



ORIGINAL ARTICLE

Effect of low-level laser therapy on nerve regeneration in median nerve-injured rats

Dhanusia Suresh^{1*}  , Prathap Sunganthirababu¹ , Manoj M¹ , Monishaa B¹ ,
Suriya N¹ , Priyadharshini Kumar¹ , Vanitha Jayaraj¹ , and Kezia Jenny VM² 

¹Department of Neurosciences, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

*** Correspondence Author:**

 dhanusiasuresh1798@gmail.com

Cite this article as: Dhanusia S, Sunganthirababu P, Manoj M, et al. Effect of low-level laser therapy on nerve regeneration in median nerve-injured rats. Univ Med 2026;45:345-354

Date of first submission, April 23, 2026

Date of final revised submission, September 15, 2026

Date of acceptance, October 13, 2026

ABSTRACT

BACKGROUND

Median nerve injury can result in persistent sensory and motor deficits despite surgical repair. Low-level laser therapy (LLLT) promotes neuroregeneration through photobiomodulation; however, evidence in median nerve injury models remains limited. This study evaluated the effect of LLLT on functional and molecular recovery following median nerve injury in Wistar rats.

METHODS

A randomized controlled study was conducted using twelve Wistar rats assigned to control (n=6) and LLLT (n=6) groups. A standardized median nerve crush injury was induced under anaesthesia. LLLT was initiated on day 1 post-injury and administered six days per week for three weeks, while the control group recovered without treatment. Functional recovery was assessed using grooming, rotarod, von Frey, and hot plate tests. Gene expression was analyzed using RT-PCR. Independent T-test and Two-way repeated-measures ANOVA was applied for rotarod, von Frey and hot plate outcomes, while grooming scores were analyzed using Mann-Whitney U tests.

RESULTS

Between-group comparisons of grooming scores using the Mann-Whitney U test showed no statistically significant differences after Bonferroni correction. Independent-samples t-tests demonstrated significantly greater improvement in the low-level laser therapy group than the control group at Day 14 and post-intervention for the von Frey, rotarod, and hot plate tests ($p < 0.05$). Two-way repeated-measures ANOVA demonstrated significant time, treatment, and time $\times$ treatment interaction effects for all three outcome measures ($p < 0.05$).

CONCLUSION

Low-level laser therapy enhanced functional and molecular recovery after median nerve injury, supporting its potential as a non-invasive adjunct for peripheral nerve regeneration.

Keywords: Peripheral nerve injury, median nerve regeneration, low-level laser therapy; functional recovery, good health and well-being

INTRODUCTION

Peripheral nerve injury (PNI) represents a significant clinical problem that can lead to long-term sensory and motor impairments, ultimately affecting functional independence and quality of life. These injuries commonly arise from trauma, compression, ischemia, or iatrogenic causes, demonstrating their complex and multifactorial etiology.^(1,2) Based on the extent of axonal and connective tissue damage, PNIs are traditionally classified as neurapraxia, axonotmesis and neurotmesis, each associated with different degrees of functional recovery and prognosis. The pathological consequences of such injuries may include conduction block, muscle atrophy, neuropathic pain and persistent disability due to incomplete neural regeneration.^(3,4) Epidemiological studies indicate that peripheral nerve injuries frequently involve the upper limb, particularly the median, ulnar and radial nerves accounting for approximately 1–3% of all traumatic injuries.^(5,6) Among these, the median nerve plays a critical role in upper limb function by innervating the forearm flexor muscles and the thenar muscle group responsible for thumb opposition and fine motor control.⁽⁷⁾ Damage to this nerve often leads to reduced grip strength, impaired thumb opposition and sensory loss over the lateral three-and-a-half digits, significantly compromising hand function and daily activities.⁽⁸⁾ Although various surgical techniques such as neurorrhaphy, nerve grafting and nerve conduits have been developed to restore nerve continuity, complete functional recovery remains difficult to achieve.⁽²⁾ Peripheral nerve injuries remain a major therapeutic challenge because successful regeneration requires coordinated axonal regrowth, Schwann cell support and restoration of functional neural pathways.⁽⁹⁾ Therefore, there is increasing interest in adjunctive therapeutic strategies aimed at enhancing nerve regeneration and improving functional outcomes.⁽¹⁰⁾

Approaches such as electrical stimulation, growth factor delivery, magnetic stimulation and cell-based therapies have been explored; however, their clinical application may be limited by cost, technical complexity and availability.^(11,12) Experimental animal models serve a crucial part in advancing the understanding of peripheral nerve regeneration and evaluating novel therapeutic interventions before clinical translation. In particular, the rat median nerve injury model provides a reliable platform for studying functional

and molecular mechanisms of nerve repair, as it closely mimics human upper-limb neuropathies while minimizing complications such as autotomy.⁽¹³⁾ The use of controlled animal models enables standardized injury induction and systematic evaluation of sensory, motor and molecular outcomes during the regeneration process.⁽¹⁴⁾ Previous experimental studies have demonstrated the beneficial effects of low-level laser therapy (LLLT) in promoting peripheral nerve regeneration following crush injuries. Wang et al.⁽¹⁵⁾ reported that 808-nm LLLT at energy densities of 3 J/cm² and 8 J/cm² significantly enhanced sciatic nerve regeneration by improving functional recovery, axonal regeneration and remyelination, and by increasing the expression of growth-associated protein-43 (GAP-43) in a rat sciatic nerve crush model. Similar findings have been reported in recent systematic reviews. Alharbi et al.⁽¹⁶⁾ concluded that low-level laser therapy enhances neurosensory recovery following peripheral nerve injuries by promoting nerve regeneration, improving sensory function, and facilitating functional recovery, although they emphasized the need for larger, well-designed clinical trials to establish standardized treatment protocols. Similarly, Rosso et al.⁽¹⁷⁾ systematically reviewed experimental studies conducted predominantly in rat models of peripheral nerve injury, including crush and transection injuries, and reported that low-level laser therapy using wavelengths ranging from 632.8 to 904 nm significantly enhanced peripheral nerve regeneration by accelerating axonal growth, increasing the expression of regeneration-associated proteins such as GAP-43, reducing inflammatory cytokines, promoting remyelination, and improving histological, electrophysiological, and functional outcomes. These findings support low-level laser therapy as a promising adjunctive intervention for peripheral nerve repair. Collectively, these studies consistently support the neuroprotective and regenerative potential of LLLT; however, the available evidence has largely been confined to sciatic nerve injury models, with relatively few investigations involving the median nerve despite its greater clinical relevance to upper-limb function. Specifically, previous studies have also demonstrated that LLLT improves functional recovery, enhances nerve conduction, and promotes histological regeneration following peripheral nerve injury. However, these investigations predominantly evaluated isolated functional, histological, or electrophysiological

outcomes, with limited integration of behavioural recovery and molecular mechanisms within the same experimental model.^(18,19) Consequently, the therapeutic effects of LLLT on median nerve regeneration remain insufficiently characterized, limiting the translational applicability of existing evidence. To address this gap, the present study employed a standardized Wistar rat median nerve crush injury model to comprehensively evaluate the effects of LLLT by integrating assessments of motor function (grooming and rotarod tests), sensory recovery (von Frey and hot plate tests) and molecular regeneration through RT-PCR analysis of neuro regeneration related genes. By simultaneously examining behavioural and molecular outcomes in a clinically relevant median nerve model, this study provides a more comprehensive evaluation of LLLT-induced peripheral nerve regeneration and strengthens the evidence supporting its potential as a non-invasive adjunctive therapy for upper-limb peripheral nerve injuries.

METHODS

Research design

An *in vivo* randomized controlled experimental study was performed from October to December 2025 at the Clinical Laboratory Animal Research (CLAR) Facility, Saveetha Medical College, Chennai, utilizing adult Wistar rats to assess the impact of low-level laser therapy on motor, sensory and molecular recovery after median nerve crush injury.

Experimental animals

Twelve healthy 10-week-old male Wistar rats weighing between 250–350 g were included in the study. The sample size was determined based on previous published experimental studies evaluating peripheral nerve regeneration in rat models, in which six animals per group were commonly used to detect treatment-related differences while adhering to the principles of reduction recommended by the ARRIVE 2.0 guidelines and the replacement, reduction and refinement (3Rs). Therefore, twelve rats ($n=6$ per group) were included in the present study.^(20,21) Only animals with normal baseline sensorimotor functions were included. Rats exhibiting aggressive behavior, difficulty in handling, or any signs of illness or injury were excluded. The animals were randomly assigned into two equal groups ($n=6$ per group): a control group and an

experimental group. The control group underwent median nerve crush injury without any intervention, whereas the experimental group underwent median nerve crush injury followed by LLLT. Animals were housed in polypropylene cages, with two rats per cage, under standardized laboratory environment maintained at a temperature of 22 ± 2 °C, relative humidity of $55 \pm 5\%$ and a 12-hour light–dark cycle. Standard rat chow and water were provided *ad libitum*.⁽²²⁾

Quarantine and pre-operative preparation

All animals underwent a 7-day acclimatization period prior to surgery. During this period, animals were observed to ensure good health and normal behaviour.

Surgical induction of median nerve injury

Following the quarantine period, surgical induction of median nerve injury was performed. Anaesthesia was administered by intraperitoneal injection of ketamine (60 mg/kg bw) and xylazine (10 mg/kg bw). After disinfection of the right forelimb with antiseptic solution a thin longitudinal incision extending from the axilla to the elbow was made to expose the median nerve at the mid-brachial level between the biceps and triceps muscles. The muscles were dissected using fine surgical scissors and forceps. Under a surgical microscope, the nerve was carefully isolated from the surrounding tissues. A standardized crush injury was then produced using an arterial forceps applied at one ratchet click pressure for 30 seconds, creating an axonotmesis-type lesion while preserving the epineurium. The injury site was marked using a 3-0 nylon suture, irrigated with sterile saline and the incision was closed using sterile staples. Care was taken to ensure a sterile environment during all surgical interventions.

Post-operative care

After surgery, the animals were observed daily for wound healing, signs of infection, pain and autotomy. Analgesia was provided using meloxicam (3 mg/kg, subcutaneous). The animals were observed until full recovery from anaesthesia before being returned to their cages.

Low-level laser therapy intervention

Low-level laser therapy was initiated on the postoperative day 1 in the experimental group. The laser probe was positioned perpendicular to the marked injury site to ensure uniform irradiation. The treatment parameters included a wavelength of

808 nm, power output of 200 mW and an energy density of 3 J/cm², with each session lasting 15 seconds.⁽²³⁾ The animals were gently restrained during treatment, and therapy was administered six days per week for three consecutive weeks. The control group did not receive laser treatment and was allowed to undergo natural recovery without intervention.

Outcome measures

Functional recovery assessments were performed on postoperative days 1, 14 and 21. Molecular analyses were conducted on day 21 by investigators blinded to the group allocation and intervention. On day 21, at the commencement of the experimental period, the animals were humanely euthanized using carbon dioxide (CO₂) inhalation in accordance with Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA) guidelines.⁽²⁴⁾

von Frey monofilament test

Mechanical sensory function and recovery from allodynia were evaluated using the von Frey monofilament test. Rats were placed on an elevated mesh platform inside a transparent chamber to allow acclimatization and limit excessive movement. A monofilament with a bending force ranging from 25 g to 80 g was applied perpendicularly to the radial palmar region of the affected forepaw corresponding to the median nerve distribution until filament bending occurred. Each stimulus was applied three times with short intervals to avoid behavioural sensitization. Withdrawal latency, including paw withdrawal, licking of the paw, or brisk hand withdrawal, were observed and recorded to assess sensory integrity.⁽²⁵⁾

Rotarod test

Motor coordination and forelimb function were evaluated using the rotarod test. Animals were placed on an accelerating rotarod apparatus

programmed to increase speed from 4 to 40 rpm with a cut-off time of 180 seconds. Latency to fall from the rotating rod was recorded as an indicator of motor performance. Each rat completed three trials with 60-second rest intervals and the mean latency value was used for analysis.⁽²⁶⁾

Grooming test

Spontaneous forelimb use and sensorimotor integration were evaluated using the grooming test, as described by Teixeira RK et al.⁽²⁷⁾ Each rat was placed individually in a transparent observation chamber and allowed to groom freely for a duration of 3 minutes. The grooming activity was assessed using a five-point ordinal scale, where a score of 0 indicated absence of grooming and a score of 5 represented complete, symmetrical grooming involving both forelimbs.

Hot plate test

Thermal nociceptive response was assessed using the hot plate test maintained at 52 ± 55 °C with a cut-off time of 20 seconds to prevent tissue damage. Each rat model was placed on the heated surface and reactions to the thermal stimulus were carefully observed. Nociceptive responses such as paw withdrawal, paw licking and jumping were noted as indicators of thermal pain perception. Each animal performed two trials separated by a 2-minute rest period and the mean withdrawal latency was recorded for analysis.⁽²⁸⁾

Molecular analysis

As the Table 1 shows, gene expression levels of Brain-Derived Neurotrophic Factor (BDNF), Glial Cell-Derived Neurotrophic Factor (GDNF), Growth-Associated Protein-43 (GAP-43) and Insulin-Like Growth Factor-1 (IGF-1) were analyzed using real-time polymerase chain reaction (RT-PCR). Total RNA was extracted from tissue samples using TRIzol reagent and RNA purity and concentration were measured with a NanoDrop spectrophotometer.

Table 1. Primer sequences used for Rt-PCR

Gene	Forward Primer (5'–3')	Reverse Primer (5'–3')	Annealing Temperature (°C)
BDNF	GGCTGACACTTTTGAGCACGTC	CTCCAAAGGCACTTGACTGCTG	60
GDNF	CCTTCGCGCTGACCAGTGACT	GCCGCTTGTTTATCTGGTGACC	60
GAP43	TGTGCCTGCTGCTGTCACTGAT	AGGTTTGGCTTCGTCTACAGCG	60
IGF1	GTGGATGCTCTTCAGTTCGTGTG	TCCAGTCTCCTCAGATCACAGC	60
GAPDH	GAAGGTCGGTGTGAACGGAT	CCCATTGTGATGTTAGCGGGAT	58

Table 2. Grooming levels of median nerve crush injury in Wistar rats following low-level laser therapy

Grooming levels	Treatment groups		p value
	Control (n=6)	LLLT (n=6)	
Day 1	6.00	7.00	0.575
Day 14	4.50	8.50	0.019
Day 21	5.00	8.00	0.056

*Data are presented as mean ranks. LLLT: low-level laser therapy. Between-group comparisons at Day 1, Day 14, and Day 21 were analysed using the Mann–Whitney U test

Approximately 2 µg of RNA was reverse transcribed to complementary DNA using a first-strand cDNA synthesis kit. Amplification of target genes was carried out with gene-specific primers using SYBR Green–based qPCR master mix in a real-time PCR system. Relative gene expression levels were calculated using the comparative CT method, and fold changes were determined by the $2^{-\Delta\Delta CT}$.⁽²⁹⁾

Statistical analysis

Statistical analyses were carried out using IBM SPSS Statistics software. Parametric or non-parametric tests were selected according to the data distribution. The normality of continuous variables, such as von Frey, rotarod and hot plate test scores, was evaluated using the Shapiro–Wilk test and Q–Q plot inspection. Variables that did not meet normality assumptions or were ordinal, including grooming scores, were analyzed with non-parametric methods. Grooming scores, which were ordinal in nature, were compared between groups at each assessment time point using the Mann–Whitney U test. Between-group comparisons of parametric outcome measures (von Frey, rotarod, and hot plate test scores) at each assessment time point were performed using the independent-samples t-test. Two-way repeated-measures ANOVA was employed to analyse parametric outcome measures such as von Frey, rotarod, and hot plate test results, considering time as the within-subject factor and treatment group as the between-subject factor. Mauchly's test was used to evaluate the assumption of sphericity, and the Greenhouse–Geisser correction was utilized as necessary. Statistical significance was established at $p < 0.05$.

Ethical approval

Ethical clearance for the study was obtained from the Institutional Animal Ethics Committee (IAEC), Saveetha Medical College, Saveetha Institute of Medical and Technical Sciences (SIMATS) (Ref No: 1183/PO/Re/S/08/CPCSEA;

Proposal No: SU/CLAR/RD/37/2025; dated 30 OCTOBER 2025). All experimental procedures were conducted in accordance with CPCSEA guidelines for the care and use of laboratory animals.

RESULTS

Grooming test

Between-group comparisons of grooming scores at Day 1, Day 14, and Day 21 were performed using the Mann–Whitney U test. No significant difference was observed between the groups at Day 1 ($p=0.575$), but a significant comparison at the Day 14 ($p=0.019$). Likewise, no significant between-group difference was observed at Day 21 ($p=0.056$) (Table 2).

Von Frey, rotarod and hot plate test

Changes in sensory and motor performance were assessed using the von Frey, rotarod, and hot plate tests at Day 1, Day 14, and Day 21. Between-group comparisons at each assessment time point were performed using the independent-samples t-test (Table 3). No significant differences were observed between the groups at Day 1 for any of the three outcome measures. However, the LLLT group demonstrated significantly greater improvement than the control group at Day 14 and Day 21 in the von Frey, rotarod, and hot plate tests (Table 3).

Two-way repeated-measures ANOVA (Table 4) demonstrated significant effects of time for the von Frey ($p=0.039$), rotarod ($p=0.005$), and hot plate ($p<0.001$) tests. Furthermore, significant time $\times$ treatment interactions were identified across all three test measures, indicating that the pattern of recovery differed significantly between the treatment groups over time. Since the assumption of sphericity was violated for the rotarod data, the Greenhouse–Geisser correction was applied. Overall, these findings indicate that low-level laser therapy promoted superior sensory and motor recovery compared with spontaneous regeneration.

Table 3. von Frey, Rotarod and Hot plate levels of median nerve crush injury in Wistar rats following low-level laser therapy

Test	Timepoints	Control (n=6)	LLLT (n=6)	p value
von Frey	Day 1	2.806±0.539	2.728±0.212	0.748
	Day 14	2.408±0.726	1.640±0.397	0.046
	Day 21	1.888±1.000	0.511±0.123	0.007
Rotarod	Day 1	0.506±0.111	0.508±0.100	0.979
	Day 14	0.810±0.115	1.721±0.199	<0.001
	Day 21	1.768±0.383	4.453±2.361	0.020
Hot plate	Day 1	5.603±0.301	5.608±0.344	0.979
	Day 14	4.478±0.337	3.040±0.602	<0.001
	Day 21	3.738±0.311	1.955±0.467	<0.001

* Data presented as mean ± SD; LLLT: low-level laser therapy. p values were obtained from independent t test. Statistical significance was set at p<0.05.

Molecular analysis

Gene expression analysis demonstrated that low-level laser therapy (LLLT) enhanced molecular activity related to nerve regeneration when compared with the control group. While the control group maintained a baseline fold change of 1.0 across all genes, the LLLT group showed increased expression of key regenerative markers. Brain-derived neurotrophic factor (BDNF) was elevated by approximately 3.85-fold, suggesting improved neuronal survival and support. Glial cell line-derived neurotrophic factor (GDNF) exhibited the greatest increase of around 4.72-fold, indicating enhanced Schwann cell activity and axonal regeneration. Growth-associated protein-43 (GAP-43) increased by nearly 3.68-fold, reflecting active axonal growth. Insulin-like growth factor-1 (IGF-1) also rose approximately 3.18-fold, suggesting improved cellular repair and neuroprotection. Collectively, these findings

indicate that LLLT promotes molecular pathways involved in peripheral nerve recovery.

DISCUSSION

The present study demonstrated that LLLT significantly enhanced functional, sensory and molecular recovery following median nerve crush injury compared to spontaneous regeneration. The significant time × group interactions observed in von Frey, rotarod and hot plate assessments indicate that LLLT accelerates peripheral nerve repair beyond natural recovery processes. These findings are aligned with prior experimental investigations evaluating LLLT in peripheral nerve injury models. Sensory recovery assessed using both mechanical (von Frey) and thermal (hot plate) measures showed greater improvement in the experimental group across day 1, day 14 and day 21.

Table 4. Treatment-by-time interaction details for von Frey, rotarod and hotplate

Test	Treatment by time interaction	
	F value (df)	p value
von Frey		
	Time	103.226 (2,20)
	Treatment	5.641 (1,10)
	Time*Treatment	17.712 (2,20)
Rotarod		
	Time	22.730 (1.019,10.187)
	Treatment	12.875(1, 10)
	Time*Treatment	5.903(1.019, 10.187)
Hotplate		
	Time	302.969(2,20)
	Treatment	30.027(1,10)
	Time*Treatment	34.501(2,20)

*F values are presented with the corresponding degrees of freedom (df). p values were obtained from two-way repeated-measures analysis of variance (ANOVA). Statistical significance was set at p<0.05

This aligns with the findings of Chacur et al.,⁽³⁰⁾ who reported that LLLT alleviated neuropathic pain and promoted functional recovery in rats with chronic constriction injury, possibly mediated through modulation of hypoxia-inducible factor-1 α (HIF-1 α) and reduction of inflammatory processes. Similarly, Uta et al.⁽³¹⁾ demonstrated accelerated peripheral nerve regeneration across a large sciatic nerve gap following low-level laser application, suggesting improved axonal growth and sensory restoration. The present findings of improved sensory responses are consistent with these observations. Motor performance assessed using the rotarod test revealed significantly greater improvement in the experimental group, with a strong group effect. These findings are comparable to those of Andreo et al.,⁽³²⁾ who reported enhanced motor recovery after end-to-side neurorrhaphy in a rat median nerve model following laser biostimulation. In addition, Bayburt et al.⁽³³⁾ observed significant improvements in sciatic nerve regeneration and motor performance after LLLT, attributing these benefits to increased axonal density and remyelination. The present findings align with these reports, suggesting that LLLT facilitates structural and functional restoration of the injured nerve.

Although grooming behaviour improved over time in both groups, no significant differences were observed between groups. This indicates that spontaneous regeneration contributes to gross functional recovery following axotomy, while more sensitive outcome measures such as von Frey, rotarod and hot plate tests are required to detect treatment-specific effects. Forootan et al.⁽³⁴⁾ stated that certain functional parameters may require longer durations to demonstrate significant differences, which may explain the lack of between-group differences in grooming scores. Thermal nociceptive recovery assessed using the hot plate test demonstrated better normalization in the laser-treated group. Alcantara et al.⁽³⁵⁾ stated that low-level laser therapy reduces inflammatory gene expression and facilitates early neural recovery following nerve injury. In line with this, the reduction in thermal hyperalgesia observed in the present study may be attributed to the anti-inflammatory and mitochondrial-stimulating effects of LLLT, which support neuronal survival and enhance recovery of nociceptive pathways. At the molecular level, the experimental group demonstrated increased expression of BDNF,

BDNF, GAP-43 and IGF-1 compared to the control group, indicating activation of key regenerative pathways. Shen et al.⁽³⁶⁾ and Alcantara et al.⁽³⁵⁾ both reported increased expression of neurotrophic and regeneration-associated genes following laser therapy. A systematic review by Siva et al.,⁽³⁷⁾ reported that low-level laser therapy significantly enhances neurotrophic factor expression and promotes peripheral nerve regeneration in experimental Wistar rat models, supporting its role as a therapeutic modality for improving functional recovery after nerve injury. In the present study, elevated BDNF suggests enhanced neuronal survival and synaptic plasticity, increased GDNF indicates improved Schwann cell activity and axonal guidance, GAP-43 reflects active axonal sprouting and IGF-1 is associated with remyelination and neuroprotection. These molecular findings support the functional improvements observed. Overall, the present findings coincide with existing literature indicating that LLLT accelerates peripheral nerve regeneration through combined anti-inflammatory, neurotrophic and mitochondrial bioenergetic mechanisms. Importantly, this study contributes additional evidence using a median nerve crush model, which has greater translational relevance to upper limb nerve injuries compared to commonly used sciatic models. The consistent improvements across behavioural and molecular parameters suggest that LLLT acts at both functional and cellular levels to enhance regeneration. These results reinforce the role of low-level laser therapy as a safe, non-invasive adjunctive modality for promoting peripheral nerve repair.

This study was limited to a single wavelength and fixed irradiation protocol, which may not represent the optimal therapeutic parameters for nerve regeneration. Only one injury severity model was evaluated, and comparisons with other adjunctive rehabilitation strategies were not explored. Future research should investigate different laser dosages and treatment durations, compare LLLT with other non-invasive modalities and examine long-term functional sustainability to strengthen translational applicability in upper limb nerve injuries.

This study provides experimental evidence that low-level laser therapy enhances peripheral nerve regeneration following median nerve crush injury by improving sensory and motor recovery while upregulating neuroregenerative biomarkers, including BDNF, GDNF, GAP-43, and IGF-1.

These findings support the biological rationale for incorporating photobiomodulation as an adjunct to conventional rehabilitation after peripheral nerve injuries. Although the present findings are limited to an experimental rat model, they provide a translational foundation for future clinical studies aimed at optimizing laser parameters, treatment timing, and patient selection for upper-limb peripheral nerve injuries.

CONCLUSION

This study demonstrated that low-level laser therapy enhances both functional and molecular recovery following median nerve crush injury in Wistar rats. Animals treated with LLLT showed greater improvement in mechanical sensitivity, thermal nociception and motor coordination compared to the control group. The observed time and group interactions across behavioural assessments further support the beneficial effects of LLLT on nerve recovery. In addition, increased expression of BDNF, GDNF, GAP-43 and IGF-1 indicates activation of key neurotrophic and regenerative pathways. Together, these findings suggest that LLLT may serve as an effective, non-invasive adjunct approach for promoting peripheral nerve regeneration. The results also highlight its potential relevance in improving functional outcomes in upper limb nerve injuries.

Conflict of Interest

Nil

Acknowledgement

The authors express their sincere gratitude to Saveetha Institute of Medical and Technical Sciences (SIMATS) for providing laboratory facilities and technical support. The authors also thank the veterinary surgeon for assistance with animal procedures and the microbiologist for support in RT-PCR analysis.

Authors' Contributions

DS contributed to study conception, design, supervision, data interpretation and manuscript drafting. PS contributed to study design, statistical analysis and critical revision of the manuscript. MM and MB contributed to data collection, experimental procedures and data analysis. SN and PK assisted in data acquisition and laboratory work. VJ contributed to data interpretation and manuscript review. KJ assisted in manuscript

preparation and formatting. All authors have read and approved the final manuscript.

Funding

This research did not receive any specific financial support from funding agencies in the public, commercial, or non-profit sectors.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declaration of AI Usage in Scientific Writing

Limited use of AI tools was employed for language refinement and grammar correction. All scientific content, analysis and interpretation were carried out by the authors.

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