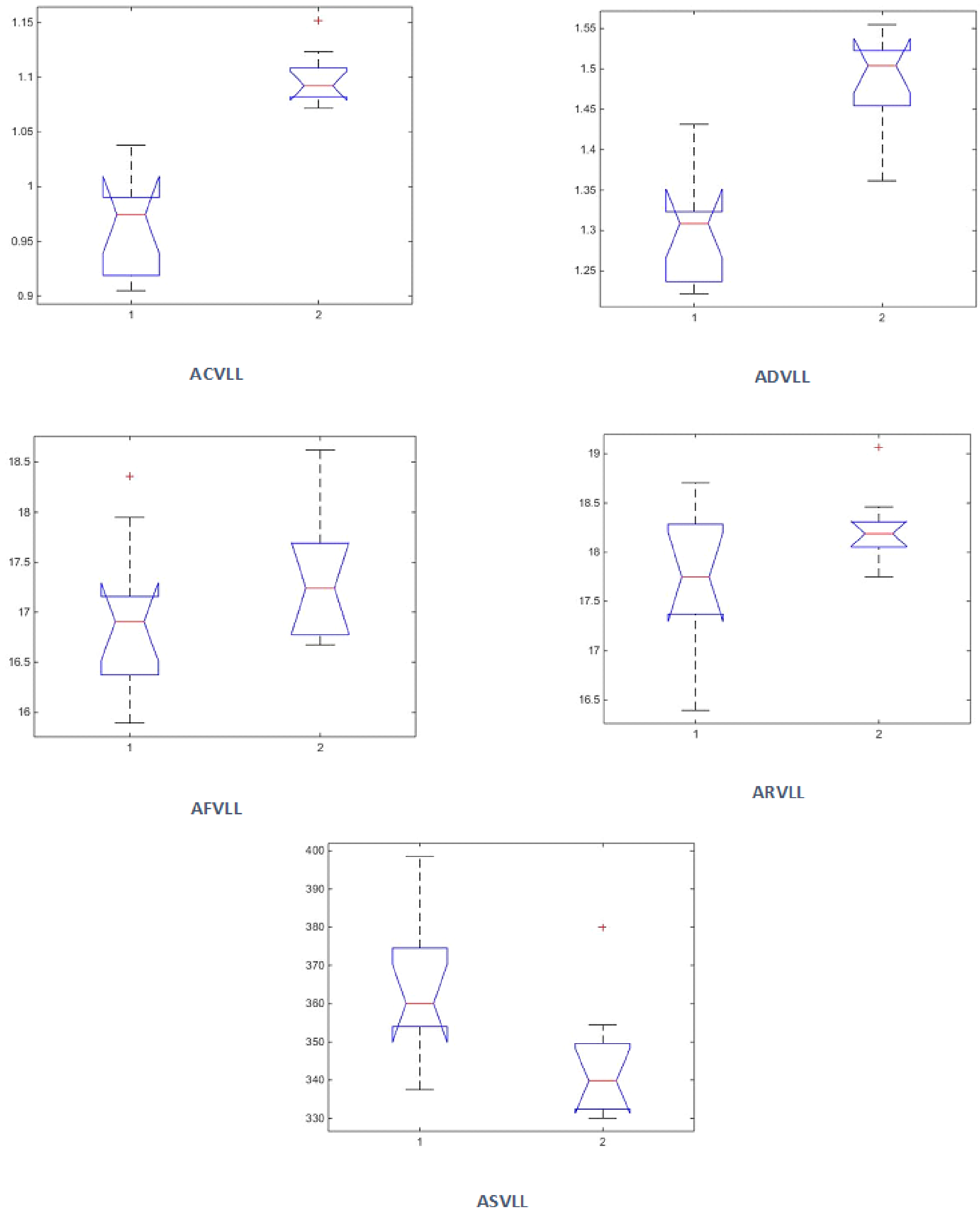

Figure 4.5: One way analysis of variance (anova1) difference of RMS values between two groups for the Vastus Lateralis Left (VLL) side muscle.

[**AFVLL**: ANOVA Frequency Vastus Lateralis Left side muscle, **ACVLL**: ANOVA Creep Vastus Lateralis Left side muscle, **ADVLL**: ANOVA Decrement Vastus Lateralis Left side muscle, **ARVLL**: ANOVA R.Time Vastus Lateralis Left side muscle, **ASVLL**: ANOVA Stiffness Vastus Lateralis Left side muscle.]

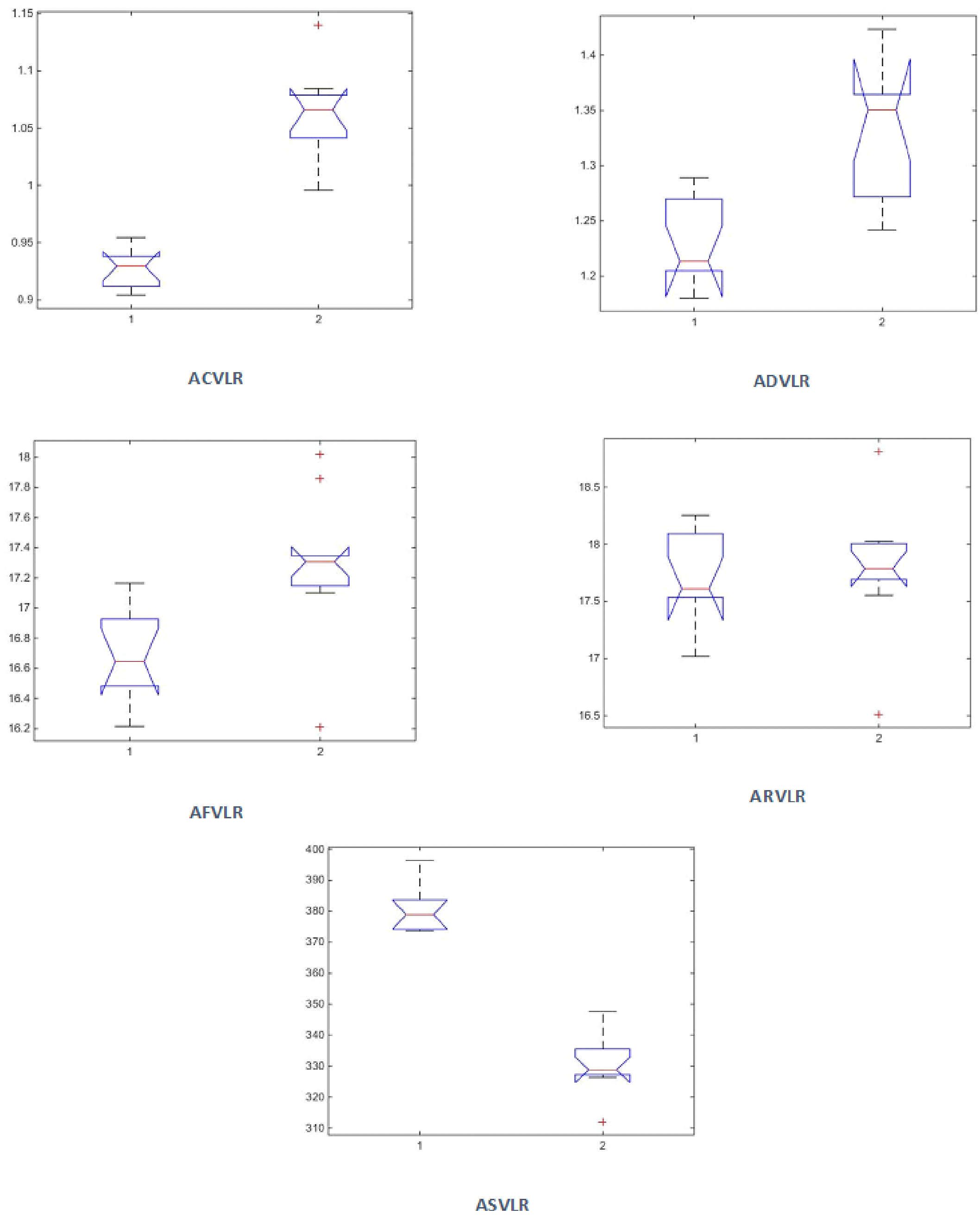

Figure 4.6: One way analysis of variance (anova1) difference of RMS values between two groups for the Vastus Lateralis Right (VLR) side muscle.

[**AFVLR**: ANOVA Frequency Vastus Lateralis Right side muscle,**ACVLR**: ANOVA Creep Vastus Lateralis Right side muscle, **ADVLR**: ANOVA Decrement Vastus Lateralis Right side muscle, **ARVLR**: ANOVA R.Time Vastus Lateralis Right side muscle, **ASVLR**: ANOVA Stiffness Vastus Lateralis Right side muscle.]

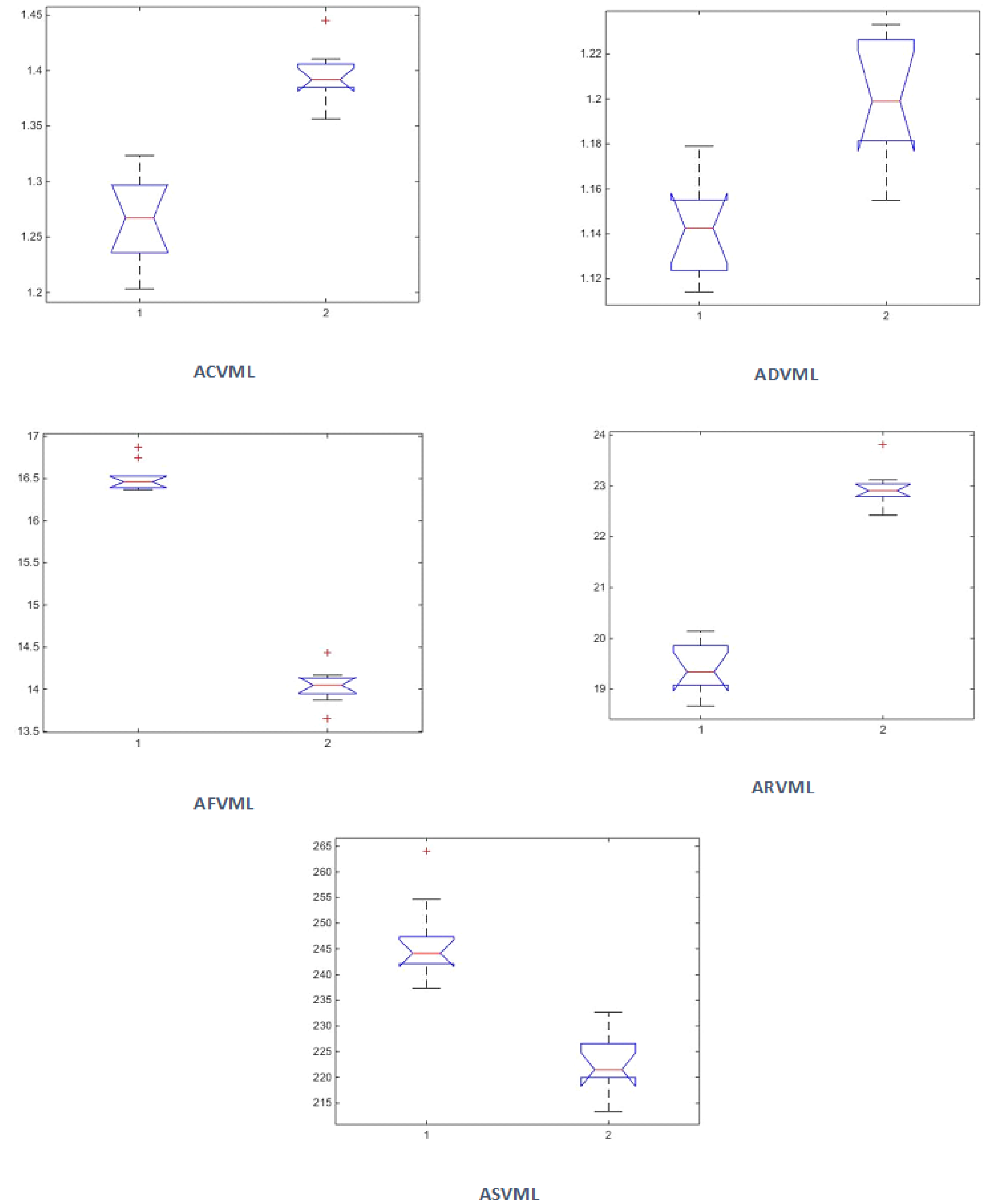

Figure 4.7: One way analysis of variance (anova1) difference of RMS values between two groups for the Vastus Medialis Left (VML) side muscle.

[**AFVML**: ANOVA Frequency Vastus Medialis Left side muscle, **ACVML**: ANOVA Creep Vastus Medialis Left side muscle, **ADVML**: ANOVA Decrement Vastus Medialis Left side muscle, **ARVML**: ANOVA R.Time Vastus Medialis Left side muscle, **ASVML**: ANOVA Stiffness Vastus Medialis Left side muscle.]

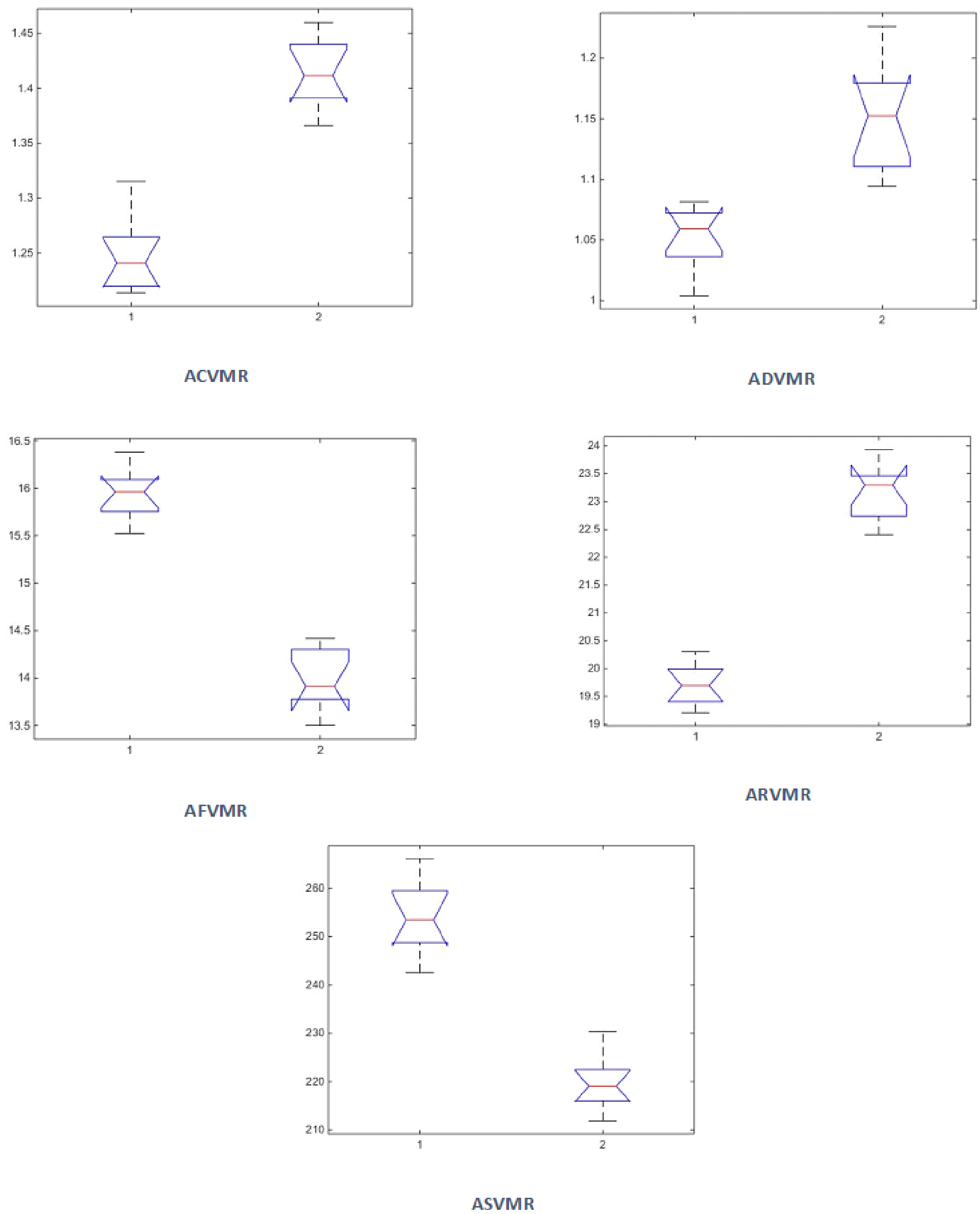

Figure 4.8: One way analysis of variance (anova1) difference of RMS values between two groups for the Vastus Medialis Right (VMR) side muscle.

[**AFVMR**: ANOVA Frequency Vastus Medialis Right side muscle, **ACVMR**: ANOVA Creep Vastus Medialis Right side muscle, **ADVMR**: ANOVA Decrement Vastus Medialis Right side muscle, **ARVMR**: ANOVA R.Time Vastus Medialis Right side muscle, **ASVMR**: ANOVA Stiffness Vastus Medialis Right side muscle.]

Chapter 5

Conclusion

The MyotonPro device is an easy, fast and portable device for measuring the quantitative muscles parameters of the human body. Here in the present study, a total of 20 healthy subjects were selected and divided into two different groups (sports active (S.A) and sport inactive (S.I)) according to their sports activity from last six months. Biomechanical parameters of three different muscles, Gluteus Maximus(GM), Vastus Lateralis (VL) and Vastus Medialis(VM) were measured before and after each set of squat exercise (05 squats) at each side (Left and Right) by using the MyotonPro device. The calculated MVA (Mean Value Analysis) and RMS (Root Mean Square) values were important to facilitate the detection of the significant difference (p-value) between each side of the muscles in a clinical way. From the results of MVA analysis, we can see that all the biomechanical parameters of each side of the muscles were fluctuating after each set of squat exercise (05 squats) and after every 02 minutes after the full squat exercise (20 squats). Among the five biomechanical parameters, Relaxation time (ms), Stiffness (N/m) and Frequency (Hz) were major important biomechanical parameters for muscles while Decrement and Creep (D.n) were minor important. After the RMS value calculation, we can observe that value of Frequency (Hz) and Stiffness (N/m) parameters were high for the sport active group (S.A) for all the three (GM,VL, and VM) measured muscles with each side (Left and Right) while the other three parameters (Creep (D.n), Decrements and R.Time (ms)) were high for the sport inactive (S.I) group. Probable reason behind this significant difference could be the people from sport active group were more expose to stretch their muscles during sports activity which makes their muscles more stiff and more muscle tone. The correlation (p-value from the anova1) of the all five biomechanical parameters for both left and right side of Gluteus Maximus(GM), Vastus Lateralis (VL) and Vastus Medialis(VM) were positive and significant for the study which illustrates the biomechanical relationship of both the groups. The results of the present study suggest that the Gluteus Maximus(GM) muscles with each side (Left and Right) were less involved in the squats exercise and these muscles were less stiff than the other types of muscles for both sport active (S.A) and sport inactive (S.I) group. While the right side of both the quadripole muscles, Vastus Lateralis (VL) and Vastus Medialis(VM) was more involved in the squat exercises. It is also showed that these two muscles (VLR and VMR) have more muscle tone (Hz) and more stiffness (N/m) than the rest of the muscles (VLL, VML, GML, GMR). The other two parameters of all muscles remain almost the same for all the muscle throughout the squat exercise and relaxation time as well. The RMS (Root

Mean Square) values of the parameters were important in the one-way analysis of variance (anova1). The results of one-way analysis of variance (anova1) show that the biomechanical parameters except for stiffness (N/m) for Gluteus Maximus(GM) muscle with each side (Left and Right) were significantly different in both the groups (Sport active and Sports Inactive). Vastus Lateralis Left (VLL) muscle was significantly different for all the biomechanical parameters except Relaxation time (ms) and Frequency (Hz) while Vastus Lateralis Right (VLR) muscle was significantly different for all the parameters except Relaxation time (ms) for both the groups (sports active and sports inactive). Vastus Medialis(VM) muscle was significantly different for all the biomechanical parameters for both the groups. The results of the study conclude that MyotonPro device is easy, fast, portable, pain-less device with reliable and reproducible results to evaluate the biomechanical parameters of the human muscles with minimum error. The study also concludes that MyotonPro device can detect the smallest difference between two muscles parameters with minimum error. MyotonPro device can be useful in many ways in the field of the clinical, medical and healthcare to diagnose and prevent serious injuries in the athlete's life. MyotonPro device can also be useful to check the recovery time from the muscle injuries.

The study might be affected by the natural properties of muscles to start relaxing immediately after each stretch. This property of the muscle might affect the relaxation time (ms) calculation. The weather conditions might also affect the study results because the study was conducted during the winter season which might affect the biomechanical parameters of the muscles like stiffness (N/m) and creep (D.n).

Future Aspects

We should conduct the similar type of study with the higher number of squats per set (10 or 20) which would give us more details about the biomechanical properties of the muscles.

We should conduct the similar type of study between male and female subjects because the muscle structure of both male and female is slightly different from each other.

We should conduct the similar type of study with the different type of exercise like running or push-ups by measuring different muscles.

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.1 Appendix

AFGMR: Anova Frequency Gluteus Maximus Right
ACGMR: Anova Creep Gluteus Maximus Right
ADGMR: Anova Decrement Gluteus Maximus Right
ARGMR: Anova Relaxation Time Gluteus Maximus Right
ASGMR: Anova Stiffness Gluteus Maximus Right
AFGML: Anova Frequency Gluteus Maximus Left
ACGML: Anova Creep Gluteus Maximus Left
ADGML: Anova Decrement Gluteus Maximus Left
ARGML: Anova Relaxation Time Gluteus Maximus Left
ASGML: Anova Stiffness Gluteus Maximus Left
AFVLR: Anova Frequency Vastus Lateralis Right
ACVLR: Anova Creep Vastus Lateralis Right
ADVLR: Anova Decrement Vastus Lateralis Right
ARVLR: Anova Relaxation Time Vastus Lateralis Right
ASVLR: Anova Stiffness Vastus Lateralis Right
AFVLL: Anova Frequency Vastus Lateralis Left
ACVLL: Anova Creep Vastus Lateralis Left
ADVLL: Anova Decrement Vastus Lateralis Left
ARVLL: Anova Relaxation Time Vastus Lateralis Left
ASVLL: Anova Stiffness Vastus Lateralis Left
AFVMR: Anova Frequency Vastus Medialis Right
ACVMR: Anova Creep Vastus Medialis Right
ADVMR: Anova Decrement Vastus Medialis Right
ARVMR: Anova Relaxation Time Vastus Medialis Right
ASVMR: Anova Stiffness Vastus Medialis Right
AFVML: Anova Frequency Vastus Medialis Left
ACVML: Anova Creep Vastus Medialis Left
ADVML: Anova Decrement Vastus Medialis Left
ARVML: Anova Relaxation Time Vastus Medialis Left
ASVML: Anova Stiffness Vastus Medialis Left
D.n: Deborah number
GM: Gluteus Maximus
GML: Gluteus Maximus left
GMR: Gluteus Maximus Right
MVA: Mean Value Analysis
RMS: Root Mean Square
ROS:Reactive Oxygen Species
S.A: Sport Active
S.I: Sport Inactive
VL: Vastus Lateralis
VM: Vastus Medialis
VLL: Vastus Lateralis Left
VLR: Vastus Lateralis Right
VML: Vastus Medialis Left
VMR: Vastus Medialis Right