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Original Article

Effect of different doses of low-intensity laser therapy on total active range of motion after hand flexor tendon repair

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Abstract

Objective

To investigate the difference between the effects of different doses of low-level laser therapy (4 or 1 J/cm^2) on the return of hand active range of motion (ROM) after flexor tendon repair.

Participants and methods

A small trial was conducted on 33 patients with 45 injured fingers of both sexes who underwent primary repair after complete cut of hand flexor tendon. Their age ranged from 20 to 40 years old. They were recruited from the plastic surgery department. The treatment began the first day postoperatively after permission by surgeons using Duran protocol and splinting. Transcutaneous electrical nerve stimulation (TENS), as well as LASER therapy, was started the seventh day after surgery. Laser treatment lasted for 3 weeks only, whereas other modalities lasted for 3 months. The sample was randomly divided into three groups each of 15 injured tendons. Group A received the conventional treatment plus laser therapy (1 J/cm^2), three sessions/week for 3 weeks. Group B received the traditional treatment plus laser therapy (4 J/cm^2), three sessions/week for 3 weeks. Control group received the conventional treatment only. All patients received the early conventional physical therapy after permission by the surgeon: TENS plus early therapeutic exercises following Duran protocol, three sessions/week for 3 months. The ROM was measured at eighth and 12th week after the commencement of treatment.

Results

At second month after commencement of treatment, there was a positive effect of laser therapy with either doses 1 or 4 J/cm^2 on total hand active ROM after flexor tendons repair, with more effect noticed in group B (4 J/cm^2). At third month after commencement of treatment, best results in hand active ROM were seen in group B (4 J/cm^2), with prognosis being excellent in 46.7% of patients, good in 33.3% and fair in 20.0% according to the modified Strickland classification.

Conclusion

The 4-J/cm^2 laser dose is more efficient than laser dose of 1 J/cm^2 in the treatment of repaired hand flexor tendons in addition to conventional treatment (TENS stimulation plus Duran protocol therapeutic exercises) in early regain of active ROM that can affect return of early better hand function.

Keywords: Active range of motion, dose, hand flexor tendon repair, laser

Introduction

Tendon healing, like many other tissues, progresses through three overlapping phases: inflammatory, proliferation, and remodeling phase. Prolonged immobilization of surgically repaired tendon may result in muscle atrophy, joint stiffness, pain that does not go away, partial loss of function in the involved joint, osteoarthritis, infection, skin necrosis, ulceration of joint cartilage, and tendocutaneous adhesion [1].

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Postoperative rehabilitation of flexor tendons in the hand consists of a short period of immobilization until pain and swelling diminished, followed by progressive mobilization to maximize the range of motion (ROM) of the affected fingers. Different rehabilitation regimens are created depending on the time after repair and immobilization period and subsequent mobilization to solve the problem of tendon adhesion [2].

Treatment option of phototherapy as laser therapies is a convenient and efficient means to apply monochromatic light energy to living tissue. Photon-tissue interaction of low-level laser therapy (LLLT) is supported in some published studies but not in others [3].

LLLT accelerates inflammation, promotes fibroblast proliferation, regulates the synthesis of type I and type III procollagen messenger ribonucleic acid, quickens bone repair and remodeling, encourages revascularization of wounds, and overall accelerates tissue repair in experimental and clinical models [4].

The appropriate dose of 600–1000 nm light promotes tissue repair and modulates pain. Low-level laser at 632.8 nm produced a higher deposition of collagen, increasing the tensile strength of surgically repaired rat tendons. Despite the intentions of studying the mechanism of low-energy laser biostimulation, no measurable benefit on wound healing was found [5].

The tissue response to laser therapy has a dose and wavelength dependence. LLLT with 0.01 J/cm^2 dose per day did not significantly increase the diameter of medial collateral ligament fibril, whereas the 685-nm laser at the dose of 3 J/cm^2 appeared to be most effective at accelerating tendinous repair [6,7].

In an animal trial, the effects of different intensities of laser energy and running exercise as combined effects on repair of Achilles' tendons after partial cut in rats were investigated: three laser doses were 4, 1, and 0 J/cm^2 and three running periods were 30, 15, and 0 min. The highest dosage of laser energy at 4 J/cm^2 and running for longer periods for 30 min performed better than others [8].

Critical decision-making skills of the hand therapist based on well-qualified information about tendon anatomy, healing concepts, and good communication with the surgeon are essential to reach the maximum hand strength and finger function [9].

Accordingly, this study was conducted to investigate the effects of different doses of laser therapy (4 or 1 J/cm^2) on the return of hand active ROM after flexor tendon repair.

Patients and methods

This study was a small trial conducted on 33 patients of 45 injured fingers primary repaired using at least two strands of a modified Kessler core suture after complete cut of flexor tendons with all factors constant except hand surgeon. Their age ranged between 20 and 40 years old, and they were selected from inpatient of the plastic surgery department. They were divided randomly into three groups; with a mean value of the control group of 25.00 ± 3.34 years, the mean value of group A of 25.93 ± 4.25 years, and the mean value of group B of 24.73 ± 4.30 years. There was no statistically significant difference in the mean value of age among the three groups ($P = 0.690$). Each patient received an explanation about procedures and signed a consent form.

Group A received the conventional treatment in addition to laser therapy of 1 J/cm^2. Group B received the conventional treatment in addition to laser therapy of 4 J/cm^2. Control group received the conventional treatment only.

Laser therapy in groups A and B was started on seventh day postoperatively, three sessions/week for 3 weeks. The conventional treatment was applied to all groups, which lasted for 3 months following Duran protocol [10]. Therapeutic exercises started the first day postoperatively after permission by the surgeon, and transcutaneous electrical nerve stimulation (TENS) began the seventh day postoperatively, three sessions/week for 3 months.

This study was conducted in Laser Unit, Physical Therapy Department, El-Mataria Teaching Hospital, Cairo, Egypt, to investigate the difference between the effects of different doses of LLLT (4 or 1 J/cm^2) on the return of hand active ROM after flexor tendon repair. Patients excluded from this study are those with tendon repair associated with a skin graft, nerve injury, arterial injury, joint injury, bone injury, systemic disease (e.g. diabetes mellitus), wound infection, or epileptic fits.

Materials

LLLT was ASA laser made in Italy with serial number (A000000296 f9000173), which is called multiwave locked system device that emits an IR laser radiation with wavelength ranged from 808 to 905 nm and continuous mode with fixed frequency for 1500 Hz. Laser dose selected for group A was 1 J/cm^2 for a total 9 J/cm^2 laser density, whereas the laser dose selected for group B was 4 J/cm^2 of a total of 36 J/cm^2 laser density.

TENS was Enraf Nonius added module 2015 with device ref. 1606950 with serial number 01.236 made in Germany.

Finger electro-Goniometer was used to measure hand total active ROM of Metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints of the injured hand and the corresponding finger in the noninjured hand during active flexion and extension. The measures were done at eighth and 12th week after the commencement of treatment.

Procedure

All patients have been treated the first day after surgery of wound and edema medically. Exercise began passively with surgeon permission within posterior slap. LASER therapy (for only group A and B) and TENS started at the seventh day after surgery during wearing posterior slap. Laser therapy discontinued after nine sessions whereas exercise and TENS continued for the 12th week after the commencement of

treatment. ROM and Strickland formula evaluation have been measured eighth and 12th weeks after commencement of treatment.

The patient was in sitting position with back supported, shoulder adducted, and forearm supinated with both feet flat on the floor.

Duran protocol [10,11] for therapeutic exercises started (after permission of surgeon) the first day postoperatively, which is divided into three phases.

The first phase lasted 1–4 weeks, with medical care and medical treatment of wound and edema. Exercises were a passive extension and passive flexion in metacarpophalangeal and interphalangeal joints, which were then replaced to active extension and passive flexion with 10–15 repetition every 2 h per day to prevent tendon adhesions.

Exercises were done within slap, whereas dressing was changed soon after a physical therapy session.

The second phase lasted 4–8 weeks with the same exercises with adding exercises 'place and hold' as the patient used uninvolved hand to place fingers compositely in flexed position then the patient held position for the count of 2–3 s with minimal tension. This is replaced to tendon gliding and grip strength exercises, beginning using a 'hock position', and then graduated to active tendon gliding in all three fist positions.

Through week 6, abduction and adduction of fingers and opposition of the pollicis toward the other fingers were performed while adding active exercise for wrist joint and light massage to prevent skin adhesions.

The third phase lasted 8–12 week, following the same aforementioned exercises while adding strengthening exercises with the ball for the intrinsic and extrinsic muscles of the hand and forearm [11,12].

Patients have been instructed to wear night splint after removal of posterior slap while gradually increasing the range of extension to gain and maintain full extension for 3 months after treatment [10].

TENS was conducted to relieve postoperative pain of all patients through applying two electrodes proximal and distal to the injured site from the seventh day postoperation three sessions per week for 3 months with the following parameters: TENS asymmetrical with phase duration of 100 μs, pulse frequency of 80 Hz, modulation program of 1/1 s, and treatment time of 15 min. These were then gradually increased in intensity to reach tingling sensation according to each patient.

Laser therapy

In this study, cluster IR laser therapy was applied on groups A and B only with a wavelength between 808 and 905 nm, continuous mode, with frequency of 1500 Hz. Laser applied perpendicular on the site of repair not contact as the participant's hand within posterior slap position. Treatment started at seventh day postoperatively, three sessions/week, for a total of 3 weeks. Laser dose was 1 J/cm^2 of the total 9 J/cm^2 laser density for group A or 4 J/cm^2 of the total 36 J/cm^2 laser density for group B.

Total active motion

In this study, total active motion (TAM) following the American Society for Surgery of the Hand was described as the ROM measurement of active flexion of metacarpophalangeal, proximal interphalangeal, and distal interphalangeal joints minus extension deficit of these three joints × 100% dashed the same for corresponding finger of the noninjured hand [13].

The following equation determines the percentage of recovery of TAM

$$\text{TAM} = \frac{\text{Active flexion (MCP + PIP + DIP)} - \text{extension deficit (MCP + PIP + DIP) of injured hand}}{\text{Same of noninjured hand}}\%.$$

Modified Strickland classification assessment represents the patient prognosis results of this equation of TAM or percentage of recovery classified, as shown in Table 1.

Statistical analysis

All statistical calculations were done using the statistical package for the social sciences (SPSS) computer program (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp) for data analysis.

Statistical procedures

(1) Mean and SD for each nonparametric variable in the three groups has been calculated
(2) Mann–Whitney test is used to measure the difference between the three groups
(3) Wilcoxon signed-rank test is used to measure the difference within groups
(4) *P* value less than 0.05 for statistical for significance.

Results

General characteristics of the patients

The purpose of this study was to investigate the difference between the effects of different doses of LLLT (4 or 1 J/cm^2) on the return of hand active ROM after flexor tendon repair.

This study was conducted on 35 patients of 45 injured fingers primary repaired after complete cut of hand flexor tendon. They were admitted to the inpatients of Plastic Surgery and Physical Therapy Department, El-Mataria Teaching Hospital, Cairo, Egypt.

Table 1: Modified Strickland classification of total active motion

Results	Percentage
Excellent	85-100
Good	70-84
Fair	50-69
Poor	<50

They were divided randomly into three equal groups. Control group consisted of 15 injured fingers treated by conventional treatments with no laser therapy, with the mean ± SD values of age were 25.00 ± 3.34 years, including one (6.7%) female and 14 (93.3%) males. Group A consisted of 15 injured fingers treated by 1 J/cm^2 laser therapy in addition to conventional treatment, with mean ± SD age of 25.93 ± 4.25 years, comprising zero (0%) female and 15 (100.0%) males. Group B consisted of 15 injured fingers treated by 4 J/cm^2 laser therapy in addition to conventional treatment, with mean ± SD age of 24.73 ± 4.30 years, comprising one (6.7%) female and 14 (93.3%) males. This study aimed to investigate the difference between the effects of different doses of LLLT (4 or 1 J/cm) on the return of hand active ROM after flexor tendon repair.

TAM of MCP, PIP, and DIP joints of an injured finger about the corresponding finger of the noninjured hand:

Within-group comparison (intragroup comparison)

In control group, there was a statistically significant increase in the value of TAM measured after 3 months of treatment (76.73 ± 10.25) when compared with its corresponding value measured after 2 months of treatment (47.13 ± 17.97), with *P* value 0.001 (Table 2 and Fig. 1).

Moreover, in group A, there was a statistically significant increase in the value of TAM measured after 3 months of treatment (69.47 ± 5.63) when compared with its corresponding value measured after 2 months of treatment (63.73 ± 13.14), with *P* value 0.017 (Table 2 and Fig. 1).

The same findings were also recorded in group B where the value of TAM measured after 3 months of treatment (82.80 ± 14.21) was significantly increased when compared with its corresponding value measured after 2 months of treatment (61.40 ± 20.34) with *P* value 0.001 (Table 2 and Fig. 1).

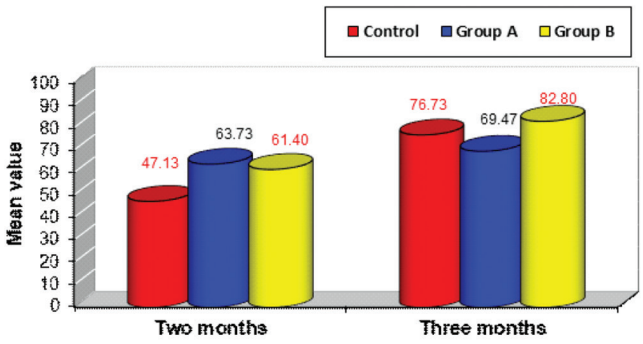

Figure 1: Mean values of total active motion in the three studied groups measured after 2 and 3 months of treatment.

Between-group comparison (intergroup comparison)

After 2 months of treatment, there was a statistically significant difference in the value of TAM among the three groups, with *P* value 0.024, where the value of TAM in both groups A and B was significantly increased when compared with its corresponding value in the control group (*P* = 0.006 and 0.049, respectively). At the same time, there was no significant difference in the value of TAM between groups A and B (*P* = 0.868) (Table 2 and Fig. 1).

Moreover, after 3 months of treatment, there was a statistically significant difference in the value of TAM among the three groups, with *P* value of 0.006, where the value of TAM in group A was significantly decreased (69.47 ± 5.63) when compared with its corresponding value in both control group (76.73 ± 10.25; *P* = 0.026) and group B (82.80 ± 14.21; *P* = 0.004). At the same time, there is no significant difference in the value of TAM between the control group and group B (*P* = 0.124) (Table 2 and Fig. 1).

Modified Strickland formula classified the results in Table 3 (Figs. 2 and 3) into excellent, good, fair, or poor as illustrated in Table 1, as TAM measurements were done at 2 and 3 months after treatment.

Discussion

The purpose of this study was to investigate the difference between the effects of different doses of LLLT (4 or 1 J/cm^2) on the return of hand active ROM after flexor tendon repair.

This small study, as a human trial, was conducted on 33 patients of 45 injured digits primary repaired after complete cut of hand flexor tendons. They have admitted to the inpatients of Plastic Surgery and Physical Therapy Department, El-Mataria Teaching Hospital, Cairo, Egypt. They were divided randomly into three equal groups. Control group consisted of 15 repaired fingers treated by conventional treatments (Duran protocol plus TENS) with no laser therapy. Group A consisted of 15 repaired fingers treated by 1 J/cm^2 laser therapy in addition to conventional treatment (Duran protocol plus TENS). Group B consisted of 15 repaired fingers treated by 4 J/cm^2 laser therapy in addition to conventional

Table 2: Intergroup and intragroup comparison between values of prognosis of total active motion in the three studied groups measured after 2 and 3 months of treatment

	Control (*n*=15) (mean±SD)	Group A (*n*=15) (mean±SD)	Group B (*n*=15) (mean±SD)	*P*[b]			Overall *P*[a]
				Control vs. group A	Control vs. group B	Group A vs. group B	
Two months	47.13±17.97	63.73±13.14	61.40±20.34	0.006*	0.049*	0.868	0.024*
Three months	76.73±10.25	69.47±5.63	82.80±14.21	0.026*	0.124	0.004*	0.006*
P[c]	0.001*	0.017*	0.001*				

P>0.05, NS.[a]Kruskal-Wallis analysis of variance test.[b]Mann-Whitney test.[c]Wilcoxon signed ranks test.**P*≤0.05, significant.

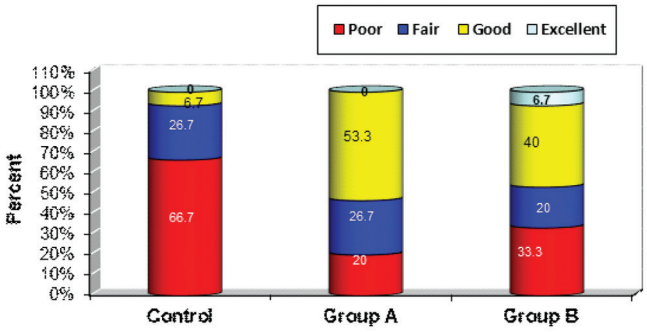

Figure 2: Degree of Strickland formula of total active range of motion (%) in the three studied groups measured after 2 months of treatment.

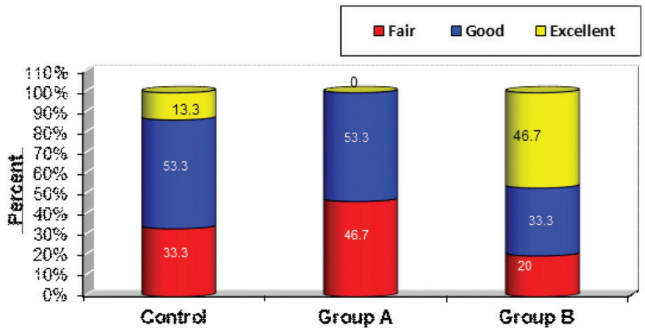

Figure 3: Degree of Strickland formula of total active range of motion (%) in the three studied groups measured after 3 months of treatment.

Table 3: Strickland formula results of total active range of motion in the three studied groups measured after 2 and 3 months of treatment

	Control (n=15) [n (%)]	Group A (n=15) [n (%)]	Group B (n=15) [n (%)]
Two months [Figure 2]			
Poor	10 (66.7)	3 (20.0)	5 (33.3)
Fair	4 (26.7)	4 (26.7)	3 (20.0)
Good	1 (6.7)	8 (53.3)	6 (40.0)
Excellent	0	0	1 (6.7)
Three months [Figure 3]			
Fair	5 (33.3)	7 (46.7)	3 (20.0)
Good	8 (53.3)	8 (53.3)	5 (33.3)
Excellent	2 (13.3)	0	7 (46.7)

treatment (Duran protocol plus TENS) to determine the effect of different doses of LLLT on the return of hand active ROM after hand flexor tendon repair.

The treatment applied to patients was Duran protocol for therapeutic exercises started (after permission of surgeon) the first day postoperative plus TENS started the seventh day postoperative three sessions/week, and both of them lasted for 3 months. However, LASER therapy started the seventh day postoperative three sessions/week for 3 weeks only.

Within-group comparison of total active motion (intragroup comparison)

The results showed that there is a statistically significant increase in the value of TAM measured after 3 months of treatment when compared with its corresponding value measured after 2 months of treatment in all groups (control, A and B). This means that conventional treatment (Duran protocol plus TENS) is effective as well as laser therapy.

Between-group comparison of total active motion (intergroup comparison)

When all groups compared together after 2 months of commencement of treatment, there was a statistically significant increased value of TAM in both groups A and B (laser groups) when compared with its corresponding value in control group (no laser therapy), with no significant difference existing between these doses of laser groups after 2 months of treatment.

However, after 3 months of commencement of treatment, the value of TAM in group A (1 J/cm^2) laser dose was statistical significantly decreased when compared with its corresponding value in both control group and group B (4 J/cm^2). As Strickland explanations of the group A showed some plateau, with minimal change occurred in only three poor patients shifted to fair, but there were no excellent patients in this group after 3 months of commencement of treatment.

This means that the dose of 4 J/cm^2 is seemed to be better than 1 J/cm^2 after 3 months of treatment in hand active ROM after hand tendon repair.

Modified Strickland formula results were classified into excellent (85–100%), good (70–84%), fair (50–69%), or poor (<50%). The measurements were done at 2 and 3 months after treatment [13].

Although the statistical results showed that there is no statistically significant difference in the number of changes occurred after 3 months of treatment when compared with their correspondents after 2 months of treatment between the control group and group B. However, in the control group, with no laser therapy (n = 15), Strickland classification of total active ROM after 2 months of treatment was no excellent patients, just good 1 (6.7%), fair 4 (26.7%), and the majority in poor 10 (66.7%) patient prognosis, which is the worst early results (elicited in Fig. 2). Moreover, after 3 months of treatment, it was excellent in only two (13.3%) patients, good in most in eight (53.3%) patients, and fair in 5 (33.3%) (Table 3 and Fig. 3).

However, in group B, using 4 J/cm^2 laser therapy (n = 15), Strickland classification after 2 months of treatment was found as follows: the only early 1 (6.7%) excellent patient prognosis (all over the three groups), the major good 6 (40.0%), fair 3 (20.0%) and poor 5 (33.3%) (elicited in Fig. 2). However, after 3 months of treatment, it was found that most showed excellent results in 7 (46.7%), good in 5 (33.3%) and fair in 3 (20.0%), which are the best results among the three groups (Table 3 and Fig. 3).

These results of this study are in agreement with the studies of Ng and Fung [8] and Delbari and Bayat [7] in an animal trial investigating the effects of different intensities of laser doses on the repair of Achilles tendons after partial cut in rats, with the results gained in laser energy 1 J/cm^2 were less than the effect of higher doses within the therapeutic window.

Moreover, the results of this study are in agreement with theory demonstrated by Nussbaum *et al*. [14]. Conforming the therapeutic window of laser doses existed between energy densities of 0.5 and 4 J/cm^2 can give biostimulatory effect, as doses above this level can provide bio-inhibitory effect and below this level can give no effect.

In this study, 26 injured fingers have dropped out of this study owing to several causes. This result agreed with Strickland [15] opinion that still several complications can be observed after tendon surgery.

Ruptured two fingers of total 45 repaired fingers occurred in this study; one in each control group and group B owing to circumstances unrelated to the regimen at the fourth week after surgery. This incidence of rupture agreed with Chesney *et al*. [16] and Ting [17] in 3–9% of cases as active ROM prevents adhesion but increases the rate of rupture.

Moreover, the study of Delbari and Bayat [7] showed that receiving nine sessions of laser therapy on alternate days had higher tensile strength values with larger mass-averaged diameters of collagen fibril than one single collected dose of laser soon after surgery of repaired medial collateral ligament (MCL).

In addition, the study of Isabel *et al*. [18] and Fillipin *et al*. [19] with samples grouped in no laser and laser groups (for 14 or 21-days laser sessions) demonstrated that laser is effective than control groups in reducing histological abnormalities, oxidative stress, and collagen concentration in an experimental model of Achilles tendon injury as reduction of fibrosis could be mediated by the beneficial effects on the oxidant/antioxidant balance.

However, tendon repair is still not fully understood. Electrical stimulation by direct current, low-level laser, and pulsed electromagnet can stimulate tendon healing [20].

The result of this study disagreed with the study of Hopkin *et al.* [21] who reported that the effect of the laser could be minimal or nonexistent on fresh injuries as cell proliferation is active. Laser response could be observed in old wounds. It is apparent that the issue of optimum dosage for LLLT is far from clear.

Moreover, in this study using laser continuous frequency (1500 Hz), some studies have reported contradictory results of this frequency as the study of Tiphlova and Tiina [22] on *Escherichia coli* division rate when irradiated with a 950-nm gallium arsenide diode laser reported that 1000 Hz laser frequency could give stimulatory effect, but above this level, inhibition can be achieved.

This study conducted by using 'multiple-diode laser with cluster head' was supported by Fung *et al*. [23], Bayat *et al.* [24], and Tokurakawa *et al.* [25] who reported that laser is effective in wound contraction and increasing wound bed cellularity. However, optimal stimulation for healing was in a combination of helium-neon and infra-red laser or a mixture of laser and nonlaser diodes when applied to soft tissue injuries, which strengthened the efficiency of laser energy. Even these ideas were not clear, but researches supported it.

Summary

This study elicited that treatment with laser therapy of either doses 1 or 4 J/cm^2 in addition to conventional treatment had a positive effect at 2 months after commencement of treatment on primary repaired hand flexor tendon and showed that treatment with LLLT is more effective than conventional treatment, which included TENS in addition to early therapeutic exercises following Duran protocol. The best results were shown at 2 and 3 months after treatment only in group B using the laser dose of 4 J/cm^2.

Conclusion

Early physical therapy treatment with low-intensity laser dose of 4 J/cm^2 is effective in magnifying the results besides with Duran protocol and TENS in early regain of better hand active ROM and early return of hand function after flexor tendon repair.

Recommendation

The most important recommendation of this study is to start physical therapy as early as possible after repair with the permission of the surgeon.

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Conflicts of interest

There are no conflicts of interest.

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