

Comparison of the efficacy of high-intensity laser therapy and low-level laser therapy in carpal tunnel syndrome: A randomized-controlled study

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ABSTRACT

Objectives: This study aims to compare the effects of low-level laser therapy (LLLT) and high-intensity laser therapy (HILT) on clinical presentation of carpal tunnel syndrome (CTS), and electroneuromyography (EMG) and ultrasound findings in patients with CTS.

Patients and methods: Between June 2020 and March 2021, a total of 114 hands of 63 patients (19 males, 44 females; mean age: 44.9±9.3 years; range, 22 to 65 years) with electrophysiologically diagnosed mild-to-moderate CTS were included in this prospective, randomized-controlled study. The patients were categorized into three groups by an independent investigator using a stratified randomization/minimization method according to CTS grade and age as follows: control group (n=20), LLLT group (n=22), and HILT group (n=21). Patients in all three groups wore a neutral wrist splint of appropriate size. All groups underwent clinical, electrophysiologic, and ultrasonographic examinations at baseline, at one and three months after the treatment.

Results: Following the treatment, statistically significant improvements were observed in electrophysiologic, sonographic, and clinical findings of both the laser groups and control groups ($p<0.001$). Comparing the treatment efficacy, the laser groups were found to be more effective in the treatment of CTS than the control group ($p<0.0167$). No statistically significant difference was observed between the LLLT and HILT ($p>0.05$).

Conclusion: The addition of laser treatment significantly increases the effectiveness of treatment. Based on these findings, LLLT and HILT yield comparable results.

Keywords: Carpal tunnel syndrome, electromyography, low-level laser therapy, median neuropathies, nerve compression syndromes, ultrasonography.

Carpal tunnel syndrome (CTS) is the most common entrapment neuropathy caused by compression of the median nerve under the transverse carpal ligament at the wrist level.^[1-3] In the literature, the prevalence of CTS in the general population is reported to be 3 to 5%, with women being affected three times more often than men.^[4] Although the prevalence is high bilaterally, it is higher in the dominant hand and symptoms and signs are often more pronounced in the dominant hand.^[4-6]

Painful numbness in the trace of the median nerve, aggravated by repetitive wrist movements and/or provocation tests on examination and

relieved by shaking the hand, particularly at night, is characteristic of the diagnosis of CTS.^[1-3] Electrophysiologic examination is used in the diagnosis of CTS to localize the lesion, to determine the extent of neuropathy, and for differential diagnosis in patients whose clinical presentation is not typical.^[7] Ultrasonography is useful to exclude possible causes of CTS (e.g., space-occupying lesion, anatomic changes) and to morphologically visualize nerve entrapment.^[8]

In the treatment of CTS, conservative treatment methods such as activity adaptations, splints, and physical therapy are primarily preferred. Surgical treatment is indicated in patients classified as severe

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CTS in electrodiagnostic studies and in patients who are unresponsive to conservative treatment.^[9] In addition to many studies showing symptomatic improvement with laser therapy, which is one of the conservative treatments, *in vitro* studies have demonstrated that laser therapy reduces retrograde degeneration and increases regeneration and proliferation of Schwann cells in neural tissue.^[10-12] Although there are many studies in the literature on low-level laser therapy (LLLT) at CTS, there are very few studies evaluating the efficacy of high-intensity laser therapy (HILT), which was approved by the United States Food and Drug Administration (FDA) in 2002.^[11,13,14] Currently, there is no consensus on the optimal dose and duration of application of laser in the treatment of CTS, mainly since there is a limited number of studies comparing two different methods of application of laser.

In the present study, we aimed to compare the effects of LLLT and HILT on clinical presentation of CTS, and electroneuromyography (EMG) and ultrasound findings in patients with CTS.

PATIENTS AND METHODS

This single-center, prospective, randomized-controlled study was conducted at Ankara Bilkent City Hospital, Department of Physical Medicine and Rehabilitation between June 2020 and March 2021. Prior to study, a written informed consent was obtained from each participant. The study protocol was approved by the Ankara City Hospital Clinical Research Ethics Committee (Date: 04.06.2020, No: E1-20-1087). The study was conducted in accordance with the principles of the Declaration of Helsinki. The study is registered at ClinicalTrials.gov with the number of NCT06219876.

Patients admitted to the hospital's EMG laboratory with a preliminary diagnosis of CTS underwent standard electrophysiologic tests for confirmation. The study included patients aged 18 to 65 years with clinical findings consistent with CTS, such as numbness along the median nerve distribution, symptom exacerbation at night, improvement with hand-shaking, and worsening symptoms during activities like driving or holding a telephone. Additionally, participants with mild CTS, defined by a sensory conduction velocity (SCV) of the second finger-wrist segment below 41.26 m/s and motor distal latency (DL) below 3.60 ms, or moderate CTS, characterized by an SCV below 41.26 m/s and motor DL exceeding 3.60 ms, were included. Exclusion

criteria included patients with local conditions, such as osteophytes, ganglion cysts, lipomas, or muscle and tendon anomalies, as well as systemic conditions such as diabetes mellitus, acromegaly, hypothyroidism, or pregnancy, that could contribute to CTS. Those ineligible for EMG due to the presence of a cardiac pacemaker or active infections in the hand-wrist region were also excluded. Patients with a history of surgical treatment for CTS, those who received an injection for CTS within the past six months, and individuals diagnosed with severe CTS characterized by the absence of sensory conduction (sensory action potential [SAP] and/or a compound muscle action potential [CMAP] below 5 mV) were not included. Furthermore, patients with other nerve injuries, such as polyneuropathy, radiculopathy, ulnar nerve injury, or radial nerve injury, as detected on EMG, were excluded. Those who did not complete the follow-up period were not considered for the study.

A total of 114 hands of 63 patients (19 males, 44 females; mean age: 44.9±9.3 years; range, 22 to 65 years) with electrophysiologically diagnosed mild-to-moderate CTS were included in the study. The patients were categorized into three groups by an independent investigator using a stratified randomization/minimization method according to CTS grade and age as follows: control group (n=20), LLLT group (n=22), and HILT group (n=21). All patients were treated by the same physiotherapist. Patients in all three groups wore wrist splints of an appropriate size in a neutral position for at least 8 h at night for three months. The first group received a wrist splint only, the second group received an additional LLLT, and the third group received an additional HILT. Patients did not take nonsteroidal anti-inflammatory drugs during treatment. The laser device manufactured by Mectronic Medicale (Medtronic Inc., CA, USA) was used for LLLT, while the laser device produced by HIRO TT (ASA S.r.l., Vicenza, Italy) was employed for HILT. Both laser therapies were applied on alternate days, totaling 10 sessions. In accordance with the recommendations of the World Association of Photobiomodulation Therapy (WALT), application was at right angles, parallel to the transverse carpal ligament, at five points along the trace of the median nerve.^[15] The LLLT and HILT are detailed in Table 1. All patients were examined clinically, electrophysiologically, and ultrasonographically at baseline and at one and three months after treatment.

TABLE 1
Low-level and high-intensity laser treatment plan

Laser components	Values
Low intensity laser treatment	
Treatment area	5 spots on transverse carpal ligament and median nerve trace
Probe distance	25 mm to skin
Wavelength	1064 nm
Power	100 mW
Energy intensity	8 J/cm ²
High intensity laser treatment	
Treatment area	5 spots on transverse carpal ligament and median nerve trace
Probe distance	25 mm to skin
Wavelength	1064 nm
Power	3000 W (mode power) 10.5 W (median power)
Energy intensity	1 st Step 139 J/cm ² 2 nd Step 6.3 J/cm ² 3 rd Step 139 J/cm ²

For clinical evaluation, the Boston Symptom Severity Scale (BSSS) and the Boston Functional Capacity Scale (BFCS) were utilized. The BSSS includes 11 items, while the BFCS contains eight items, with each item rated on a scale from 1 to 5. The mean score is determined by adding the points for each item and dividing the total by the number of questions. Higher scores reflect more severe symptoms and reduced functional capacity.^[16]

The electrophysiologic assessment was conducted using the Nihon Kohden Neuropack 2 MEB 7102-K device (Nihon Kohden, Tokyo, Japan). Throughout the procedure, the room temperature was maintained at 25°C, and the extremity temperature was kept above 32°C. In this study, the reference values defined by Oh^[17] were utilized. For the evaluation of motor conduction of the median nerve, a superficial bar electrode was positioned over the abductor pollicis brevis muscle to record responses. Stimulation was applied at the wrist and at the antecubital fossa, 6 cm proximally from the recording electrode. Both CMAP (mV) and distal motor latency (millisec) were documented. Sensory conduction was examined by orthodromic stimulation at the second finger and recording at the wrist with a superficial rod electrode. The conduction velocity of the SAP was recorded.

The ultrasound examination was performed with a Logiq™ 9 (GE Medical Systems Ultrasound & Primary Care Diagnostics, Milwaukee, WI, USA)

by an independent physician who was blinded to the patient's clinic or the study group in which the patient was enrolled. During the ultrasound examination, the patient was in a sitting position, arms next to the body, the elbow in 90° flexion, the forearm in supination, the hands fixed on a pillow, and the fingers in a semi-flexion position. Using the ultrasound machine's available software, the cross-sectional area of the median nerve along with its minor and major axes were calculated. The echogenic line surrounding the nerve was excluded, and a manual tracing was performed along the nerve border around the hyperechoic epineurium. At the proximal carpal tunnel level (distal wrist line), the scaphoid and carpal bones served as landmarks, and measurements of the median nerve's cross-sectional area as well as the major and minor axes were taken. The flattening ratio, obtained by dividing the major axis by the minor axis, was recorded.

Statistical analysis

Study power analysis and sample size calculation were performed using the G*Power version 3.0.10 software (Heinrich Heine University Düsseldorf, Düsseldorf, Germany). Considering an effect size of 0.138 (i.e., η^2 - (partial) eta-squared) according to the repeated measures analysis of variance in terms of the mean change in any of the electrophysiologic or sonographic indicators according to follow-up time, at least 108 hands diagnosed with CTS (with at least 36 hands in each group) were evaluated to

test the statistical significance of the differences between the groups with 80% power and 5% error level. An effect size of 0.138 was selected in accordance with clinical predictions.

Statistical analysis was performed using the SPSS version 25.0 software (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was employed to evaluate the distribution of continuous numerical variables, while Levene's test assessed the homogeneity of variances. Continuous variables were presented in mean $\pm$ standard deviation (SD) or median (25th-75th percentile), while categorical variables were presented in number and frequency. One-way analysis of variance (ANOVA) was used to test for differences between groups concerning means. When parametric test assumptions were not met for continuous variables, the Kruskal-Wallis test was applied. If the Kruskal-Wallis test indicated statistical significance, Dunn-Bonferroni post-hoc tests identified the groups responsible for differences. Categorical data were analyzed using

the Pearson chi-square test or the Fisher-Freeman-Halton test. To evaluate changes in measured values within groups over follow-up periods, the Friedman test was used. Significant Friedman test results were further examined with Dunn-Bonferroni multiple comparison tests to pinpoint the specific follow-up periods causing differences. Additionally, a Bonferroni correction was applied throughout the study to adjust for type 1 errors in multiple comparisons. A *p* value of <0.05 was considered statistically significant.

RESULTS

The study flowchart is shown in Figure 1. The demographic data and clinical characteristics of the patients included in the study were similar (Table 2). The groups were similar in terms of BSSS and BFCSS scores, electrodiagnostic and ultrasonographic measurements before treatment ($p>0.05$) (Table 3).

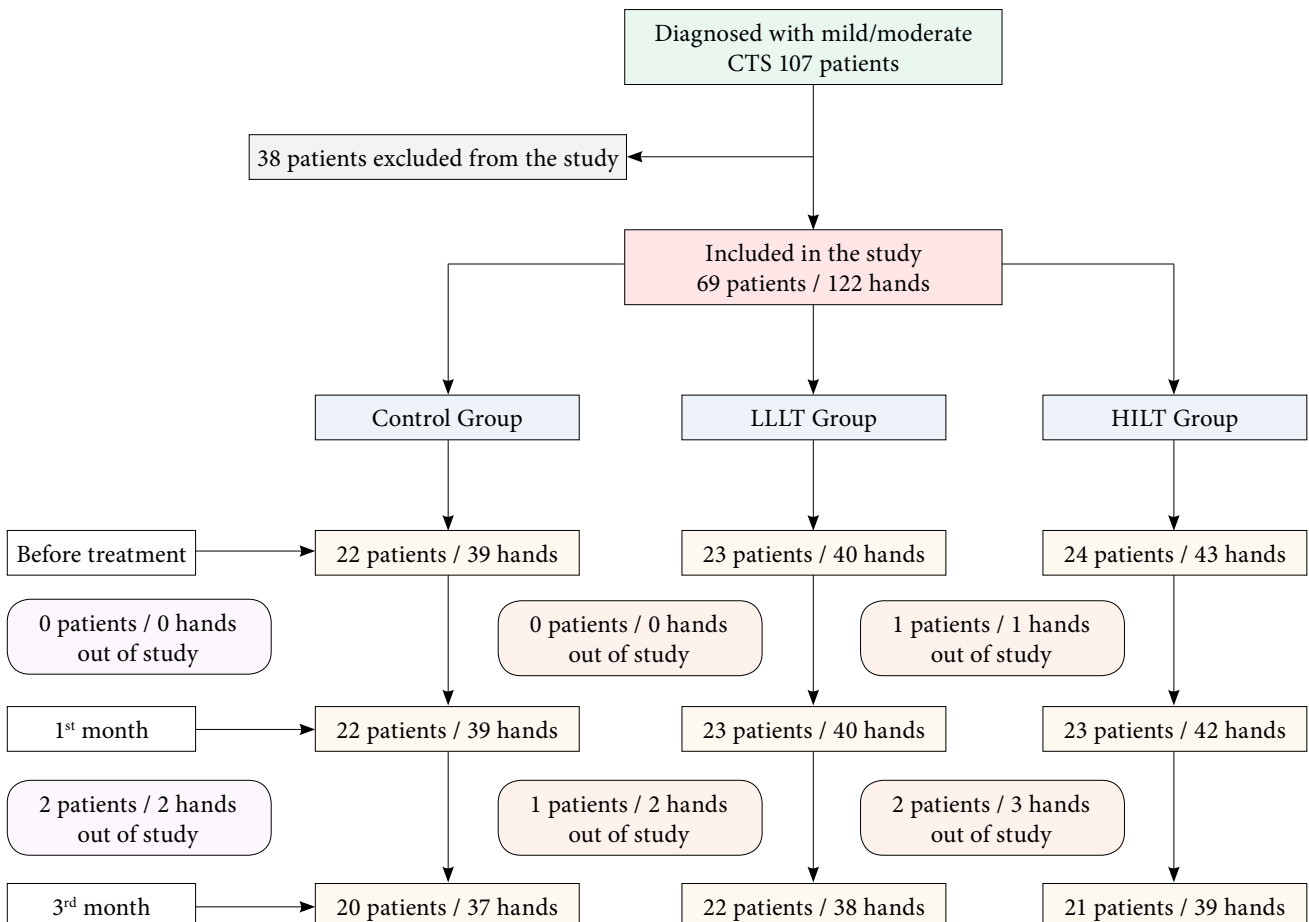


Figure 1. Study flowchart.

CTS: Carpal tunnel syndrome; LLLT: Low-level laser therapy; HILT: High-intensity laser therapy.

In the control group, a significant improvement in BFCS, but not BSSS was observed after one month compared to baseline, while significant changes in BSSS and BFCS were observed in both LLLT and HILT after one month (Table 4). The change in BSSS and BFCS scores at one and three months was statistically significantly higher in the LLLT and HILT groups than in the control group ($p<0.001$); however, there was no statistically significant difference between the two laser modalities ($p=0.194$ and $p>0.999$).

A statistically significant decrease in motor DL was observed in all three groups at one and three months compared to baseline ($p<0.001$). In the LLLT and HILT groups, there was a significant improvement in S speed at both one and three months compared to baseline ($p<0.001$). In the control group, SAP velocity was similar to baseline at one month ($p>0.01$), but as of three months, a significant improvement was noted compared to baseline ($p<0.001$) (Table 4). While the changes in motor DL measurements at one month were statistically similar between groups ($p=0.382$), the decrease in motor DL at three months was statistically significantly higher in the LLLT and HILT groups than in the control group ($p=0.004$

and $p=0.011$, respectively). The improvement in SAP conduction velocity at one month and three months compared to baseline was statistically significantly higher in the LLLT and HILT groups than in the control group ($p<0.001$). However, there was no statistically significant difference between the LLLT and HILT laser modalities in motor DL and SAP conduction velocity ($p>0.05$).

The cross-sectional area of the median nerve and the flattening rate were significantly lower in the LLLT and HILT groups after one and three months compared to baseline ($p<0.001$). In the control group, the flattening rate was significantly lower than before treatment at one and three months ($p<0.001$), while the cross-sectional area of the median nerve was similar to that before treatment at one month ($p>0.01$) and significantly lower than before treatment at three months ($p<0.001$) (Table 4). The improvement in the cross-sectional area of the median nerve was greater in the LLLT and HILT groups than in the control group ($p=0.856$ and $p>0.999$, respectively), but the change was similar between the laser groups. There was no statistically significant difference between the groups in terms of flattening ratio improvement ($p>0.05$).

TABLE 3
Comparisons between groups in terms of clinical measurements before treatment

	Control group		LLLT group		HILT group		<i>p</i> †
	Median	25 th -75 th percentile	Median	25 th -75 th percentile	Median	25 th -75 th percentile	
Clinical assessment							
BSSS	2.9	2.5-3.4	3.2	2.9-3.5	3.1	2.8-3.5	0.114
BFCS	3.0	2.2-3.5	3.0	2.6-3.7	3.2	2.5-3.8	0.353
Electrophysiological evaluation							
Motor distal latency (msec)	3.97	3.54-4.50	4.04	3.74-4.57	4.10	3.87-4.92	0.511
CMAP (mV)	11.8	9.2-15.2	12.2	9.6-15.9	11.2	9.3-16.3	0.946
Motor transmission speed (m/sec)	52.3	51.4-54.0	52.8	51.1-56.1	51.8	50.8-53.4	0.118
Sensory latency (msec)	3.48	3.18-4.12	3.46	3.08-3.96	3.58	3.30-4.11	0.580
Sensory conduction velocity (m/sec)	32.1	28.2-34.2	33.0	31.1-35.8	31.4	28.8-35.8	0.389
Sensory amplitude (μV)	10.6	8.7-12.6	12.0	7.6-14.0	9.9	6.0-15.2	0.616
Ultrasonographic evaluation							
Median nerve cross-sectional area (cm²)	0.13	0.12-0.17	0.14	0.12-0.16	0.15	0.13-0.19	0.044
Minor axis (cm)	0.22	0.19-0.24 ^a	0.24	0.21-0.27	0.24	0.22-0.28 ^a	0.002
Major axis (cm)	0.77	0.71-0.83 ^b	0.72	0.65-0.76 ^b	0.77	0.70-0.82	0.004
Flattening ratio	3.52	3.18-3.85 ^{a,b}	2.96	2.64-3.41 ^b	3.08	2.78-3.47 ^a	<0.001

LLL: Low-level laser therapy; HILT: High-intensity laser therapy; BSSS: Boston symptom severity scale; BFCS: Boston functional capacity scale; CMAP: compound muscle action potential; $\dagger$ Kruskal Wallis test, results were considered statistically significant for $p<0.0167$ according to Bonferroni correction. ^a The difference between control and HILT is statistically significant ($p<0.01$); ^b The difference between control and LLLT is statistically significant ($p<0.01$).

TABLE 4

Boston symptom severity, Boston functional capacity scores, measurements of motor distal latency, sensory conduction velocity, median nerve cross-sectional area and flattening ratio levels according to groups and follow-up times

	Before treatment		1 st Month		3 rd Month		<i>p</i> †
	Median	25 th -75 th percentile	Median	25 th -75 th percentile	Median	25 th -75 th percentile	
BSSS							
Control	2.9	2.5-3.4 ^a	2.8	2.4-3.2	2.5	2.2-3.2 ^a	< 0.001
LLLT	3.2	2.9-3.5 ^{a,b}	2.4	2.0-2.8 ^{b,c}	2.0	1.7-2.5 ^{a,c}	< 0.001
HILT	3.1	2.8-3.5 ^{a,b}	2.3	1.7-2.7 ^b	1.9	1.5-2.5 ^a	< 0.001
BFCS							
Control	3.0	2.2-3.5 ^{a,b}	2.5	2.2-3.4 ^b	2.2	2.0-3.4 ^a	< 0.001
LLLT	3.0	2.6-3.7 ^{a,b}	2.5	2.0-3.0 ^{b,c}	2.0	1.7-2.7 ^{a,c}	< 0.001
HILT	3.2	2.5-3.8 ^{a,b}	2.2	1.6-2.7 ^b	1.9	1.4-2.6 ^a	< 0.001
Motor distal latency (msec)							
Control	3.97	3.54-4.50 ^{a,b}	3.87	3.46-4.42 ^b	3.83	3.41-4.32 ^a	< 0.001
LLLT	4.04	3.74-4.57 ^{a,b}	3.86	3.60-4.12 ^{b,c}	3.69	3.49-3.92 ^{a,c}	< 0.001
HILT	4.10	3.87-4.92 ^{a,b}	3.92	3.55-4.76 ^b	3.70	3.36-4.62 ^a	< 0.001
Sensory conduction velocity (m/sec)							
Control	32.1	28.2-34.2 ^a	32.6	27.5-35.1	33.1	27.6-35.4 ^a	< 0.001
LLLT	33.0	31.1-35.8 ^{a,b}	35.3	32.6-38.6 ^{b,c}	36.6	34.3-40.2 ^{a,c}	< 0.001
HILT	31.4	28.8-35.8 ^{a,b}	35.9	30.8-39.5 ^b	36.3	32.3-40.6 ^a	< 0.001
Median nerve cross-sectional area (cm ²)							
Control	0.13	0.12-0.17 ^a	0.13	0.11-0.15	0.13	0.11-0.14 ^a	< 0.001
LLLT	0.14	0.12-0.16 ^{a,b}	0.12	0.11-0.13 ^b	0.11	0.10-0.12 ^a	< 0.001
HILT	0.15	0.13-0.19 ^{a,b}	0.12	0.11-0.15 ^b	0.12	0.10-0.14 ^a	< 0.001
Flattening rate							
Control	3.52	3.18-3.85 ^{a,b}	3.40	3.04-3.66 ^b	3.28	3.08-3.58 ^a	< 0.001
LLLT	2.96	2.64-3.41 ^{a,b}	2.67	2.43-3.12 ^b	2.70	2.32-3.00 ^a	< 0.001
HILT	3.08	2.78-3.47 ^{a,b}	2.88	2.45-3.13 ^b	2.80	2.55-3.08 ^a	< 0.001

BSSS: Boston symptom severity scale; LLLT: Low-level laser therapy; HILT: High-intensity laser therapy; BFCS: Boston functional capacity scale; † Friedman test, results were considered statistically significant for $p < 0.0167$ according to Bonferroni correction. ^a The difference between pre-treatment and 3rd month is statistically significant ($p < 0.001$); ^b The difference between pre-treatment and 1st month was statistically significant ($p < 0.0167$); ^c The difference between 1st month and 3rd month is statistically significant ($p < 0.01$).

The comparisons of the changes in BSSS, BFCS scores, motor DL measurements, SCV, median nerve cross-sectional area, and flattening ratio measurements over time are presented in Table 5.

DISCUSSION

In the present study, we compared the effects of LLLT and HILT on clinical presentation of CTS, and EMG and ultrasound findings in patients with CTS. According to the results, electrophysiologic, sonographic, and clinical improvements were observed in both the laser groups and the control group, and the laser groups were found to be more

effective in treating CTS than the control group. No significant difference in efficacy was observed between LLLT and HILT.

In the study by Hojjati et al.^[18] comparing the efficacy of LLLT and HILT at CTS, a decrease in BSSS and BFCS scores and an increase in grip strength were noted in all groups. The laser groups were found to be more effective than the control group, although no significant difference was found between LLLT and HILT. These results are similar to those of our study, but in the study by Ezzati et al.,^[19] the patients were divided into five groups and LLLT (8J/cm² and 20J/cm²) and HILT (8J/cm² and 20J/cm²)

TABLE 5
Comparisons among the groups in terms of the changes in Boston symptom severity, Boston functional capacity scores, measurements of motor distal latency, sensory conduction velocity, median nerve cross-sectional area and flattening ratio measurements over time

	Control group		LLLT group		HILT group		<i>p</i> †
	Median	25 th -75 th percentile	Median	25 th -75 th percentile	Median	25 th -75 th percentile	
BSSS							
1 st Month-Baseline	-0.2	-0.3 to -0.1 ^{a,b}	-0.6	-0.9 to -0.4 ^a	-1.1	-1.3 to -0.5 ^b	<0.001
3 rd Month-Baseline	-0.4	-0.5 to -0.1 ^{a,b}	-1.0	-1.2 to -0.7 ^a	-1.2	-1.5 to -0.7 ^b	<0.001
3 rd Month-1 st Month	-0.2	-0.3 to 0.0 ^a	-0.4	-0.5 to -0.02 ^a	-0.2	-0.4 to -0.1	0.002
BFCS							
1 st Month-Baseline	-0.2	-0.5 to -0.1 ^{a,b}	-0.6	-1.0 to -0.5 ^a	-0.7	-1.0 to -0.5 ^b	<0.001
3 rd Month-Baseline	-0.4	-0.7 to -0.1 ^{a,b}	-1.0	-1.2 to -0.7 ^a	-1.1	-1.5 to -0.8 ^b	<0.001
3 rd Month-1 st Month	-0.1	-0.4 to 0.1 ^{a,b}	-0.2	-0.5 to -0.2 ^a	-0.4	-0.6 to -0.1 ^b	0.004
Motor distal latency (m/sec)							
1 st Month-Baseline	-0.10	-0.15 to -0.08	-0.12	-0.22 to -0.06	-0.19	-0.34 to -0.02	0.382
3 rd Month-Baseline	-0.17	-0.24 to -0.10 ^{a,b}	-0.26	-0.52 to -0.18 ^a	-0.34	-0.52 to -0.10 ^b	0.002
3 rd Month-1 st Month	-0.05	-0.11 to 0.01 ^a	-0.12	-0.20 to -0.06 ^a	-0.10	-0.26 to -0.01	0.002
Sensory conduction velocity (m/sec)							
1 st Month-Baseline	0.6	0.2 to 1.1 ^{a,b}	2.1	1.0 to 3.4 ^a	2.1	1.4 to 4.0 ^b	<0.001
3 rd Month-Baseline	1.1	0.6 to 1.7 ^{a,b}	3.5	2.5 to 5.8 ^a	3.5	1.9 to 5.2 ^b	<0.001
3 rd Month-1 st Month	0.4	0.1 to 0.9 ^a	1.5	0.7 to 2.5 ^a	1.0	0.0 to 2.1	<0.001
Median nerve cross-sectional area (cm ²)							
1 st Month-Baseline	-0.01	-0.02 to 0.00 ^{a,b}	-0.02	-0.03 to -0.01 ^a	-0.02	-0.03 to -0.02 ^b	<0.001
3 rd Month-Baseline	-0.01	-0.03 to 0.00 ^{a,b}	-0.03	-0.04 to -0.01 ^a	-0.03	-0.05 to -0.02 ^b	<0.001
3 rd Month-1 st Month	0.00	-0.01 to 0.00	-0.01	-0.01 to 0.00	-0.01	-0.01 to 0.00	0.166
Flattening rate							
1 st Month-Baseline	-0.20	-0.33 to -0.04	-0.28	-0.38 to -0.02	-0.24	-0.42 to -0.08	0.464
3 rd Month-Baseline	-0.28	-0.49 to -0.08	-0.33	-0.54 to -0.20	-0.24	-0.54 to -0.01	0.378
3 rd Month-1 st Month	-0.07	-0.28 to 0.09	-0.07	-0.23 to 0.02	0.00	-0.12 to 0.20	0.077
LLLT: Low-level laser therapy; HILT: High-intensity laser therapy; BSSS: Boston symptom severity scale; BFCS: Boston functional capacity scale; † Kruskal Wallis test, results were considered statistically significant for p<0.0167 according to Bonferroni correction; ^a The difference between control and LLLT is statistically significant (p<0.0167); ^b The difference between control and HILT is statistically significant (p<0.0167).							

were applied at two different power densities. In this study, the Visual Analog Scale (VAS) was used, and as a result of the study, the decrease in VAS values was more significant in the group in which HILT was applied with low power intensity (8J/cm²) compared to the other groups. However, the VAS scale in this study was a more subjective assessment; therefore, the Boston Carpal Tunnel Questionnaire was used in our study.

In the study conducted by Yağcı et al.^[20] to evaluate the effectiveness of LLLT, a decrease in both BSSS and BFCS was observed in the LLLT

group, whereas a decrease in BSSS but no significant change in BFCS was observed in the splint control group. Similarly, in the study by Akar et al.,^[21] a decrease in symptom severity was observed and no significant change in functional capacity score was detected in the control group, whereas a significant improvement in both scores was observed in the LLLT group. In the study by Chang et al.^[13] comparing LLLT with sham laser, the VAS score was used for symptom assessment. A decrease in the VAS score was observed in both groups and the change was found to be more significant in the laser group. The LLLT was also not found to be superior

to sham laser therapy in some studies using VAS for pain assessment.^[22-24] Casale et al.^[14] compared the efficacy of LLLT with transcutaneous electrical nerve stimulation (TENS) in a pilot study, finding that the decrease in VAS scores after treatment was significant in the LLLT group compared with the TENS group. In our study, we used BSSS and BFCSS to assess symptoms and functional status. While no significant change was observed in the BSSS in the early phase in the splint-only group, an improvement was observed in the laser groups in the early phase, and improvement in the functional severity scale and BSSS scores was observed in all three groups at three months in the follow-up phase. The improvement in the laser groups was statistically more evident than in the control group. No significant difference was found between LLLT and HILT. Our results in which improvement in the BSSS score was also noted in the control group are partially consistent with the literature.

There are studies in the literature demonstrating the efficacy of laser treatment on electrophysiologic parameters in patients with CTS. Different results were obtained in the studies. In a study conducted with LLLT, Tascioglu et al.^[24] observed an increase in SCV of the median nerve after treatment. Evcik et al.^[22] reported an increase in SCV of the median nerve and a decrease in distal motor and sensory latency in controls at 12 weeks. In the study by Fusakul et al.,^[23] an increase in sensory nerve conduction velocity and a decrease in distal motor and sensory latency were also observed at follow-up. In the study by Chang et al.,^[13] assessments were performed before treatment, at the end of treatment, and two weeks after the end of treatment. Electrophysiologic changes were found to be insignificant. Hojjati et al.^[18] compared the efficacy of LLLT and HILT; no significant change was found in the electrophysiologic assessments. Also, in a study by Ezzati et al.^[19] comparing the efficacy of LLLT and HILT, the reduction in distal motor latency and improvement in motor amplitude were found to be more significant in the HILT group than in the other groups. In our study, the change in SCV in the early follow-up period was observed only in the laser groups, whereas in the long-term follow-up period, electrophysiologic improvement was observed in all groups, including the control group. The electrophysiologic changes were significantly higher in the laser groups than in the control groups. There was no significant difference in efficacy between LLLT and HILT.

In a study by Tascioglu et al.^[24] to evaluate the efficacy of LLLT, the patients were divided into three groups, with one group receiving a sham laser and the other two groups receiving LLLT with different energy densities (1.2 J/cm² and 0.6 J/cm²). In this study, the cross-sectional area of the median nerve was measured at the level of the proximal carpal tunnel for sonographic assessment. The authors found no statistically significant change in the cross-sectional area of the median nerve in all three groups. In another study by Tezcan et al.^[25] to evaluate the efficacy of LLLT (0.8 J/cm²) in CTS using ultrasound, no significant change in the cross-sectional area of the median nerve at the level of the proximal carpal tunnel was noted after treatment in the control group that received splint treatment alone, whereas a decrease was noted in the group that received laser treatment.^[25] In the small number of available studies evaluating the efficacy of HILT in CTS, ultrasonographic evaluation is inadequate. In the studies conducted with LLLT, the number of studies that include long-term follow-up is low, and different results were obtained in the studies on the effect of LLLT on the cross-sectional area of the median nerve. In our study, no significant change in the cross-sectional area of the median nerve was observed in the control group treated with splinting in the initial phase, whereas a change was observed in both laser modalities in the initial phase. In the long term, the cross-sectional area of the median nerve decreased in all patient groups. This change was greater in the laser groups, whereas no significant difference was observed between the two laser modalities. The main reason for this difference in the results of laser treatment on CTS could be the differences in the choice of dose, application method, duration, and number of sessions in the studies. In some studies, the entire transverse carpal ligament was treated, while in others, only specific points along the course of the median nerve were treated. Another factor that may alter the results is that the intensity of laser energy is chosen differently in the studies and there is no standardization. In a review by Bekhet et al.^[26] which included eight studies and evaluated the efficacy of LLLT at CTS, the energy density applied to each point varied from 2.7 to 11 J, and the total energy applied throughout the treatment varied from 81 to 300 J. A review by Cheung et al.^[27] evaluated six studies. In this review, the applied energy density varied from 0.072 to 7 J. The total applied energy ranged from 2.16 to 300 J.

in the studies. The duration of application, total number of sessions, and laser wavelength vary in the studies of the aforementioned reviews.^[26,27] These parameters also vary in a limited number of studies performed with HILT in CTS. To illustrate, the energy density applied to a single point was 20J in the study by Hojjati et al.^[18] and 250J in the study by Casale et al.^[14] Based on these results, we can speculate that all of these differences in application may result in different treatment outcomes.

The main limitation TO this study is that there is no consensus in the literature on the application method, dose, and duration of laser treatment. In addition, due to the novel coronavirus disease 2019 (COVID-19) pandemic, many fewer patients were enrolled during the patient enrollment than we were able to reach. This represents another limitation of our study. Furthermore, the absence of a sham laser group and the lack of blinding are significant weaknesses of the study, as these limitations may have influenced the objectivity and reliability of the results.

In conclusion, our study results suggest that the addition of laser to splint therapy in the treatment of patients with mild and moderate CTS contributes both symptomatically and functionally, and the improvement in electrophysiologic and ultrasonographic findings is more prominent. However, there is no significant difference between LLLT and HILT in terms of treatment efficacy. We believe that our study is valuable in that it demonstrates the efficacy of using laser in the treatment of CTS. However, further multi-center, large-scale, prospective, randomized-controlled studies with longer-term follow-up are warranted to tailor the optimal treatment for the use of laser therapy in CTS.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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