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Original Article

Comparison of the effect of separate and simultaneous application of Tecar therapy and low-level laser therapy on the neurological symptoms of type 2 diabetic patients with peripheral neuropathy of lower limbs

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ABSTRACT

Objectives: The study aimed to compare the effects of separate and simultaneous application of Tecar therapy and low-level laser therapy on neurological symptoms of type 2 diabetic patients.

Patients and methods: In this randomized control trial conducted between November 2021 and February 2022, 45 patients (30 females, 15 males; mean age: 65.7±7.6 years; range, 51 to 76 years) with type 2 diabetes and peripheral sensory neuropathy of the lower limbs were randomly divided into three groups: Tecar + sham laser (n=15), Tecar + laser (n=15), and laser + sham Tecar (n=15). Outcome measures for both right and left limbs included tibial motor nerve conduction velocity (MNCV), sural nerve amplitude, sole sensation, and ankle-brachial index (ABI) measured before and after 10 sessions and after a three-month follow-up.

Results: In intergroup comparison, the Tecar + laser group significantly improved compared to the laser + sham Tecar group in terms of tibial MNCV in both limbs after 10 sessions and all measured outcomes after three months ($p<0.05$). In addition, comparison between the Tecar + laser and Tecar + sham laser groups for tibial MNCV ($p=0.021$ for the right limb and $p=0.002$ for the left limb) and ABI ($p=0.001$ for the right limb and $p=0.002$ for the left limb) in both limbs after three months was significant. In the intragroup comparison, a significant improvement was found in the laser + sham Tecar group for sole sensation ($p<0.001$) and ABI ($p<0.001$) of both limbs after three months compared to before the interventions, whereas in the other two groups, significant improvements were found in all four outcomes.

Conclusion: A significant increase was found in neurological outcomes in all three groups after 10 sessions. Moreover, the use of combined Tecar therapy and laser compared to Tecar or laser alone could lead to a more lasting effect in improving the sensory symptoms of type 2 diabetic patients with peripheral neuropathy of the lower limbs.

Keywords: Diabetic neuropathy, laser, nerve conduction velocity, neuropathy symptoms, sensation, Tecar.

Diabetic neuropathy is one of the most common problems experienced by patients with type 2 diabetes mellitus. Distal peripheral neuropathy (DPN) is the most common cause of diabetic foot complications, which often affects the motor part of patients following the sensory disorder.[1] The prevalence and progression of DPN increases with the chronicity of diabetes and improper blood sugar control. The presence of pain in DPN is due to damage to the vessels feeding sensory nerves and atrophy of axons. In this disease, moreover, all nerve fibers, particularly small myelinated fibers and unmyelinated fibers that transmit pain and heat, are damaged.[2]

According to two studies, the use of physiotherapy modalities such as electrical stimulation, low-level laser therapy (LLLT), infrared light, and electromagnetic waves was suggested to improve DPN symptoms.[3,4] The LLLT can be extensively effective

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in relieving many painful conditions and repairing nerve tissues. In fact, the laser holds the potential to create a biostimulation effect on the nervous system.[5] Other possible mechanisms have been attributed to the increase of adenosine triphosphate and the release of endorphins associated with its anti-inflammatory effect.[6,7] Some researchers mentioned the LLLT as a new treatment method for diabetic patients with DPN symptoms and suggested that using it should be part of the peripheral nerve rehabilitation algorithm in these patients.[7-9] Another intervention used to control the symptoms of this disorder is low-frequency electromagnetic waves, and several studies confirmed its effects on the improvement of complications caused by peripheral neuropathy.[10-12] The effect of these waves on the tibial motor nerve conduction velocity (MNCV) and pain improvement in diabetic peripheral neuropathy has been reported.[13] Tecar is one of the electromagnetic waves whose beneficial effects have been reported in the treatment of musculoskeletal injuries such as low back pain[14] and Achilles tendonitis.[13] The word Tecar means the transfer of energy in two ways, capacitive and resistive, with a frequency of 300-1000 kHz, described as a high-frequency energy. Therefore, it can increase the normal physiological process of the tissue and transfer energy without introducing radiation from the outside environment. One of its advantages is the ability to use Tecar therapy at a low energy level. Therefore, it can be used in the acute and subacute phases and in cases where there is a sensory disorder.[15] Cell renewal following tissue oxygenation, increased metabolic rate and faster separation of oxygen from hemoglobin, release of endorphins, and subsequent pain reduction have been reported as the possible physiological mechanisms of Tecar therapy.[16]

Therefore, the positive effect of both Tecar therapy and LLLT on the improvement of the sensory symptoms of DPN patients has been proven, but to our knowledge, no study has investigated the simultaneous effect of these two interventions on the improvement of the sensory symptoms of patients. Regarding the complications caused by neuropathy and the positive effect of Tecar therapy and LLLT as physiotherapy modalities to help these patients improve sensory symptoms, this study aimed to compare the effect of these two modalities applied separately and simultaneously with a long-term follow-up (three months) on the neurological symptoms of type 2 diabetic patients. We hypothesized that the combination of Tecar and laser would have longer-lasting therapeutic effects than either laser or Tecar alone.

PATIENTS AND METHODS

The double-blind randomized control trial was conducted at the Shahid Beheshti University of Medical Sciences Department of Physiotherapy between November 2021 and February 2022. Forty-five patients (30 females, 15 males; mean age: 65.7±7.6 years; range, 51 to 76 years) suffering from type 2 diabetes with DPN were randomly divided into three groups of therapeutic intervention: Tecar + sham laser (Group 1), Tecar + laser (Group 2), and laser + sham Tecar (Group 3; Figure 1). Patients referred by the endocrinologist were included in the study if they were eligible. Inclusion criteria were age >50 years, patients with at least six months of peripheral neuropathy of the lower limbs, patients with symptoms of DPN of the lower limbs diagnosed by a neurologist through electromyography in the last three months before the intervention, body mass index <30, and glycated hemoglobin <8.5, tibial MNCV <40, and a minimum pain score of 4 based on the Visual Analog Scale.[17] Patients were excluded from the study in case of nondiabetic neuropathy symptoms, systemic peripheral vascular involvement, pregnancy, suffering from malignant tumors, coronary artery disease, having a pacemaker or a mechanical insulin pump, knee arthroplasty and the presence of metal plaques in lower limbs and back, and addiction to drugs, smoking, and alcohol.

The blocked randomization method was used to allocate the participants into three groups of 15 people. Each group was assigned a code, and according to the number of each group, the code of the group was inside the closed envelope, and the patient randomly chose an envelope. The main researcher did not divide the individuals into three groups, and it was conducted by the research assistant who was a physiotherapy expert. The participants were blind to the type of group, and the therapist was unaware of the evaluation results, including before and after 10 sessions and after three months of follow-up. Patients were blinded to real and sham conditions. Electromyography data including MNCV and sural nerve amplitude (SNA) were measured by a neurologist and sole sensation, and ankle-brachial index (ABI) was measured by the main researcher who was a physiotherapist. Additionally, the statistics specialist was completely unaware of the grouping of participants.

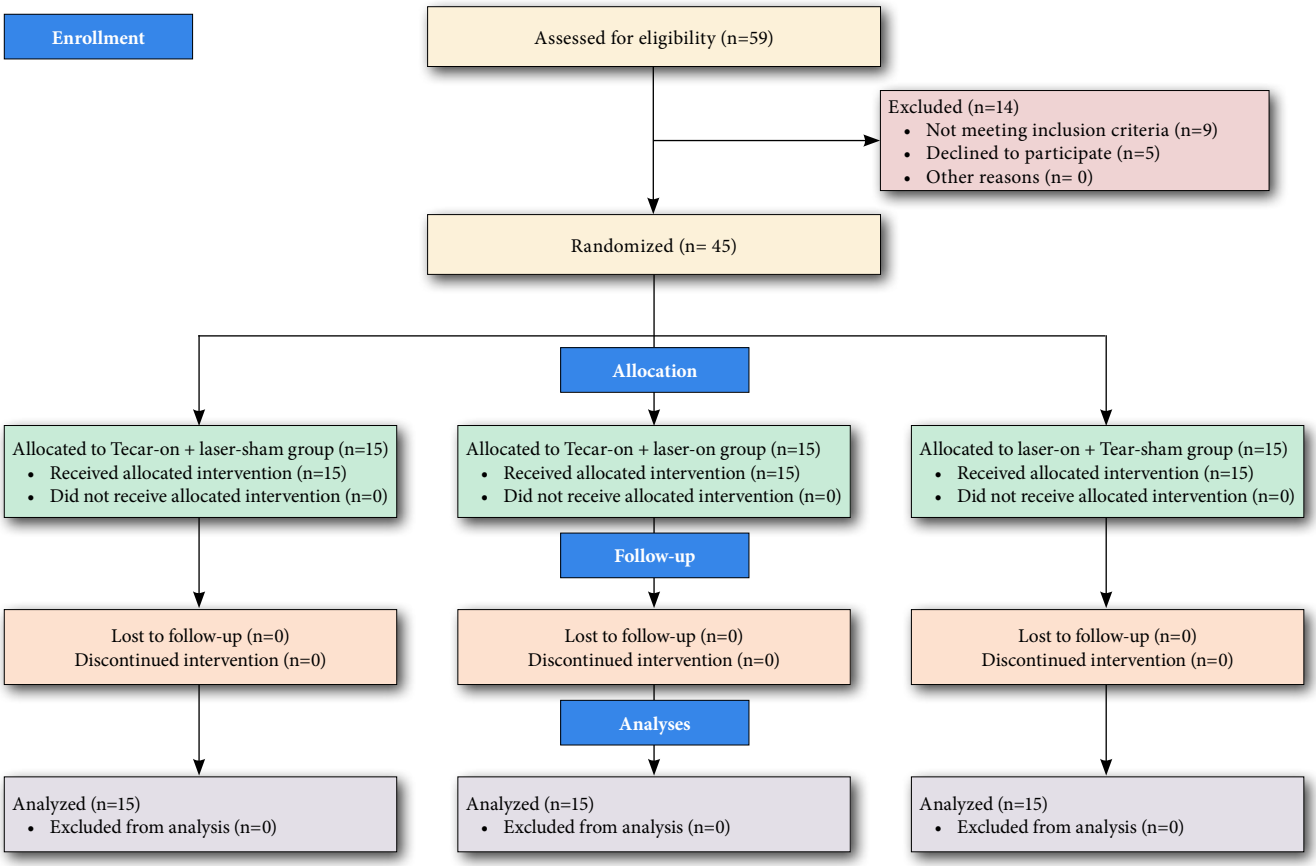

Figure 1. Consolidated Standards of Reporting Trials flowchart of study.

Interventions

The LLLT uses light amplification by stimulated emission of radiation, and it has no thermal effect. It is a nonionizing radiation that is not capable of causing changes in the molecular structure and causes no cell damage. The basis of using LLLT is the direct effect of biostimulation energy on body cells. In the present study, a two-channel laser device (Mustang 2000 Technica Co., Russia) with two probes was utilized (Figure 2). The first probe is infrared with a wavelength of 890 nm, power of 15 W, and frequency of 80 Hz, which produces infrared pulse waves. The second probe has a wavelength of 630 nm and power of 10 mW and produces continuous waves of red light.[18]

In this study, a capacitance-resistance Tecar device (TEKRA XCRT; New age, Italy) with an output

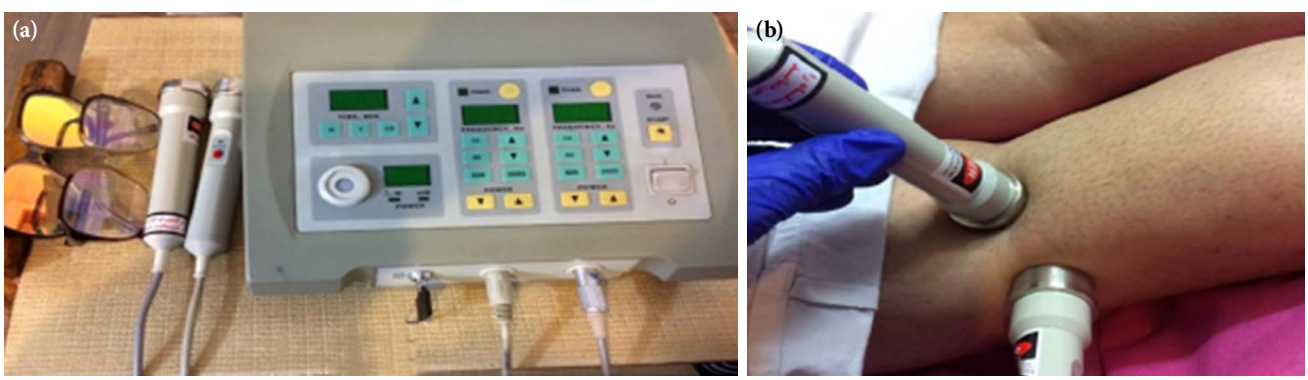

Figure 2. (a) The laser device used in this study. **(b)** Application of the laser device (the probe above had infrared waves; the probe below had waves of red light).

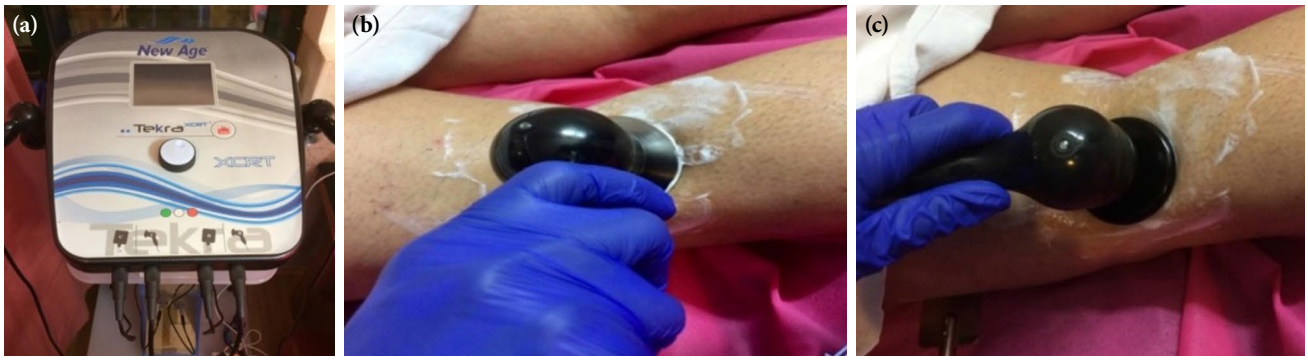

Figure 3. **(a)** The Tecar device used in this study. **(b)** Application of resistance Tecar (metal probe). **(c)** Application of capacitive Tecar (silicon probe).

power of 300 W, capacitive and resistive frequencies of 250 kHz and 500 kHz, respectively, two metal plates (passive electrode), and two capacitive and resistive ergonomic handpieces was used (Figure 3).[13] The output heat intensity was manually adjustable between 0 and 100%, and in this study, the Tecar device was set at 40 to 50% intensity. Due to diabetic patients having sensory impairment, it is not possible to use 100% of the thermal energy caused by Tecar devices. Furthermore, we used the information of a previous study for heat intensity of the Tecar device set below 50% on diabetic patients.[13]

Outcome measures

The two variables of tibial MNCV and SNA were evaluated using an electromyography device. For tibial MNCV in an orthodromic manner, the recorder electrode was placed on the bulk of the abductor hallucis muscle, and an inactive electrode was placed on the base of the thumb. Moreover, the stimulating electrode was placed on the ankle and malleolus (10 cm proximal to the recorder electrode), and it was placed on the knee slightly medial to the popliteal fossa. A tibial MNCV <40 m/sec was considered diabetic neuropathy.[13]

Sural nerve amplitude was also measured by placing the active electrode in the posterior and below the lateral malleolus and the reference electrode 3 cm distal to the active electrode. The stimulation performed by a neurologist was slowly recorded in the midline, the lower one-third of the posterior leg, by placing the cathode in the distal area at a distance of 17 cm from the active electrode.[19] A SNA <10 μV was considered diabetic neuropathy.[20]

This variable was evaluated using a monofilament tool, usually applied to the sole. This test has a reliability of 0.89 and Cronbach's alpha coefficient of 0.72, approved in a previous study.[21] This tool has calibrated nylon strings with a thickness between 1.65 and 6.65 g. The thicker the string, the more force is needed to bend it. Usually, three thicknesses of 4.17, 5.07, and 6.10 g are used to diagnose DPN. When a person has a loss of sole sensation, they cannot recognize this pressure. According to the evidence, the best thickness and strength are 5.07 and 10 g, respectively.[19] In this study, the person sat and closed their eyes. Then, the evaluator pressed the 10-g monofilament for 10 min on each point of two feet. Ten points on each sole, including three points on the first, second, and third toes, three points on the first, second, and third metatarsal heads, three points on the medial and lateral sides of the mid-foot, one point on the heel region, and one on the dorsum of the foot, were selected, and each filament was placed on each of these 10 points. The participant was asked to report whether the filament hit their sole foot and where it hit. Each of these points had one score if the person felt the applied pressure. It should be noted that the inability to perceive the monofilament at any site was considered abnormal. The total score of each foot is 10.[22]

This variable is the ratio of systolic blood pressure in the ankle to systolic blood pressure in the arm used to evaluate vascular disorders in diabetics and peripheral artery disease, and its normal range is 0.9 to 1.4. If this index is >1.4, it indicates the stiffness of the vessel wall, and <0.9 indicates the narrowing of the arteries. Anke-brachial index measurement is recommended for all diabetic patients over 50 years old, people with symptoms of peripheral artery disease, and other cardiovascular risk factors.[23] In this study, the ABI was measured by an automatic digital manometer.

Data collection

After the allocation of groups, each person was prepared to receive the assigned treatment. Before the interventions, fasting blood sugar and glycated hemoglobin were recorded in a clinical laboratory. Then, electrophysiological parameters including tibial MNCV and SNA were recorded by a neurologist. After 10 min of rest, evaluation of the sole sensation was done and recorded by the monofilament instrument. Next, after 5 min of rest, the systolic pressure of the ankle above the malleolus line and the systolic pressure of the arm in the supine position were measured, and their indexes were calculated and recorded.

The intervention of Tecar and LLLT on patients was applied by the main researcher. The patient comfortably slept in the prone position with a pillow under the abdomen and ankles to start the treatment in Group 2. At first, an LLLT was used in the L2-L4 region in four points and in the popliteal area in two points for 2 min (12 min in total). Two laser wavelengths were simultaneously irradiated by two probes to save time and prevent patient fatigue, which required about 15-20 min. After the end of the treatment in each session, the patient rested for 5 min, and then the treatment started with the capacitor Tecar. For this purpose, the inactive (metal) electrode dipped in a special cream was placed in the abdomen area, and then the active electrode was slowly moved using the cream for 15 min on the lumbosacral area. In the same way, it was done with the resistance method for 10 min and with the same intensity in the lumbosacral area. Afterward, the treatment was started with the capacitance method in the popliteal area by placing an inactive electrode dipped in the cream in the upper area of the patella. In this case, the capacitive active electrode was slowly moved for 15 min in the popliteal region and the head of the fibula. After finishing this method, the resistance method was applied in the same way and with a special resistance probe for 10 min. One of these interventions was performed in the laser-only and the Tecar-only groups; the Tecar or laser device was switched off for the sham intervention, and patients did not notice the absence of their current.

All participants were treated in the morning and the room temperature was between 25 and 27°C. In all three study groups, 10 treatment sessions were performed for three sessions per week. All the tests were carried out before the start of the treatment, after 10 sessions, and a three-month follow-up. In all three groups, after 5 min of rest, therapeutic exercises, including strengthening and stretching exercises and weight-bearing exercises, were performed for 15 min. The patients were followed by phone calls to remind the individuals to exercise at their homes during the follow-up period.

Statistical analysis

The G*Power version 3.1.9.4 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) was used to determine the sample size. According to a pilot study in two groups of Tecar-only and laser-only (five individuals in each group) and the ABI, the required sample size per group was calculated as 15, with a 95% confidence level and 80% power.

Data were analyzed using IBM SPSS version 20.0 software (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to check the normality of data distribution in the groups. As for demographic characteristics and clinical features at baseline, the difference between the three groups was compared using one-way ANOVA (analysis of variance) or the chi-square test. Intergroup comparison of normal variables over time was done with two-way mixed repeated measures ANOVA, and the Bonferroni method was used for intragroup comparison. A p-value <0.05 was considered statistically significant.

RESULTS

The demographic and clinical characteristics of the participants are given in Table 1. With no significant difference between the three groups in these variables ($p>0.05$). Table 2 shows the mean of the variables related to the right and left limbs separately. Table 3 shows the results of intergroup comparison, and Table 4 demonstrates the intragroup comparison of variables related to right and left limbs.

Intergroup comparison

According to Table 3, after 10 sessions of the intervention compared to before the intervention, a significant difference was observed in the direction of increase in tibial MNCV between Groups 1 and 2 ($p=0.034$) and between Groups 2 and 3 ($p=0.008$). The difference between any of the groups was not significant for the variables SNA, ABI, and sole sensation after 10 sessions of the intervention.

In the intergroup comparison, after the three-month follow-up compared to before the intervention for the right limb, a significant difference was found between the three groups (the results were

TABLE 1
Demographic characteristics of patients

Variables	Tecar-on + laser sham (n=15) n	Tecar-on + laser sham (n=15) SD	Tecar-on + laser on (n=15) n	Tecar-on + laser on (n=15) SD	Laser-on + Tecar sham (n=15) n	Laser-on + Tecar sham (n=15) SD	*p*
Age (year)	63.93	7.44	64.46	7.69	68.60	7.31	0.187
Sex							0.741
Female	11		9		10		
Male	4		6		5		
Body mass index (kg/m^2)	26.54	1.58	26.15	1.12	25.29	2.34	0.150
Duration of diabetes (year)	13.47	1.5	13.13	1.92	13	1.30	0.715
Duration of neuropathy (year)	2.66	1.23	2.86	1.06	3.20	0.86	0.390
HbA1c for three months	7.06	0.6	7.13	0.67	7.32	0.71	0.551
Fasting blood sugar	132	8.81	132.32	9.35	129.73	8.64	0.689

TABLE 2
Mean and standard deviation of the variables related to the right and left limbs

	Right limb			Left limb		
	Tecar-on + laser sham (n=15)	Tecar-on + laser on (n=15)	Laser-on + Tecar sham (n=15)	Tecar-on + laser sham (n=15)	Tecar-on + laser on (n=15)	Laser-on + Tecar sham (n=15)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Tibial MNCV (m/s)						
Before intervention	36.93±1.32	36.30±1.55	37.13±0.74	36.83±1.34	36.33±1.50	37.13±0.99
After 10 sessions	39.16±1.21	40.26±1.38	38.93±0.79	39.50±1.29	40.33±1.34	38.40±0.96
After 3 months	38.60±1.31	39.83±1.45	37.26±0.72	38.00±2.61	40.44±1.47	36.60±0.91
SNA (mv)						
Before intervention	7.1±0.75	6.96±1.06	7.30±0.90	7.12±0.80	6.94±1.07	7.70±0.88
After 10 sessions	8.67±0.56	8.82±0.95	8.44±0.84	9.21±0.57	8.76±1.00	8.88±0.89
After 3 months	8.58±0.58	9.38±1.19	7.44±0.84	8.82±0.53	9.28±1.08	7.80±0.89
A/B index						
Before intervention	0.88±0.04	0.89±0.05	0.88±0.06	0.88±0.04	0.89±0.05	0.89±0.06
After 10 sessions	0.96±0.07	1.00±0.05	0.95±0.07	0.96±0.07	1.01±0.03	0.97±0.07
After 3 months	0.98±0.07	1.07±0.05	0.93±0.06	0.98±0.07	1.12±0.13	0.95±0.06
Sole-foot sensation						
Before intervention	6.02±1.01	6.13±0.91	6.27±0.59	6.13±1.06	6.20±0.94	6.20±0.94
After 10 sessions	8.60±0.63	8.33±0.81	8.33±0.97	8.67±0.61	8.53±0.64	8.33±0.81
After 3 months	8.73±0.79	9.07±0.70	7.60±1.05	8.80±0.56	9.20±0.56	7.53±0.83

SD: Standard deviation; MNCV: Motor nerve conduction velocity; SNA: Sural nerve amplitude; ABI: Ankle brachial index.

in favor of Group 2; Figure 4a) in the tibial MNCV variable. The differences in SNA and sole sensation were significant between Groups 1 and 3 and Groups 2 and 3. Regarding the ABI, the comparison between Groups 1 and 2 (p=0.001) and Groups 2 and 3 (p<0.001) was found to be significant after the three-month follow-up compared to before the intervention (results were in favor of Group 2; Figure 4c).

According to Table 3, after 10 sessions of the intervention compared to before the intervention, the comparison of Groups 1 and 3 (p=0.034) and the comparison of Groups 3 and 2 (p=0.008) regarding the tibial MNCV variable was significant (results were in favor of Group 2; Figure 5a). Regarding other parameters, no significant difference was observed in the direction of improvement.

The comparison after the three-month follow-up compared to before the intervention between the three groups for the left side, the statistical results were similar to the right limb.

Intragroup comparison

For the right limb, between before the intervention and after 10 intervention sessions, as well as between before the intervention and after the three-month follow-up, a significant increase was observed in all variables in Group 1 (Table 4). For the left limb, a significant increase was observed between before the intervention and after 10 sessions for all four outcomes ($p<0.001$). Although there was no significant difference in tibial MNCV on the left side between before the intervention and after three months, this difference was significant for other variables.

The differences in Group 2 for the right limb between before the intervention and after 10 sessions, as well as between before the intervention and after three months of follow-up, were the same as Group 1. For the left limb, the differences between before and after 10 sessions and before and after three months were significant in all four variables in the direction of increase.

In Group 3, for both the right and left limbs, a significant increase was observed in all four measured variables after 10 sessions compared to before the intervention. These changes for the right side after three months compared to before the intervention were significantly increased in the two variables of ABI ($p<0.001$) and sole sensation ($p<0.001$). The changes for the left side in the three variables of ABI ($p<0.001$), sole sensation ($p=0.001$), and tibial MNCV ($p=0.044$) after three months compared to before the intervention were significant in the direction of increase.

DISCUSSION

The definitive diagnosis of diabetic neuropathy is confirmed by neurophysiological tests. Due to the lack of regular control of blood sugar for a long time, changes are made in the structure of the peripheral nerves. Therefore, there are changes in the nerve layers of the axon and the myelin sheath of peripheral motor and sensory nerves, which lead to a decrease in the MNCV and a decrease in nerve amplitude.[24] For examining the results of using physiotherapy interventions in this study, the tibial MNCV and SNA were investigated.

TABLE 3
Comparison between groups using one-way ANOVA after 10 sessions and after three months in the right and left limbs

	Right limb							Left limb						
	Comparison between groups after 10 session			Comparison between groups after 3 months				Comparison between groups after 10 session			Comparison between groups after 3 months			
	p value			*p* value				*p* value			*p* value			
	Group 1 & 2	Group 1 & 3	Group 2 & 3	Group 1 & 2	Group 1 & 3	Group 2 & 3		Group 1 & 2	Group 1 & 3	Group 2 & 3	Group 1 & 2	Group 1 & 3	Group 2 & 3	
Tibial MNCV (m/s)	0.034*	0.847	0.008*	0.021*	0.012*	<0.001**		0.157	0.044*	<0.001**	0.002*	0.099	<0.001**	
SNA (mv)	0.873	0.725	0.423	0.052	0.004*	<0.001**		0.319	0.523	0.928	0.318	0.007*	<0.001**	
ABI	0.339	0.904	0.166	0.001*	0.06	<0.001**		0.216	0.998	0.238	0.002*	0.494	<0.001**	
Sole-foot sensation	0.508	0.508	1.000	0.636	0.001*	<0.001**		0.963	0.555	0.717	0.208	<0.001**	<0.001**	

ANOVA: Analysis of variance; MNCV: Motor nerve conduction velocity; SNA: Sural nerve amplitude; ABI: Ankle brachial index; Group 1: Tecar + sham laser; Group 2: Tecar + laser; Group 3: Laser + sham Tecar; * $p<0.05$; ** $p<0.001$.

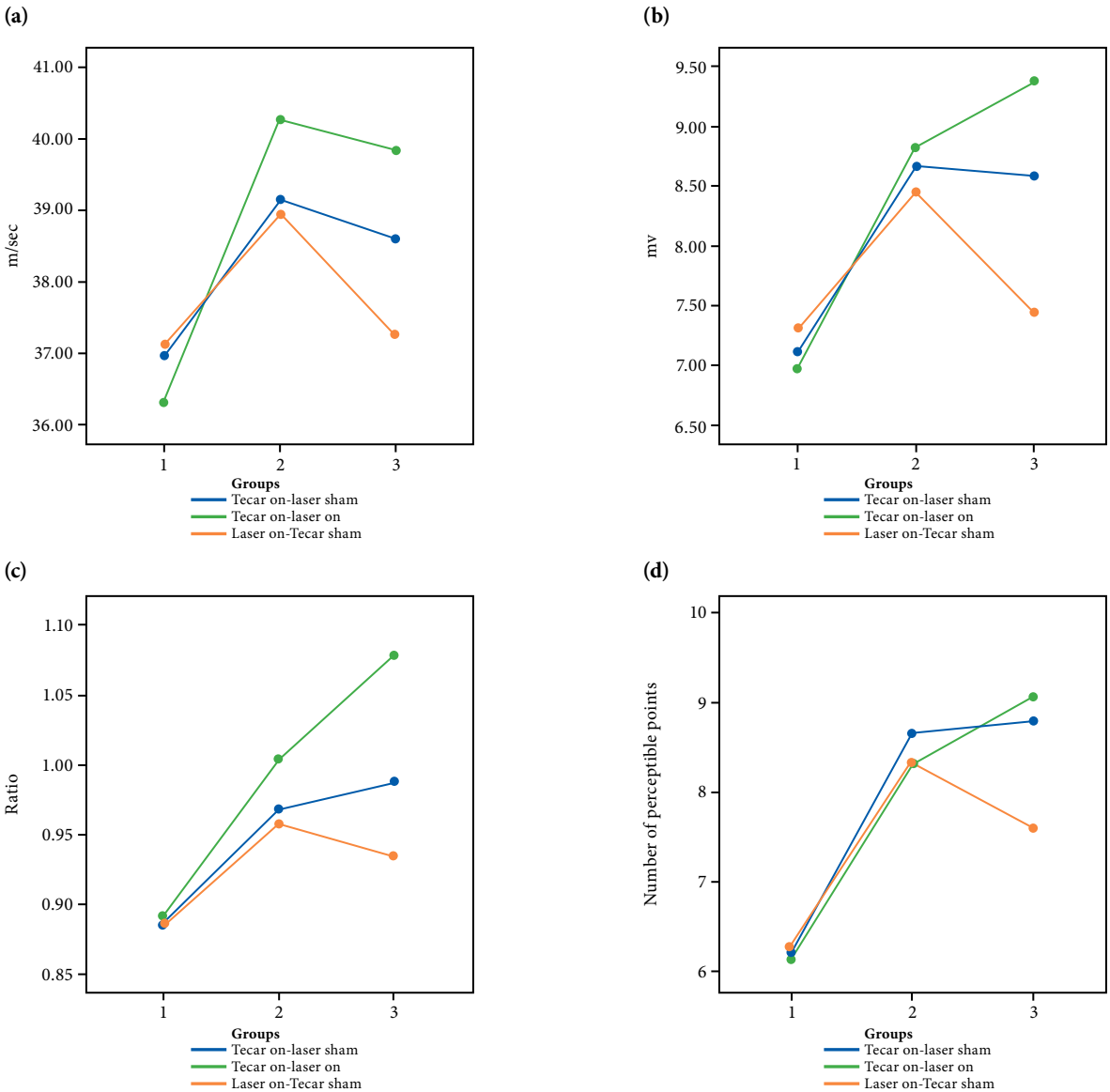

Figure 4. The right-limb neurological variables. **(a)** Tibial MNCV, **(b)** sural SNA, **(c)** ankle brachial index, and **(d)** foot sensation of the right limb (1: Before the intervention; 2: After 10 sessions; 3: After three months).
MNCV: Motor nerve conduction velocity; SNA: Sural nerve amplitude.

The findings of the present study regarding the effect of Tecar therapy on improving tibial MNCV were significant after three months of follow-up, which could be due to using of capacitance-resistance Tecar. Generally, resistance Tecar is effective on high-resistance tissues (e.g., tendons, ligaments, and bones), and capacitive Tecar is effective on low-resistance tissues (e.g., arteries and muscles).[25] Based on the results, it appears that the combination of Tecar and laser has a more durable effect on the improvement of DPN symptoms than Tecar or laser alone. The present study is consistent with the study of Bosi et al.[26] in patients with type 2 diabetes. The results of their study showed that with four months of follow-up, the tibial MNCV in type 1 and 2 diabetic patients was significantly increased by frequency-modulated electromagnetic neural stimulation. Graak et al.[27] mentioned that electromagnetic waves could increase the tibial MNCV in patients with moderate to severe symptoms of peripheral neuropathy by affecting the polarity of the cell membrane and improving their metabolism.

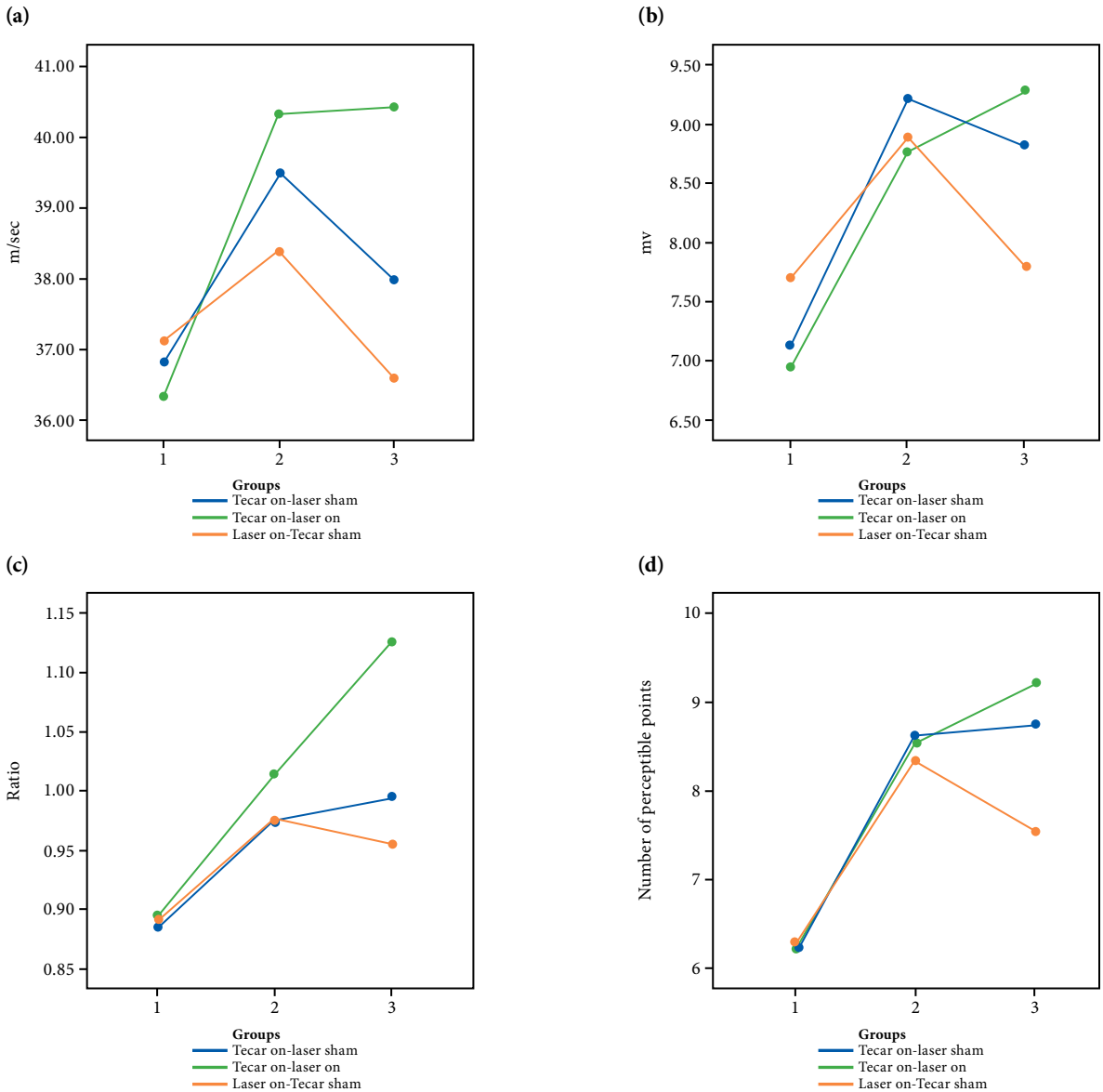

Figure 5. The left-limb neurological variables. **(a)** Tibial MNCV, **(b)** sural SNA, **(c)** ABI, and **(d)** foot sensation of the left limb (1: Before the intervention; 2: After 10 sessions; 3: After three months).
MNCV: Motor nerve conduction velocity; SNA: Sural nerve amplitude; ABI: Ankle brachial index.

The findings of the present study regarding the effect of LLLT on improving the tibial MNCV are consistent with the results of Yamany et al.,[28] indicating that LLLT could be an effective treatment modality in improving neurovascular function and tibial MNCV. They mentioned the cause of changes in electrophysiological parameters as the effect of laser biostimulation on the nervous system.[3] Therefore, based on the results of the present study, it can be stated that the application of Tecar therapy, along with the common LLLT, has led to an increase in the tibial MNCV by affecting the polarity of the neuron membrane and helping to regenerate the nerve cell.

The findings of the present study showed different statistical results on tibial MNCV of the right and left limbs. The results of tibial MNCV in the right limb were in favor of Tecar + laser after 10 sessions and also in favor of Tecar + laser compared to laser + sham Tecar after a 3-month follow-up. It should be noted that the dominant limb of the participants was the right in the present study. Previous studies have stated that a concentration on

TABLE 4
Intragroup comparison using repeated measure test in the right and left limbs

		Right limb				Left limb			
		Tibial MNCV (m/s)	SNA (mV)	ABI	Sole-foot sensation	Tibial MNCV (m/s)	SNA (mV)	ABI	Sole-foot sensation
		p value	*p* value	*p* value	*p* value	*p* value	*p* value	*p* value	*p* value
Group 1									
Before intervention	Before intervention	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
Before intervention	Before intervention	<0.001**	<0.001**	<0.001**	<0.001**	0.157	<0.001**	<0.001**	<0.001**
After 10 session	After 10 session	0.079	1.000	<0.001*	1.000	0.086	0.006*	<0.001**	1.000
Group 2									
Before intervention	Before intervention	<0.001**	<0.001**	<0.001**	<0.001*	<0.001**	<0.001**	<0.001**	<0.001**
Before intervention	Before intervention	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
After 10 session	After 10 session	0.080	<0.001**	<0.001**	<0.001**	1.000	<0.001**	0.028*	<0.001**
Group 3									
Before intervention	Before intervention	<0.001*	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**
Before intervention	Before intervention	0.311	0.051	<0.001**	<0.001**	0.044*	0.418	<0.001**	0.001*
After 10 session	After 10 session	<0.001**	<0.001**	0.020*	0.004*	<0.001**	<0.001**	0.022*	<0.001**

MNCV: Motor nerve conduction velocity; SNA: Sural nerve amplitude; ABI: Ankle brachial index; Group 1: Tecar + sham laser; Group 2: Tecar + laser; Group 3: Laser + sham Tecar; * p<0.05; ** p<0.001.

the dominant limb is higher in training patterns, resulting in higher MNCV.[29,30] Furthermore, since the tibial MNCV is related to limb strength, evidence has shown a significant asymmetry in leg muscle strength between dominant and nondominant limbs in diabetic peripheral neuropathy.[31,32] Therefore, statistically different results in two limbs may be due to the asymmetry in the severity of tibial nerve involvement in the right and left limbs, which has led to a significant difference in the results of the tibial MNCV of lower limbs.

Decreased bilateral SNA as electrophysiological changes is indicated in all type 2 diabetic patients.[19] In the present study, a significant increase in the SNA was observed after 10 sessions in all three groups, while after three months of follow-up, this increase in the right limb was not significant in the LLLT group. In a study without follow-up, Shanb et al.[33] concluded that the SNA significantly increased with either electromagnetic therapy or laser therapy in addition to medications, but this increase was not significant in the group receiving only the regular medications. These results have also been supported by some recent studies.[34,35] In general, this improvement caused by LLLT may be due to the improvement of perfusion and microcirculation of the tissue in the ischemic area, followed by the improvement of neurophysiological function.[36,37]

The finding on SNA indicated that the laser + Tecar group could have longer therapeutic effects than the laser-only or Tecar-only groups. A possible reason can be due to the effects of oxygenation and improvement of vascular nutrition of peripheral nerves that are ischemic and damaged. In a study, Yamany and Sayed[3] observed a significant increase in the SNA, sural sensory nerve conduction velocity, and foot skin microcirculation in the laser group. They mentioned this improvement following the effect of laser biostimulation on the nervous system. Other studies were of the opinion that laser radiation stimulates Schwann cell proliferation, allows higher neural metabolism, and increases myelination and axon regeneration.[38,39] In the present study, the significant increase in the SNA in both the laser-only and the Tecar-only groups can be due to the effects of these treatments in the superficial tissues and be effective in the small fibers of the peripheral nerves. Therefore, Tecar therapy along with LLLT can have a better effect on the sensory nerves, including the SNA, thereby having a longer effectiveness.

Low-level laser therapy can lead to an increase in skin temperature by affecting the peripheral blood flow.[40] Due to the increase in the vascular network, laser therapy can improve the peripheral blood flow.[41] Therefore, the results of the present study regarding the positive effect of LLLT on ABI for both limbs can be attributed to these reasons, and the continuation of the results in the laser group after three months of follow-up may be due to the combination of strength and stretching exercises and weight-bearing exercises, resulting from maintaining the flexibility of vessels and better tissue blood flow following continued exercises.[42] Moreover, with its physiological effects, Tecar therapy can cause the improvement of peripheral and intramuscular blood flow with less energy, following better oxygenation, vascular dilation, and effect on the neurovascular system.[23] It seems that Tecar therapy can lead to significant changes in improving the ABI in type 2 diabetes patients, and the continuation of exercises in both Tecar-only and Tecar + laser groups may increase the flexibility of the walls of blood vessels and muscles and improve tissue blood flow, thereby improving the ABI and continued improvement up to three months after the intervention.

Additionally, the combination of Tecar and laser compared to Tecar or laser alone improved ABI after three months of follow-up. Since LLLT leads to new vascularization of damaged tissues due to the biostimulation effect and improvement of blood flow, capacitive therapy could also lead to improvement of blood flow and oxygen supply and flexibility of the vessel wall. Therefore, the use of both modalities can have longer-lasting effects after three months of follow-up on the ABI.

Based on the findings, Tecar intervention had a greater increase than LLLT in improving the sole sensation after a three-month follow-up; thus, the use of Tecar alone and combined with laser caused a significant improvement in this outcome. This effect can be attributed to the thermal and nonthermal effects of Tecar therapy in improving the peripheral and intramuscular blood flow.[43] In addition, due to the improvement in the temperature of deep tissues and the effect on hemoglobin saturation, it appears that Tecar therapy can increase oxygen and blood supply to hypoxic nerve tissues.[44] The current study on a significant role of Tecar therapy in improving the sole sensation, is consistent with the results of Niajalili et al.[13] In our study, the combined effect was achieved by applying the resistance-capacitance Tecar. With capacitance Tecar, it was aimed to provide blood flow

and oxygen to hypoxic tissues, and with resistance Tecar, it was aimed to increase the flexibility of high-resistant tissues.[25,44] This finding is in line with the results of the study of Bosi et al.[26] in patients with diabetes. They concluded that electromagnetic waves accelerate the release of vascular activation factors that result in increased blood flow in the damaged nerve tissue, causing an increase in the sole sensation score and a decrease in the tremor threshold.

One of the limitations of the present study was that only patients over 50 years of age were included, and it is not possible to generalize the results to other age groups. Furthermore, it was not possible to fully control diabetic people during the entire study period in terms of the time of taking diabetes control drugs, nutrition, and other environmental factors. Moreover, according to the duration of the evaluation of the measured indicators in the first session and 10th session of the treatment, the patient was fatigued. It is suggested to conduct a similar study for individuals with type 1 diabetes. In addition, the effect of capacitive Tecar with resistance Tecar on the symptoms of peripheral neuropathy of the lower limbs of type 2 diabetic patients should be compared.

In conclusion, a significant increase was found for neurological outcomes in all three groups after 10 sessions. After three months of follow-up, a significant improvement was found in the Tecar + laser group compared to the Tecar or laser alone groups. Therefore, the use of combined Tecar and laser could lead to a longer-lasting effect in improving the sensory symptoms of type 2 diabetic patients with peripheral neuropathy of the lower limbs.

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