The Effect of Electrical Stimulation in Improving Muscle Tone (Clinical)

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Abstract. Electrical stimulation (ES) and also known as neuromuscular electrical stimulation (NMES) and transcutaneous electrical stimulation (TES) involves the use of electrical current to stimulate the nerves or nerve endings that innervate muscle beneath the skin. Electrical stimulation may be applied superficially on the skin (transcutaneously) or directly into a muscle or muscles (intramuscularly) for the primary purpose of enhancing muscle function. The basic theoretical premise is that if the peripheral nerve can be stimulated, the resulting excitation impulse will be transmitted along the nerve to the motor endplates in the muscle, producing a muscle contraction. In this work, the effect of mere electrical stimulation to the muscle bulk and strength are tested. This paper explains how electrical stimulation can affect the muscle bulk, muscle size, muscle tone, muscle atrophy and muscle strength. The experiment and data collection are performed on 5 subjects and the results obtained are analyzed. This research aims to understand the full potential of electrical stimulation and identifying its possible benefits or disadvantages to the muscle properties. The results indicated that electrical stimulation alone able to improve muscle properties but with certain limits and precautions which might be useful in rehabilitation programme.

Keywords: ES, Muscle Atrophy, Muscle Contraction

1. Introduction

Electrical muscle stimulation (EMS) or otherwise named as neuromuscular electrical stimulation (NMES) is the elicitation of muscle compression using electrical driving forces or impulses [1]. Transcutaneous electrical nerve stimulation (TENS) focus the electrical stimulation on nerve rather than muscle. While TENS is focus on relieving chronic and acute pain [2], EMS has a different role which will be discussed further later in this paper.

People who involved in accidents or serious illness sometimes led to broken limbs or bedridden due to comma. These types of injuries usually associated with immobility can last for months. Prolong immobility will lead to muscle atrophy, which is the state where the muscle lost its mass, size and its functions degrades, which can be seen in Fig. 1. Thus, rehabilitation process is needed where a specialized healthcare is perform to improve or restore mobility, physical strength and cognition

IOP Conf. Series: Materials Science and Engineering **260** (2017) 012020 doi:10.1088/1757-899X/260/1/012020

[3]. From the literature, there are many published work that indicate electrical stimulation to play a major role as well as becoming an essential rehabilitation tool to give back patients the control of their muscle function through Functional Electrical Stimulation (FES) and improve their mobility [4]. A normal healing process without electrical stimulation intervention which normally takes almost a year can now be done in average of three month with the aid of electrical stimulation.

However a certain degree of effectiveness of electrical stimulation in rehabilitation or healing process directly related to muscle still remains unclear. The most significant limitation is that a rehabilitation process with electrical muscle stimulation (EMS) must come with functional task to ensure the effectiveness of the therapy. In this paper, the effect of EMS on muscle tone, size and strength was examined to find out the limits and extend of EMS in improving all of these parameter.

Fig. 1: Example of muscle atrophy patient. The right leg seems smaller than the left one. Retrieved from https://www.slideshare.net/hallerbakk/the-muscular-system-38480382

2. Related Work

In utilizing the EMS, the frequency, pulse width, ramp time, duty cylcle and amplitude are among the vital parameters of EMS that will be reviewed in this research work. Frequency refers as the pulses produced per second during stimulation and in the units of Hertz. Most clinical regiment's uses frequency between 20 to 50Hz to obtain optimum results, although, it also differs accordingly to the intervention, intention or objectives at that time [5]. Higher frequencies have proven to be more comfortable because the force response is smoothed and only given out tingling effect, whereas, lower frequencies give out a tapping effect which distinguished the individual pulses [6]. The pulses produce by the electrical stimulator device usually are represented by a geometrical shape either square, sine wave or peaked wave. The time taken for each single pulse is known as pulse duration or pulse width, the example is shown in Fig. 2. Besides pulse width, another time variable parameter is also consider vital that is the ramp time. It is refers as the time taken for the stimulation to turned on and reach the desirable frequency depending to the actual onset [7]. This 1 to 3 seconds time period is essential when a subjects muscle tone increase to create resistance when stimulation occur.

This time variable is define as the ratio of time taken for each stimulation against the rest time. A ratio of 1:2 means that it on for 10 seconds and off for another 20 seconds. The purpose of this duty cycle is demonstrated where the muscle tissue was able to recover more faster and produce greater torque when the periods of force development were interrupted with silent periods [8]. Usually a duty cycle of 1:3 is considered standard for clinical purpose. This however, can still be change to accommodate specific patient's conditions. Measured in ampere, this is the value of the maximum current being administrated during the stimulation. A higher amplitude of EMS will activates a larger number of muscle fibers for contraction force to occur, however overdosing it will caused antidromic transmission which is when the both motor and sensory impulses are block to travel to the spinal motor pool causing less activation of the central nervous system [9].

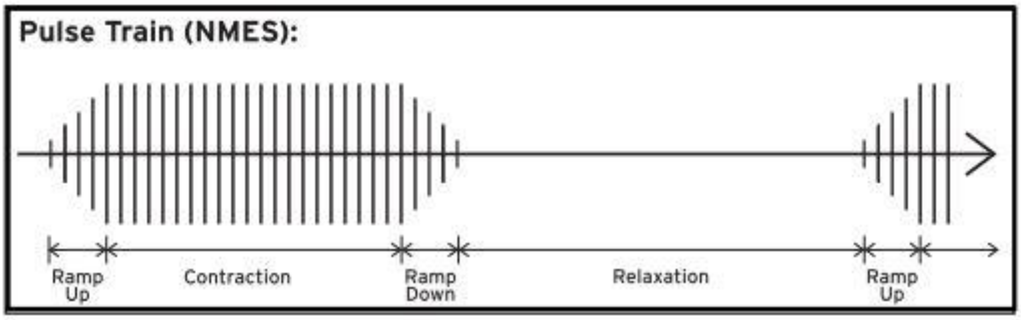

Fig. 2: Pulse Train of EMS/NMES. Retrieved from https://lh3.googleusercontent.com/0X44ujeA2pcv906ljv8lQYf2QHv7lmhL5kw3OF6gbOyCG7abWa-a18tdiIBOw-t4q7E9=s170

For a home based therapy purposes, either for rehabilitation, chiropractic or even physiotherapy, a simple and small portable stimulator device which is normally battery operated is used. A transcutaneous surface electrodes that adhere to the skin is used to deliver the current from the device to the muscle. The standard pre-gelled electrode’s has adhesive to ease the removal and application of the electrode to the skin. It is important to highlight it here that the outcomes can be dependable to the quality of the skin-electrode interface and the consistency of the electrode placement in the tested area [1]. Moreover, the repeatability of the placement spot of the electrode can affect the outcomes of the stimulation.

In NMES therapy, a suggested electrode placement guides or charts are usually provided by the manufacturer, included with the purchase of the device. This is for getting the optimum result and utilizing the positive and negative terminal of the stimulator device. In a research, the larger the surface area of the electrodes, the more of the muscle tissue will be activated, though it will also disperse the current in a wider surface area, making the current density decreasing. Whereas a smaller electrodes will focus more current densities, giving a full focal concentration of current which lessen the chance of the stimulation to migrate to unwanted nearby muscle, however this dense current can also increase feeling of discomfort or even worse, pain [10]. It is also advice to not share the same adhesive electrodes with other test subjects for hygiene purpose and keep in mind the repeatability of using the electrodes which normally last for 5 to 20 times of use, according to the material use for the electrodes.

The use of electrical stimulation (ES) as muscle atrophy rehabilitation intervention had been discuss in various research works. Johnsen et al. [2] proposed integrating surface electrode into a modular polymer cast design to introduce EMS to the forearm muscle groups without removing the cast for patient undergoing cast immobilization due to forearm bone fracture. Their target patient for the therapy regiment were the patients who had been cast for 3-4 weeks, where they introduce their research intervention up till the cast was completely remove.

A research from both by Ali & Qin [11] and Dupont Salter et al. [12] focus on using animal model for their works. Ali & Qin [11] approach the use of different frequencies ranging from 1 to 20 Hz on a rat model. While Dupont Salter [12] works also involved a rat model, they approach by introducing a lower frequency at a range of 2 to 10 pulses per second.

In Lo et al. works [13], a short-term propulsion of ES was introduced accompanied by a functional leg-cycling task to patient with stroke. They hypothesized that this intervention can reduce the spasticity of the affected leg muscle. Another work by Keller et al. [14] use a novel approach of using a multi-channel stimulation which perform a real-time spatial and temporal variations of the electrical current density on the surface and deep tissue layer of the skin. This approach was hypothesized to generate a better muscle selectivity and improved muscle activation patterns.

The result and discussion of every work and research mentioned above show a positive feedback but still bound to several limitations and challenges. In the work by Johnsen et al. [2], a throughly safety measures must be planned for their prototype. The use of a microcontroller, and some hardware and software programming introduce a complex intervention. A simple mistake in the coding part will render the the entire system inoperable. Nevertheless, this intervention is a good progress in rehabilitation engineering as it can reduce the post-recovery time necessary to restore normal strength and motor function of the affected muscle beside preventing muscle

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atrophy. The research by Ali & Qin [11] and Dupont Salter et al. [12] show a contradiction in their result. Ali & Qin [11] stated that the use of 20 Hz give the highest percentage of soleus muscle mass and the trabecular bone volume recovery of the animal model. Thus, suggested that this frequency is the most optimum frequency for the therapeutic treatment for disuse induced muscle atrophy. Dupont Salter [12] works on the other hand stated that a frequency of 2 pulses per second is better than higher-frequency stimulation for the level of atrophic changes the muscle experienced. The 2 pulses per second frequency give the least percentage of mean atrophy in the slow soleus muscle.

Lo et al. [13] works although give a promising results, the research introduced a functional task using their leg-cycle wheelchair prototype. This prototype will be costly and need supervision by the expert and not a do-it-yourself intervention for the patient that undergo home-based rehabilitation. The effect also varied according to the muscle tone of the patient which is the higher the tone of the muscle, the lower the spasticity level of the muscle was reduced. Although, this intervention promise the quickest therapy regiment with high effectivity. The multi-channel stimulation approach by Keller et al. [14] shows a more throughly intervention involving the integration of stimulation hardware into a garment sleeve. The experiment on the patient with stroke shows a positive outcome as they can generate selective finger and wrist extension movement in the affected area. The challenges will be once again the integration of this new intervention to ease the use, stimulation and wear comfort. Nevertheless, it can be a better intervention that the art ES system which operate with predetermined electrode positions.

3. Design and Methodology

A normal human body can only withstand a certain amount of electrical current before the body cells are damaged. At 100mA, a severe contraction of muscle is occurring and between 100 to 300mA of current causes electrocution to the body [15]. Therefore, a typical EMS stimulator produce 9 to 15mA according to the resistor used. The main core of the work here is the electrical stimulation. The area tested is the upper limb of the hand, focusing on the 3 main muscle that is the biceps, triceps and deltoid, as shown in Fig. 3. For this work, the left, undominant hand is undergoing the ES treatment, while the right, dominant hand is kept constant as control variable. Thus, a total of 5 healthy subjects of a college-aged (21-24 years old), weight around 50 to 60kg and did not commit to any heavy exercise routine, especially in the upper body section for the past 3 month before the therapy is done voluntarily participated in this research. Prior to the experiment, all of the test subjects have signed the ethical as well as the consent form. The parameters of the tested muscle that are focus on this work is the muscle tone, muscle size and muscle strength.

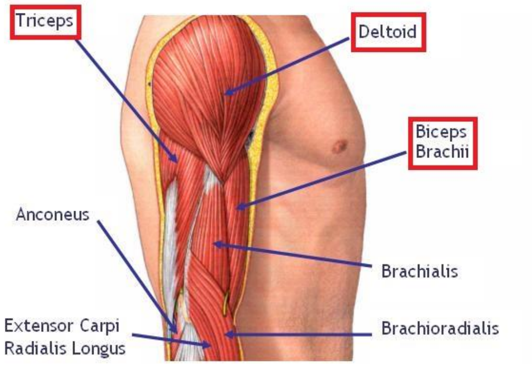

Fig. 3: Muscle anatomy (only biceps, triceps and deltoids were tested). Retrieved from http://thebettyrocker.com/sexy-arms-5-great-moves-for-your-biceps-and-triceps-no-equipment-required/

Fig. 4: The MediStim XP. Retrieved from http://www.neurotechgroup.com/us/products/avivastim-xp

The EMS stimulator used in this work is the MediStim XP from the Neurotech as shown in Fig. 4, commonly used by medical expertise for rehabilitation. It offers up to 9 pre-set programs according to the condition and indication needed, from rehabilitation process to acute pain management. The specification of this stimulator is shown in Table. 1. For the therapy work, the program number 2 was chosen as the parameters listed in Table. 2 is the same as the one needed for this work.

Table 1: The specification of MediStim XP

Nominal output voltage / power			
Parameter	500Ω	1kΩ	1.5kΩ
Output RMS voltage (RMSV)	7.5 V	12.32 V	13.74 V
Output RMS current (RMSA)	15 mA	12.3 mA	9.16 mA
Output frequency	4 – 99 Hz	4 – 99 Hz	4 – 99 Hz
DC Component	0 C	0 C	0 C
Pulse width	80 – 400 µs	80 – 400 µs	80 – 400 µs

Table 2: The parameter of program no. 2 of the MediStim XP

Program	Frequency (Hz)	Pulse Width (µs)	Ramp Up (s)	Ramp Down (s)	On time	Off time	Burst or Trigger
1	50	300	1	1	5	5	Trigger
2	50	300	1	1	5	10	Trigger
3	50	300	1.5	1.5	10	20	Trigger
4	35	400	1	1	5	5	Trigger
5	10	300	1	0.5	5	5	Trigger
6	Ch. 1: 50 Ch. 2: 10	300	1	0.5	5	5	None
7	35	350	1	0.5	5	5	None
8	8	80	1	0.5	5	5	Trigger
9	4 – 99	150	Continuous (TENS)				Trigger

The therapy lasted for the duration of 3 months. Each week, all the 5 test subjects undergo 30 minutes per day of electrical stimulation therapy on the targeted muscles for 4 days on every Monday, Wednesday, Friday and Sunday. Each targeted muscles spend 10 minutes of therapy then add up to 30 minutes per session for each biceps, triceps and deltoid. Test subjects was advised to wear loose shirt only during the therapy. During the therapy, a series of pre-test is conducted to alert the changes in the targeted muscle parameters. The muscle size is noted by measuring the arm circumference using a measuring tape as shown in Fig. 5. For the muscle strength, a digitalized approach was used.

Fig. 5: Measuring the circumference of the left hand using a measuring tape.

IOP Conf. Series: Materials Science and Engineering **260** (2017) 012020 doi:10.1088/1757-899X/260/1/012020

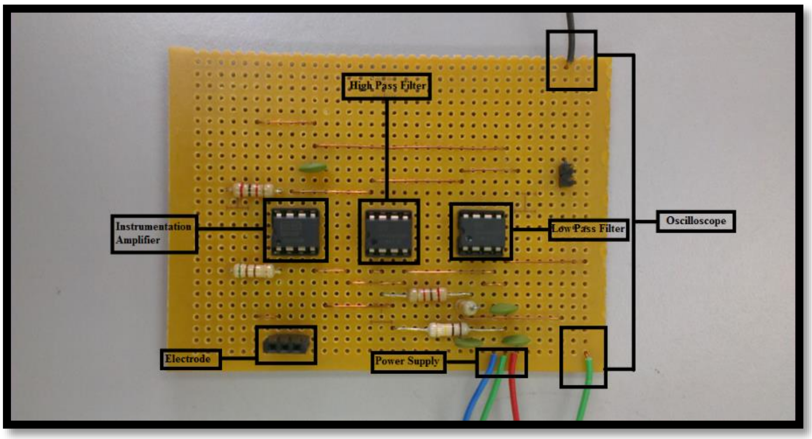

Fig. 6: The EMG conditioning circut. Retrieved from F.A. Kamal, Final Year Project, ECE Department, IIUM.

With the use of National Instrument NI-USB 6216, a data acquisition (DAQ) module, EMG signal conditioning circuit in [16, Fig. 6], and the LabVIEW software, it produce a clean EMG signal and graph that shows the change in muscle strength parameter. Both the right and left hand was tested to compare the strength between a dominant and non-dominant hand side. All the test subject flexed their arm to see the muscle contraction. Thus, a changes in muscle contraction force was depicted through EMG signal and graph. After 3 months of therapy, the final measurement was taken and a series of question was asked to the test subjects to note any respond from them personally after the therapy.

4. Result and Analysis

4.1 Muscle bulk

It is identified that the muscle size of all test subjects increase throughout the 3 months therapy. Test subjects 3 and 5 have a 4.35% increase, while test subject 2 and 4 have 3.88% increment and the last, test subjects 1 has an increase of 4.74% in muscle bulkiness. The factor influencing the rate of increment is the level of thickness of the subcutaneous fat tissue and the muscle condition. The 2 test subjects of 3.88% muscle bulk increment have a thicker subcutaneous fat tissue, therefore decreasing the rate of current density flowing to the muscle [17]. The only test subjects of 4.74% muscle bulk development was influenced by the therapy the test subjects had taken during the part 1 of this work. Thus, given the condition of a trained muscle to the test subjects, resulting in higher rate of muscle bulk expansion. as the subcutaneous fat tissue thickness, the electrode size and the duration of the therapy. Moreover electrical stimulation do not give a permanent effect in the muscle bulkiness as it shown a descending rate of muscle bulk after a long period of break, suggesting that electrical stimulation must be done periodically to ensure the positive impact. The results were summarized in Table 3.

Table 3: The result of muscle bulk measurement of the left hand side

Date/TS	TS 1	TS 2	TS 3	TS 4	TS 5
25 Sept	25.3cm	25.8cm	24.3cm	26.4cm	25.3cm
2 Oct	-	-	-	-	-
9 Oct	-	-	-	-	-
16 Oct	25.6cm	26.0cm	24.6cm	26.6cm	25.6cm
23 Oct	25.7cm	***break***	***break***	***break***	***break***
30 Oct	25.8cm	26.1cm	24.7cm	26.7cm	25.7cm
6 Nov	25.9cm	26.2cm	24.8cm	26.8cm	25.8cm
13 Nov	26.0cm	26.3cm	24.9cm	26.9cm	25.9cm
20 Nov	26.1cm	26.4cm	25.0cm	27.0cm	26.0cm
27 Nov	26.2cm	26.5cm	25.1cm	27.1cm	26.1cm
4 Dec	26.3cm	26.6cm	25.2cm	27.2cm	26.2cm
11 Dec	26.4cm	26.7cm	25.3cm	27.3cm	26.3cm
17 Dec	26.5cm	26.8cm	25.4cm	27.4cm	26.4cm

TS = test subject

4.2 Muscle strength

The raw EMG signal read from the muscle will undergo filtering and amplification before obtaining a clean EMG signal. The EMG signal is then projected in the LabVIEW software to be analysed. The value to be analysed from the signal obtained were the root mean square (RMS) value and the signal amplitude. From the graph, it can be seen that the signal intensity of right hand side from Fig. 8, which is the dominant hand was still higher than the left hand side, shown in Fig. 7. This indicates that EMS alone cannot afford to develop the muscle strength or isometric muscle contraction. This was due to the incapability of EMS in increasing the fast-twitch myofibrils, which is the muscle fibre responsible in giving the muscle its strength and power characteristic. To efficiently increase the rate of isometric muscle contraction, a series of functional activity or exercise must be done, while EMS aids in giving faster and efficient effect.

However, from the test conducted, the relationship between EMG signal and muscle strength was proven as the linearity of the relationship was recorded in the graph obtain. The RMS value shows a higher reading when the test subject flex their arm, indicating the isometric muscle contraction rate increasing. Thus, mark the increase of the muscle strength when flexing compared to when resting. A research by Heloyse et al. [18] pointed out that the magnitude of the EMG signal is directly proportional to muscle strength but with some limitations to be considered. The factors were the EMG signal cross-talk, non-fixed electrodes recording placement and the involvement of other muscle fibre in force generation.

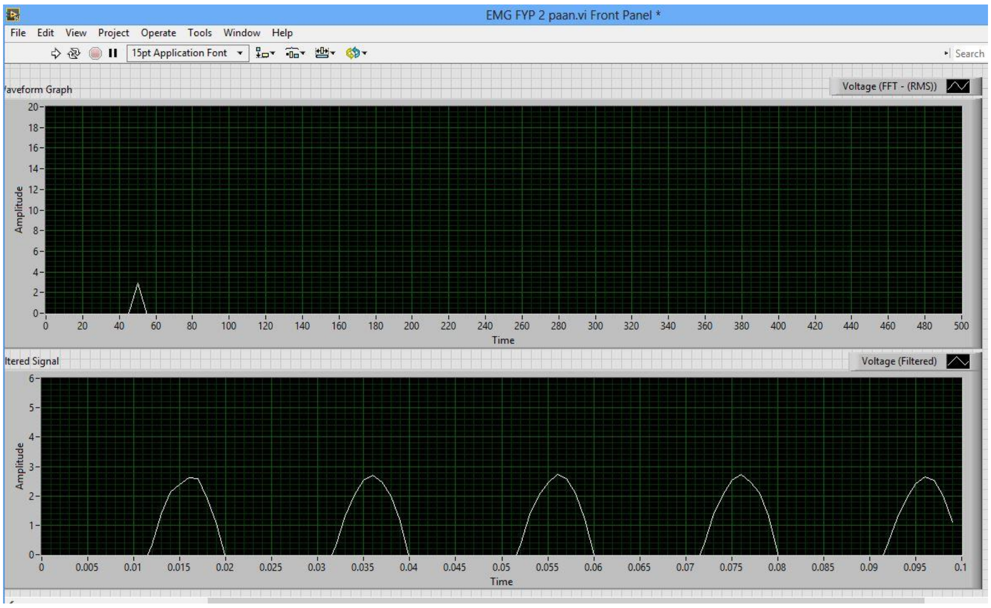

Fig. 7: RMS and amplitude value of the EMG signal for the left handside.

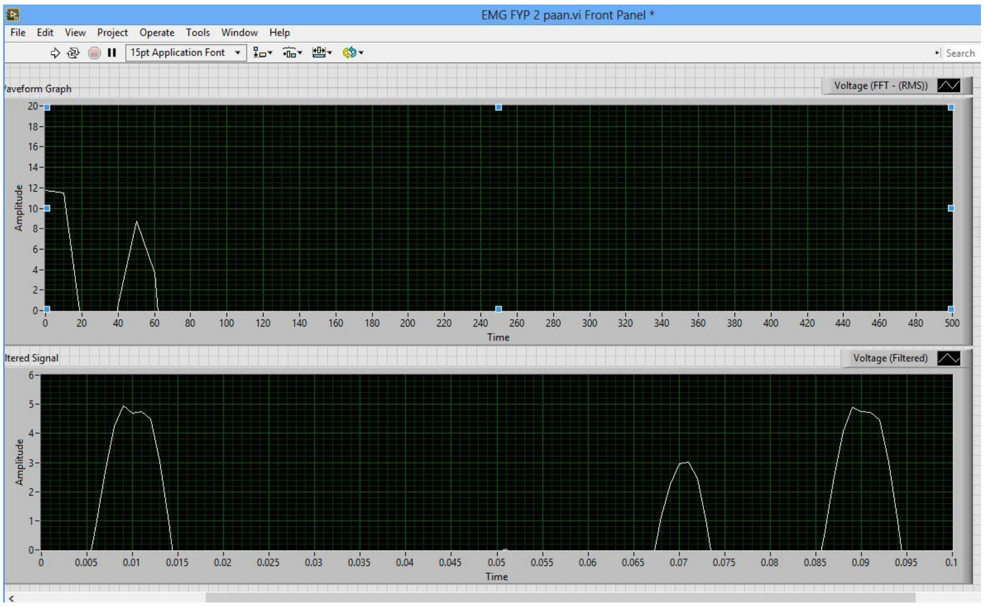

Fig. 8: RMS and amplitude value of the EMG signal for the right handside.

5. Conclusion

From this research work, it is evident that electrical muscle stimulation can promote and develop muscle bulk along side continuous therapy, although, lacking the capability to increase muscle strength. Factors that can influences the rate of increment of muscle bulk by EMS were the level of subcutaneous fat tissue thickness the electrode size, the duration of the therapy and the condition of muscle whether trained or not. As for the muscle strength, EMS alone cannot increase the fast-twitch myofibrils to give a higher output in muscle strength development. It must come with functional activities or exercise routine to trained the muscle. However, the relationship between EMG signal and isometric muscle contraction force were proven linear. Based on the outcome, EMS prove to be a promising rehabilitation intervention to avoid muscle atropy, especially to the patients experiencing injury due to sports.

Acknowledgement

The authors would like thank all the test subjects who participated and cooperated in the electrical muscle stimulation therapy session. A warm gratitude to Dr. Nadia Mohd Mustafah from the Universiti Teknologi MARA, Sungai Buloh, for sharing valuable input to the design of the methodology of this work. Thank you also to Assoc. Prof. Dr. Ahmad Aidil Arafat Bin Dzulkarnain from the Kulliyyah of Allied Health Sciences for providing us with information on ethical clearence to conduct all of this experiment.

IOP Conf. Series: Materials Science and Engineering **260** (2017) 012020 doi:10.1088/1757-899X/260/1/012020

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