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Effect of Low Level Laser Therapy on Quadriceps Muscle Strength in Lower Limb Burn

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This study was conducted to examine the effect of low level laser therapy (LLLT) on quadriceps muscle strength in lower limb burn. Sixty patients who suffered from second degree lower limb burn of thermal injury with total body surface area (TBSA) for burns ranged from 20% to 35% and their ages ranged from 25-40 years were selected randomly and divided into two equal groups each one composed of 30 patients. Study group received LLLT before strengthening exercises for quadriceps muscle, 3 sessions / week for 8 weeks, while control group received 8 weeks of quadriceps muscle strengthening exercises, 3 times weekly. All Patients were received traditional physical therapy program as a routine treatment. Quadriceps muscle peak torque was measured before and after 8 weeks of treatment for both groups by using isokinetic dynamometer. Results: there was a statistically significant increase in the mean values of quadriceps peak torque after 8 weeks of treatment in both groups while there was a significant difference in post treatment mean values of quadriceps peak torque in the study group when compared to control group. Conclusion: It can be concluded that LLLT is an effective modality for improving muscle strength and performance in lower limb burned patients when preceding strengthening exercise training.

Keywords: (low level laser therapy, quadriceps muscle strength, strengthening exercises, lower limb burn).

INTRODUCTION

Severe burns trigger a pathophysiological systemic response which continues for two years after injury. The increased turnover in skeletal muscle amino acid results from persistent adrenergic stress and inflammation following burn. Increased protein degradation and synthesis in skeletal muscle are hallmarks of the stress response to burn leading to chronic loss of amino acid. This imbalance between protein synthesis and proteolysis is considered the main leading cause of muscle cachexia in burned patients (Jeschke et al., 2011).

Burn injuries lead to long immobilization period which may last for several weeks and produce a greater loss of muscle strength and mass particularly in the antigravity muscles. These changes become more prominent after only two weeks of bed rest (Padfield et al., 2005).In addition to impairment of motor control, diminshed cognitive status, anxiety and pain. Therefore, the management of muscle weakness has become important research areas in burn rehabilitation during chronic stage (Trees et al., 2003).

Burn injury induces alterations in mitochondrial function of skeletal muscles which contribute to increase post burn hypermetabolism (Porter et al., 2016). In severe burn, there is uncoupling of mitochondrial respiration for more than one year following burn leading to increase the heat production which accounts for approximately one third of burn survivors total energy expenditure and provides a therapeutic goal to attenuate and manage hypermetabolism (Porter et al., 2014).

Lower limb burns adversely affect the patients function by decreasing joint range of motion, impairing muscle strength and balance (Fauerbach et al., 2001). These will lead to persistent physical disability, decreased work capacity or difficulty to return to work and impaired quality of life (Edgar et al., 2010, Van Baar et al., 2006).

Strength training (also called resistance training) is considered the most convenient method for increasing muscular strength. It is characterized by performance of exercise against an external load or resistance (ACSM, 2009).In addition, strength training develops an increase in muscle hypertrophy which is accompanied by neural adaptations, increasing strength and performance of exercised muscle (Folland and Williams, 2007).

Recently, phototherapy was shown to demonstrate ergogenic effects by improving the muscle contractile function. Exposing skeletal muscle to selected doses of laser therapy enhance physical performance by maintaining the output of muscle contractile force and resisting the fatigue onset when challenged with strengthening exercise (Leal Junior et al., 2009b). Skeletal muscle exposed to laser irradiation also showed less cellular damage following exercise which indicate that phototherapy can provide a protection from muscle damage induced by exercise (Leal Junior et al., 2010b).

Serious burn injury leads to excessive decrease in muscle mass, strength and function which directly reduces endurance, limits standing and walking ability and impairs functional capacity thus hindering post burn rehabilitation. So, this study is designed to investigate the therapeutic benefits of pre-exercise LLLT on quadriceps muscle strength in lower limb burn and to assist in planning an ideal treatment regimen for muscle weakness and rehabilitation of burned patients during chronic period.

MATERIALS AND METHODS

Sixty patients (37 males and 23 females) who had second degree lower limb burn of thermal injury with TBSA for burns ranged from 20% to 35% and ages from 25-40 years participated in this study. All patients provided informed written consent. The study was conducted in Physical Therapy Department for Burn, Orabi Hospital for Burn, Al Obour City, Egypt between May 2017 and December 2018. Patients with uncontrolled cardiovascular, neurological, pulmonary, renal, musculoskeletal and equilibrium disorders, malignant conditions, psychiatric illness, severe cognitive or behavior disorders also those who received any previous strengthening exercise program were excluded**.**

Patients were randomly assigned into 2 equal groups (study and control groups) each of them composed of 30 patients. Study group received LLLT and strengthening exercises for quadriceps muscle, three sessions weekly for eight weeks while control group received strengthening exercises for quadriceps muscle, three times / week for eight weeks**.** Patients in both groups were received traditional physical therapy program in the form of (range of motion exercise, splinting, stretching, massage, ambulation training and functional training for daily activities). Patients were begun the treatment program after complete wound healing.

Evaluative procedure

The peak torque (Nm) of quadriceps muscle was measured before the treatment and after 8 weeks of treatment for both groups by using Biodex Isokinetic Dynamometer (Biodex Medical System, Shirley, NY, USA) at the isokinetic unit in Faculty of Physical Therapy, Cairo University. Patients were asked to complete their personal data. The height and weight scale was used for recording the height and weight of each patient. Patients warmed up on a cycle ergometer for 5 min then they stretched the quadriceps and hamstrings muscles. Each muscle group was stretched five times for 30 s alternately for 5 min. After warming-up, Patients were positioned in the isokinetic device according to the instructions of the equipment; the backrest reclined 5° from vertical, the hip joint angle 100° and the trunk, waist and distal thigh were stabilized by straps . The axis of rotation of the dynamometer was aligned with the knee joint axis at the level of the lateral femoral epicondyle while the dynamometer strap was attached to the distal leg 5cm proximal to the medial malleolus. Correction of gravity effect and calibration of isokinetic device were performed prior to each evaluation session as recommended by the manufacturer's instructions then the therapist demonstrated and explained the test procedure to the patients.

Initially, patients performed 3 submaximal contractions without load as warming-up for familiarization with the test without more repetitions to prevent the onset of fatigue then they performed 2 sets of 5 consecutive maximal concentric isokinetic contractions at an angular velocity 150º/s with 2 minutes of resting between the two sets but there was no rest between the five contractions. All participants were encouraged

Verbally and by the visual feedback from the dynamometer in order to achieve their maximal level of voluntary effort during all contractions. Values of the highest peak torque were calculated by the Biodex software system and mean value of the 2 sets was taken for statistical analysis.

Treatment procedures

Low level laser therapy (LLLT) protocol

LLLT was applied using an infrared laser device (Polaris 2) (manufactured by Astar ABR, Poland). Patients were received an infrared Gallium-Alluminum-Arsenide (Ga-Al-As) laser with a wavelength (808 nm) immediately before each strengthening exercise training session. LLLT was applied on eight application points on quadriceps muscle defined by palpation of muscle bellies: three points on rectus femoris, three points on vastus lateralis and two points on vastus medialis using the contact technique in which the probe was kept stationary in contact with skin at an angle of 90° and slight pressure with the following parameters: Continous output**,** 100 mW power output**,** 7 J energy per application point, 90 seconds at each point and 56 J total energy delivered**,** 3 sessions weekly for 8 weeks. Both the therapist and patients should wear protective goggles each time on laser irradiation for eye protection.

Strengthening exercise training protocol

Patients performed the following exercises for quadriceps muscle using free weights (sand bags and dumbbells), 3 sessions per week for 8 weeks, each exercise was done 3 sets:1- Straight-leg raising exercise from supine position.2- Quadriceps short arc exercise (terminal knee extension exercise).3- Seated knee extension exercise from 90° to full extension.4- Quadriceps step-up and down exercise.5- Mini squat exercise from 0 to 45° of knee flexion holding weights in hands with progression of squats to greater ranges of knee flexion during the advanced phases of treatment and then increase the exercise difficulty by performing unilateral resisted mini squats (single leg squat).

The strengthening exercise program was performed with gradual progression including the exercise intensity and number of repetitions. During the first (1-2) weeks, patients lifted a weight corresponding to 50–60% of their individual three-repetition maximum (3RM). Then, the lifting weight was increased to 70–75% of their 3RM and maintained for weeks (3–6). Finally, the intensity of exercise was increased to 75–85% of the 3RM and continued for weeks (7–8).Number of repetitions was set at 12–15 repetitions in each set during the first 2 weeks, 8–10 repetitions in each set during weeks (3-6) and 8–12 repetitions in each set during weeks (7-8) with approximately 1 min rest interval between sets.

Statistical analysis

Descriptive statistics and Unpaired t-test were conducted for comparison of subject characteristics between both groups. Chi- squared test was used for comparison of sex distribution between groups. Normal distribution of data was checked using the Shapiro-Wilk test. Levene's test for homogeneity of variances was conducted to ensure the homogeneity between groups . Unpaired t-test was conducted to compare the mean values of quadriceps peak torque between the study and control groups. Paired t-test was conducted for comparison between pre and post treatment in each group. The level of significance for all statistical tests was set at $p < 0.05$. All statistical analysis was conducted through the statistical package for social studies (SPSS) version 22 for windows (IBM SPSS, Chicago, IL, USA)

RESULTS

Subject characteristics:

Table (1) showed the Subject characteristics of the study and control groups. There was no significant difference between both groups in the mean age, BMI and TBSA ($p > 0.05$). Also, there was no significant difference in sex distribution between groups ($p = 0.79$).

Effect of treatment on quadriceps peak torque:

Within group comparison:

There was a significant increase in quadriceps peak torque post treatment in the study and control groups compared with that pre-treatment ($p < 0.0001$). The percent of improvement in the study and control groups were 50.62% and 32.28% respectively as shown in table (2) and demonstrated in figure (1).

Between groups comparison:

There was no significant difference in quadriceps peak torque between both groups pre-treatment ($p > 0.05$). Comparison between the study and control groups post treatment revealed a significant increase in quadriceps peak torque of the study group compared with that of the control group ($p < 0.0001$) as shown in table (2) and demonstrated in figure (1).

Table (1): Comparison of subject characteristics between study and control groups:

	x̄±SD		MD	t- value	p-value
	Study group	**Control group**			
Age (years)	30.53 ± 4.2	30.26 ± 3.75	0.27	0.25	0.79*
BMI (kg/m²)	27.12 ± 1.86	26.51 ± 1.9	0.61	1.23	0.22*
TBSA (%)	28.46 ± 3.43	29.16 ± 3.7	-0.7	-0.75	0.45*
Males/females	18/12	19/11		(χ^2 = 0.07)	0.79*

x̄, Mean; SD, Standard deviation; MD, Mean difference; χ^2, Chi squared value; p value, Probability value;*, Non-significant.

Table (2): Mean Quadriceps peak torque pre and post treatment of the study and control groups:

	Study group	**Control group**			
Quadriceps peak torque (Nm)	**x̄±SD**	**x̄±SD**	**MD**	**t- value**	**P value**
Pre Treatment	90.77 ± 6.65	90.21 ± 7.12	0.56	0.31	0.75*
Post treatment	136.72 ± 10.05	119.33 ± 10.9	17.39	6.42	0.0001**
MD	-45.95	-29.12			
% of change	50.62%	32.28%			
t- value	-56.69	-31.6			
	*p = 0.0001***	*p = 0.0001***			

x̄, Mean; SD, standard deviation; p-value, level of significance; *, Non-significant; **, Significant.

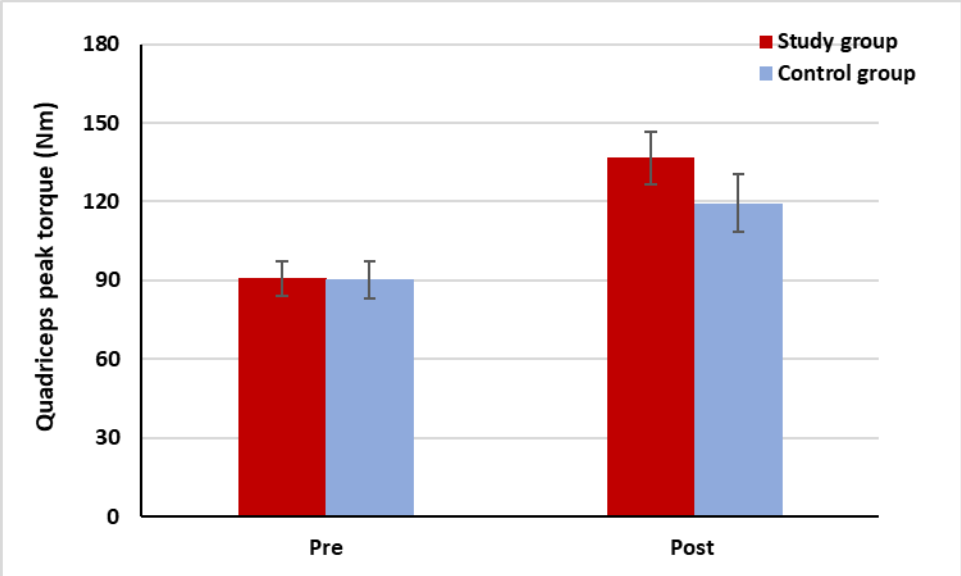

Figure 1. Mean quadriceps peak torque pre and post treatment of study and control groups.

DISCUSSION

Increased skeletal muscle catabolism adversely cause a loss of body lean mass, significant decrease in aerobic and functional capacity (Esselman, 2007). Rehabilitation strategies for burn aim to assist burned patients to achieve optimal functional recovery and independence with the maximum goal is reintegration into community (Spires et al., 2007).Therefore, it is essential to maintain and improve the muscle strength of burned patients.

Previous researches demonstrated that low level laser therapy has a valuabe effect for promoting muscle performance in animal studies (Leal Junior et al., 2010a, Santos et al., 2014) also in humans in strength exercise training and maximum tests in isokinetic dynamometry (Baroni et al., 2015, Ferraresi et al., 2011) but no previous studies examined the effect of LLLT on improving muscle strength in burned patients.

The results of the present study showed that post treatment mean values of quadriceps peak torque were significantly increased in both groups but when comparing between the two groups, there was a significant difference in mean values of quadriceps peak torque after 8 weeks of treatment in laser group compared to that in control group and this explained that this effect not only resulting from strengthening exercises but also from the effect of LLLT.

The incorporation of strengthening exercise into burn rehabilitation regimens is essential. Progressive resistance exercise in addition to standard care lead to increase the lean body mass, improve muscle strength and power and enhance amino acids assimilation into muscle proteins in burned patients compared to those who have received only the standard care (Diego et al., 2013).

During exercise, phototherapy could provide ergogenic effects by increasing intramuscular microcirculation (Ihsan, 2005), decreasing the production of lactic acid (Leal Junior et al., 2009a) and improving the exercising muscle antioxidant capacity (De Marchi et al., 2012). Also application of phototherapy immediately prior to resistance exercises delay the fatigue response by extending both the time and the total repetitions number untill fatigue (Leal Junior et al., 2008).

Phototherapy could also provide prophylactic effect to the exercised muscle when applied before strenuous high intensity exercise by limiting muscle cellular damage induced by exercise through reduction in the postexercise levels of creatine kinase (CK), lactate dehydrogenase (LD) and C-reactive protein (CRP) which is directly enhance muscular recovery after exercise (Baroni et al., 2010).

LLLT acts to increase the cell number per muscle fiber and enlarge the diameter of muscle fibers as demonstrated in previous experimental models (Gigo et al., 2010, Nakano et al., 2009). Laser therapy also acts to activate muscle satellite cells and modulate the expression of myogenic transcription factors as myoD (myogenic differentiation) and myogenin (myogenic factor 4), markers of muscular growth and hypertrophy (Holterman and Rudnicki, 2005). This explained that LLLT may take a part in the formation of new muscle fibers and increase the muscle hypertrophy so enhance the muscle strength gain and this support our results.

Physiological adaptations to strength exercise training represents the relation between the extent of muscle damage and the possible higher satellite cell activation (Petrella et al., 2008). LLLT seems to modulate the metabolism of satellite cells which had a direct positive effect on muscle tissue regeneration (Shefer et al., 2002). In addition, LLLT modulates the gene for expression of myostatin (GDF-8), which inhibit the proliferation of satellite cells and thus the process of muscle regeneration and repair leading to less muscle hypertrophy (Charge and Rudnicki, 2004). LLLT could also alter the expression of genes responsible for muscle hypertrophy and mitochondrial biogenesis (Coffey and Hawley, 2007, Hawley, 2009).

As previously mentioned, Burn trauma induces skeletal muscle mitochondrial dysfunction .So in our study, LLLT acts to improve skeletal muscle mitochondrial function which is impaired by burn injury and this is evidenced by the significant increase in quadriceps peak torque post treatment in the study group and the significant difference between both groups.

Muscle satellite cells are affected by burn with the increase in proliferation of satellite cells does not match with apoptosis increase resulting in a net reduction in satellite cells with the final result is lean body mass reduction (Fry et al., 2016).Therefore, application of LLLT in this study seems to activate muscle satellite cells thus accelerate muscle regeneration after exercise.

Our previous explanation is consistent with (Das Neves et al., 2016), who proved that after LLLT application, there was an increase in knee extensors peak torque, increase the time to onset of muscle Fatigue, improvement in both the quality and the duration of the maximum voluntary contraction and significant reduction in pain intensity after exercise in the paretic lower limb in patients with spasticity. ALso with (Toma et al., 2016), who stated that LLLT increased quadriceps muscle performance and isokinetic parameters in elderly women who recieved strength training associated with LLLT.

The results of current study is also confirmed by (Macagnan et al., 2018), who found a significant increase in maximal handgrip strength after application of photobiomodulation with doses of 60 J and 90 /arm while no changes occurred with placebo or 120 J/arm and the best dose for increasing handgrip strength was 60 J/arm in chronic kidney disease patients under chronic hemodialysis treatment. ALso with (Mahran, 2015), who reported that LLLT improves the performance of trunk flexor muscles in isokinetic dynamometry and increases muscle ability to resist the fatigue in patients with post incisional hernia repair.

Two systematic reviews (Borsa et al., 2013, Leal-Junior et al., 2013) showed that photobiomodulation therapy using LLLT immediately before resistance exercise sessions provides ergogenic benefits to muscle by enhancing physical performance, improving the outcomes such as muscular thickness and torque. These reviews also confirmed that pre strength exercises LLLT application protects the muscle against tissue damage produced by exercise and speeds up muscle recovery. Therefore, this scientific evidence completely supports our results and the use of LLLT before strengthening exercises.

Our above results regarding LLLT effect on improving muscle strength, performance and increasing the fatigue resistance are based on three main hypotheses; first hypothesis concerning the effect of laser on the mitochondria. Structural changes occurred in mitochondria with the application of laser therapy involved giant mitochondrial formation. LLLT promotes the mitochondrial growth, increasing their density in the tissues and this is consequently associated with greater enzymatic activity for production of ATP (Manteifel and Karu, 2005). The cellular mitochondria play an essential role in energy production which is necessary in endurance exercise also in providing higher energy availability in high-intensity exercises (Tonkonogi et al., 2000, Sahlin et al., 2007). Phototherapy stimulates the respiratory chain through the mitochondrial enzyme cytochrome c oxidase. This activation generates different biochemical reactions which increase ATP synthesis required for maintaining muscle function (Silveira et al., 2009).

Second hypothesis (phosphocreatine resynthesis): Phosphocreatine (anaerobic metabolism) provides the skeletal muscle with ATP during more intense physical activity. This mechanism involves resynthesis of creatine to phosphocreatine for continuing ATP supply during exercise. Synthesis of ATP depends on ATP production by mitochondria aerobically via the mitochondrial creatine shuttle mechanism (Hayworth et al., 2010, Tonkonogi and Sahlin, 2002). Thus, increasing fatigue resistance and improving muscle strength of the laser group may have been attributed to the higher a lactic energy (phosphocreatine) amounts which would have a greater ability to provide the energy required for the next sets of muscle contractions during the training sessions.

Third hypothesis (Lactic acid removal and oxidation of lactate by mitochondria): combination of laser with exercise may decrease the concentration of lactate dehydrogenase (LDH) enzyme, a pyruvate reductase which is responsible for transformation of pyruvic acid into lactic acid (Hashimoto et al., 2006). Thus, reduced concentration of LDH results in lower lactic acid production which lead to decrease or postpone the onset of fatigue (Spriet et al., 2000). Decreased the levels of blood lactate after exercise also suggested that lactic acid is oxidized to pyruvate, which is then utilized by the mitochondria to produce ATP (Brooks et al., 1999).

CONCLUSION

Finally it can be concluded that LLLT is a new effective, safe, non-pharmacologic and noninvasive modality for improving muscle strength, enhancing exercise performance and reducing fatigue response in patients with lower limb burn when preceding strengthening exercises. Combined LLLT with strengthening exercises is more effective than strengthening exercises alone. So, it should take into consideration to add LLLT as a fundamental part of physiotherapy rehabilitation program for management of muscle weakness in burned patients in order to take all these advantages and to achieve all positive clinical outcomes.

CONFLICT OF INTEREST

The authors declared that present study was

performed in absence of any conflict of interest.

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AUTHOR CONTRIBUTIONS

NMK designed and conducted the research, data collection, data analysis and also manuscript writing. Prof.Dr. AAHN helped in data collection and writing the manuscript and Prof.Dr. MIM helped in reviewing the manuscript. All authors read and approved the final version.

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