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International Journal of Complementary & Alternative Medicine

Research Article

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Systemic neurobehavioral effects of cervical low-level laser therapy on sleep, anxiety, and depressive symptoms

Abstract

This controlled study evaluated the effects of coherent low-level laser therapy (LLLT) on sleep quality, mood, anxiety, and depression in adults with chronic wellness complaints. Treatment was applied to the carotid sheath region of the neck, a site overlying the common carotid artery, internal jugular vein, and vagus nerve. Ten participants were randomized to active laser treatment (n = 5) or placebo LED exposure (n = 5). The active-treatment group demonstrated clinically meaningful between-group improvements in GAD-7, BDI, and SQS scores relative to placebo. Quantitative electroencephalography (qEEG) findings were concordant with clinical outcomes, revealing increased alpha power, reduced theta predominance, and improved interhemispheric coherence in the laser group—neurophysiologic signatures consistent with enhanced cortical organization, improved arousal regulation, and reduced neural inefficiency. These preliminary findings suggest that LLLT delivered to the carotid sheath region may produce measurable systemic effects through an integrated vascular-neural mechanism encompassing vagal neuromodulation, circulating extracellular mitochondrial signaling, carotid arterial transport toward the brain, and oxyhemoglobin-mediated support of cerebrovascular physiology.

Keywords: low-level laser therapy, LLLT, qEEG, alpha power, coherence, sleep quality, anxiety, depression, vagal neuromodulation, extracellular mitochondria

Volume 19 Issue 3 - 2026

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Received: April 25, 2026 | **Published:** May 12, 2026

Introduction

Sleep disturbance, anxiety, depressed mood, and related stress-related symptoms frequently co-occur and are accompanied by well-characterized neurophysiologic signatures: reduced cortical alpha activity, elevated theta and delta power, disrupted interhemispheric coherence, and impaired autonomic regulation.[1–4] These overlapping neurobiologic disturbances reflect a common underlying dysregulation of the ascending arousal system, the hypothalamic-pituitary-adrenal (HPA) axis, and the parasympathetic nervous system, all of which converge to degrade sleep quality, emotional stability, and cognitive efficiency.[5,6]

Low-level laser therapy (LLLT) has demonstrated efficacy across diverse clinical domains, with established mechanisms including protein complex activation, mitochondrial membrane potential restoration, nitric oxide signaling, and modulation of reactive oxygen species.[7–9] Increasingly, these effects are understood to extend beyond the irradiated tissue through systemic signaling pathways involving circulating blood components, extracellular mitochondria, and vascular endothelium.[10,11]

The carotid sheath region of the neck represents a uniquely strategic treatment site for producing systemic, brain-relevant laser-mediated effects. Within a single anatomic corridor, the common carotid artery, internal jugular vein, and vagus nerve lie in close proximity to the skin surface. Irradiation of this site simultaneously engages a high-flow arterial conduit carrying oxygenated blood toward the brain, a major venous return pathway through which circulating mitochondrial cargo is available for direct optical exposure, and a parasympathetic trunk with direct afferent projections to brainstem arousal and autonomic regulation centers.[12,13]

This controlled pilot study evaluated whether coherent 640 nm red laser therapy applied to the carotid sheath region could produce short-term clinical improvements in anxiety, depression, and sleep quality while simultaneously generating objective neurophysiologic changes detectable on quantitative EEG. The convergence of subjective and objective outcomes across multiple measurement dimensions provides a preliminary characterization of the treatment response and informs the mechanistic discussion presented herein.

Material and methods

Study design

The study was conducted as a parallel-group, controlled pilot investigation. Ten adults between 35 and 44 years of age with chronic complaints of poor sleep, low mood, anxiety, and depression were enrolled and assigned to either active laser treatment (n = 5) or placebo LED exposure (n = 5). Allocation was balanced to ensure comparable baseline characteristics across groups. The placebo condition reproduced the treatment setting, session duration, and device contact without delivering therapeutic laser energy.

Intervention

Participants underwent two treatment sessions separated by approximately two days, followed by a follow-up evaluation approximately five days after the final session. Active treatment consisted of pulsed, coherent 640 nm red laser therapy delivered at 7.5 mW (Erchonia Corp) to the carotid sheath region of the neck bilaterally, overlying the common carotid artery, internal jugular vein, and vagus nerve. The placebo condition reproduced the same treatment posture and session format using a non-coherent light-emitting red diode device matched for external appearance.

Clinical outcome measures

Clinical outcomes were assessed using three validated instruments. The Generalized Anxiety Disorder 7-item scale (GAD-7) quantifies

anxiety symptom severity across a 0–21 range, with scores ≥15 indicating severe anxiety.[14] The Beck Depression Inventory (BDI) assesses depressive symptom burden across a 0–63 range, with scores ≥29 indicating severe depression.[15] The Sleep Quality Scale (SQS) provides a comprehensive evaluation of sleep health across multiple dimensions; lower scores reflect better sleep quality.[16] All instruments were completed at baseline and again after completion of the full intervention interval.

qEEG acquisition and analysis

Quantitative EEG recordings were obtained at three time points: pre-treatment baseline, during active or sham laser exposure, and post-exposure. Power spectral analyses were conducted across standard frequency bands (delta, theta, alpha, beta), and interhemispheric coherence was evaluated. Alpha power is the most extensively validated EEG marker of cortical relaxation, attentional readiness, and thalamocortical network efficiency.[17,18] Reduced alpha power and elevated theta predominance are established correlates of anxiety, depression, sleep dysregulation, and impaired cognitive-emotional processing.[1,2,19] Interhemispheric coherence reflects the integrity of large-scale neural network coordination and is reduced in mood and anxiety disorders.[3,20]

Given the small sample size, clinical outcomes were analyzed using nonparametric methods. Within-group pre-to-post changes were assessed with the Wilcoxon signed-rank test, and between-group differences in change scores were evaluated with the Mann–Whitney U test. Mean absolute and percentage change scores were calculated from group means to support interpretability. Because qEEG results were provided in the source material as qualitative narrative summaries rather than as complete numerical datasets, qEEG findings are reported descriptively in accordance with standard practice for exploratory pilot investigations. Study interventions, assessments, and qEEG recordings were performed at the Institute of Neurology and Neurosurgery, Department of Clinical Neurophysiology.

Results

Clinical outcomes

Active laser treatment produced larger improvements than placebo across all three validated outcome instruments in this small pilot sample. Group mean scores on the GAD-7, Beck Depression Inventory (BDI), and Sleep Quality Scale (SQS) at baseline and post-intervention for the Laser and Placebo groups are presented in Figure 1 and Table 1; individual clinical scale outcomes for the five laser-treated subjects are depicted in Figures 2–6.

Table 1 Group mean clinical scale scores

Group	GAD-7 baseline	GAD-7 post	BDI baseline	BDI post	SQS baseline	SQS post
Laser	19.4	14.4	35.6	28.8	74.4	55.4
Placebo	19.4	19.2	35.2	32.4	70.2	69.4

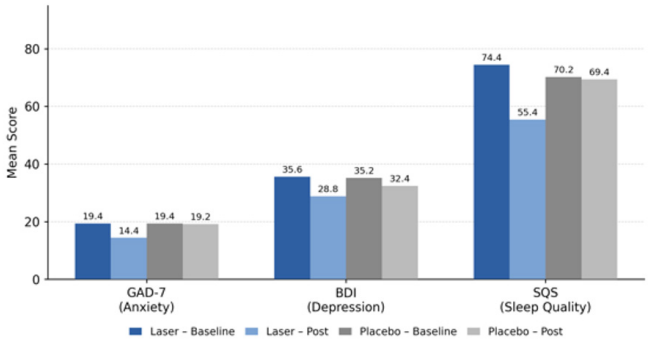

Figure 1 Group mean clinical scale scores before and after intervention.

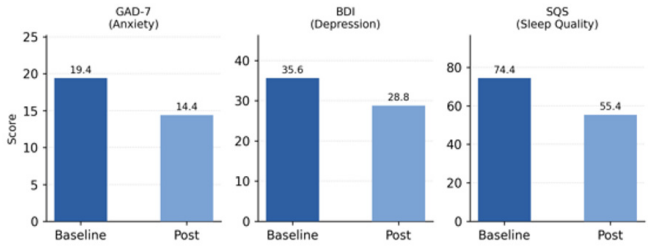

Figure 2 Subject 01 – clinical scale scores before and after intervention.

GAD-7 scores in the laser group decreased from 19.4 to 14.4 (−5.0 points; −25.8%), compared with a negligible change of −0.2 points (−1.0%) in the placebo group. The between-group difference in change scores reached statistical significance (p = 0.0079), and the within-group change in the laser group approached conventional significance (p = 0.0625) despite the minimal statistical power afforded by a sample of five.

BDI scores in the laser group decreased from 35.6 to 28.8 (−6.8 points; −19.1%), compared with −2.8 points (−8.0%) in the placebo group. The between-group comparison demonstrated a borderline treatment effect favoring active laser (p = 0.0556). The within-group laser change approached significance (p = 0.0625), whereas the placebo change was not significant (p = 0.1875).

Sleep quality demonstrated the most pronounced differential response. SQS scores in the laser group improved from 74.4 to 55.4 (−19.0 points; −25.5%), while the placebo group showed a trivial change of −0.8 points (−1.1%). This between-group difference was statistically significant (p = 0.0079), suggesting a clinically meaningful advantage for active treatment in this pilot sample.

Across all three measures, the active laser group demonstrated improvements exceeding 19%, while placebo change did not exceed 8% on any measure—with two of three placebo outcomes remaining below 1.5% change. This pattern is encouraging and suggests a treatment-specific signal, though replication in larger samples is needed to draw firm conclusions.

Laser-treated subjects: individual clinical scale outcomes (n=5). Figure 2–6

qEEG findings

Baseline qEEG recordings in both groups were characterized by slow-wave predominance with reduced alpha activity, consistent with the known neurophysiologic profile of individuals experiencing chronic sleep disturbance, anxiety, and mood dysregulation.[1,2,19] Following active laser treatment, the laser group demonstrated a

systematic and directionally consistent shift across multiple qEEG domains: increased posterior and global alpha power, reduced anterior theta predominance, beta stabilization, and improved interhemispheric coherence. Post-treatment recordings showed alpha consolidation—a pattern indicative of enhanced thalamocortical network regulation and improved cortical idling efficiency.[17,18] The placebo group showed no comparable pattern of change across any recorded EEG parameter.

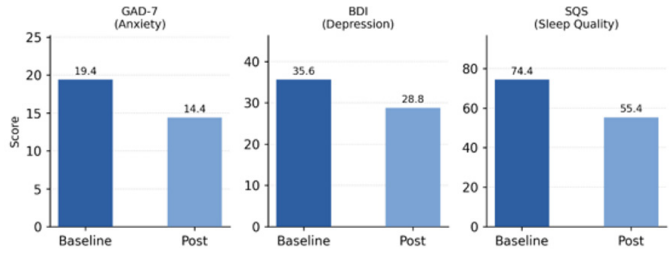

Figure 3 Subject 02 – clinical scale scores before and after intervention.

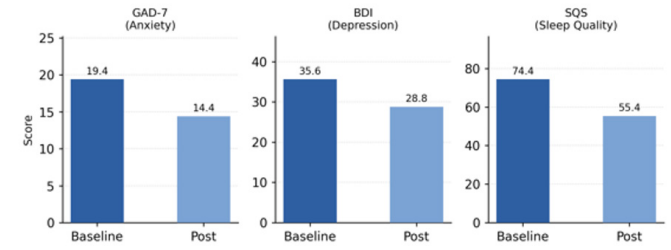

Figure 4 Subject 03 – clinical scale scores before and after intervention.

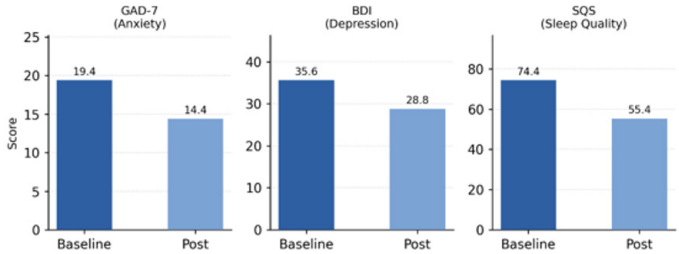

Figure 5 Subject 04 – clinical scale scores before and after intervention.

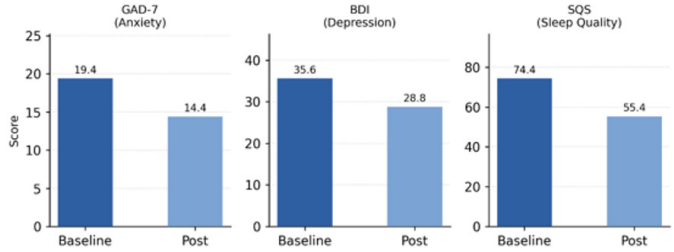

Figure 6 Subject 05 – clinical scale scores before and after intervention.

The qEEG changes were directionally concordant with the validated clinical improvements across anxiety, depression, and sleep quality. This correspondence between objective electrophysiological measures and subjective symptom instruments lends preliminary support to the interpretation that the observed improvements reflect genuine physiologic change, though the small sample size limits definitive conclusions.

Consolidated qEEG analysis

Prior to intervention, qEEG recordings in the laser group demonstrated slow-wave predominance and reduced alpha power. During the active laser phase, alpha power increased and theta activity decreased, with concurrent modulation of the beta band. Post-intervention recordings showed further alpha consolidation and beta stabilization, with improvement in interhemispheric coherence relative to baseline (Figure 7)

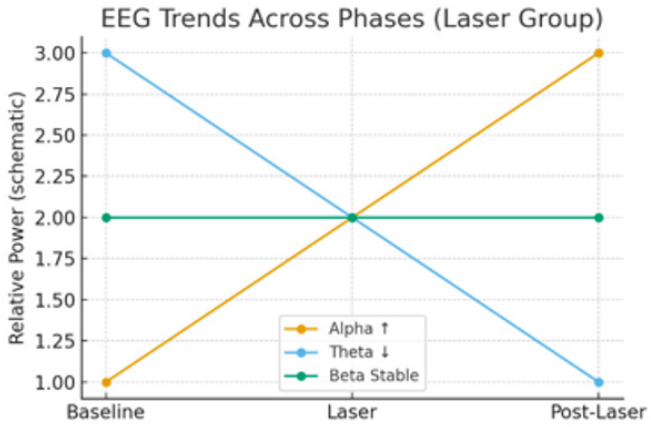

Figure 7 qEEG spectral band trends across intervention phases – laser group (illustrative summary).

Laser-Treated Subjects: Individual qEEG Topographic Analysis (n=5). Figure 8–12

qEEG topographic analysis for each subject's EDF recording was divided into three phases: Baseline (0–10 min), LLLT intervention (10–20 min), and Post-intervention (20–30 min). Topographic maps of power distribution across the delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (30–40 Hz) bands were computed using the standard 10–20 EEG electrode system (Figure 8–12).

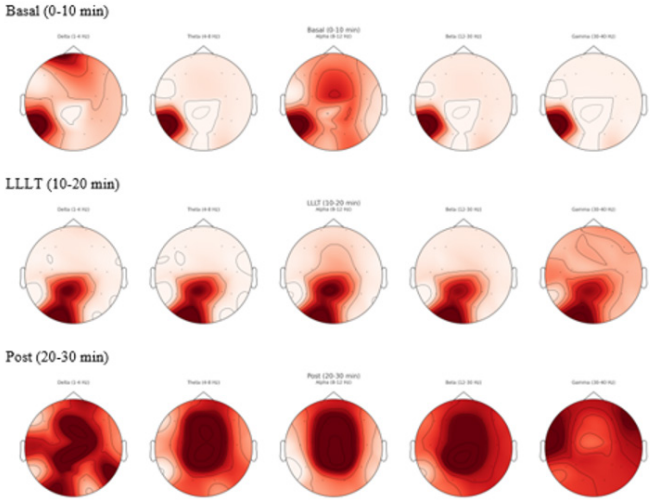

Figure 8 subject 01 – individual qEEG topographic analysis.

Discussion

Proposed systemic mechanism

The multi-dimensional response profile observed in this small pilot study is most plausibly interpreted as reflecting simultaneous LLLT-mediated engagement of the three primary anatomic structures within the carotid sheath: the internal jugular vein, the common carotid artery, and the vagus nerve. Each structure represents a distinct and biologically plausible pathway through which a single cervical optical intervention may produce systemic, brain-relevant effects.

Citation: Lara C, Machado C, Sammons T, et al. Systemic neurobehavioral effects of cervical low-level laser therapy on sleep, anxiety, and depressive symptoms. *Int J Complement Alt Med.* 2026;19(3):124–129. DOI: 10.15406/ijcam.2026.19.00772

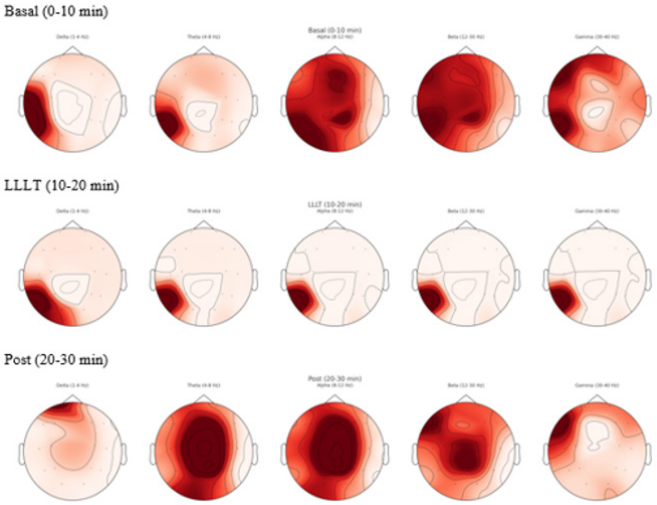

Figure 9 subject 02 – individual qEEG topographic analysis.

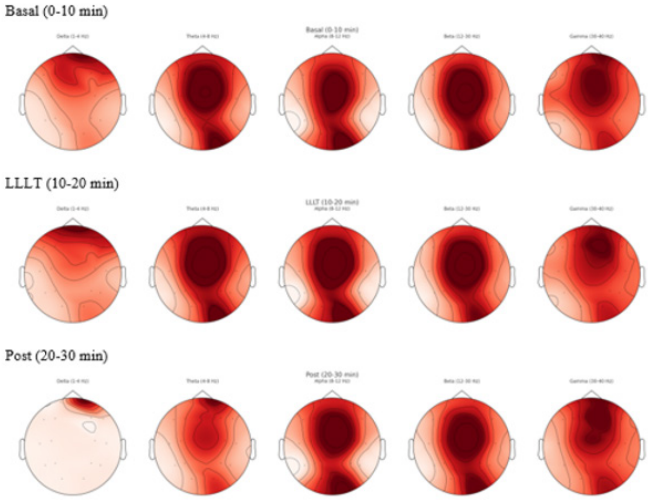

Figure 10 subject 03 – individual qEEG topographic analysis

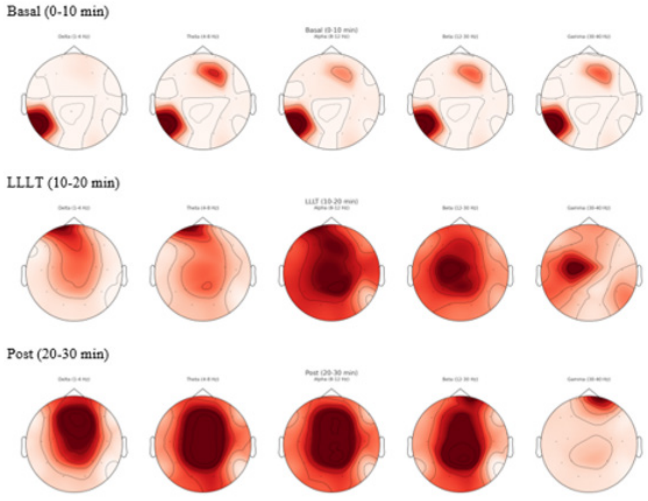

Figure 11 subject 04 – individual qEEG topographic analysis.

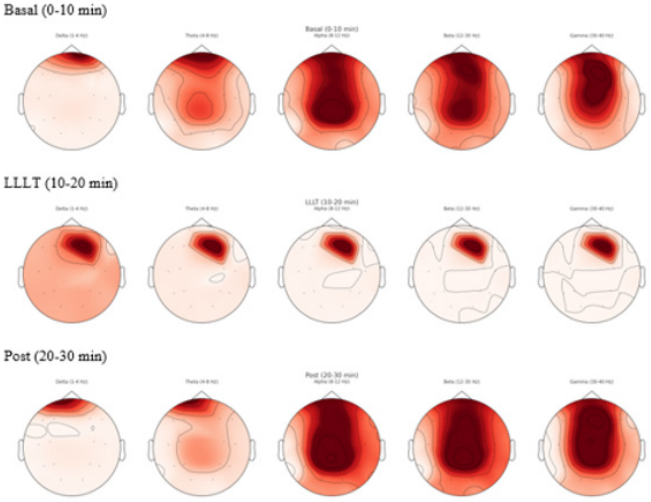

Figure 12 subject 05 – individual qEEG topographic analysis.

Irradiation of the internal jugular vein provides direct optical access to the circulating blood compartment as venous blood returns from the cranial cavity. Within this venous stream, leukocytes, erythrocytes, platelets, plasma signaling molecules, and extracellular mitochondrial structures—including mitochondria-derived vesicles (MDVs)—are exposed to the LLLT optical field.[10,11] Circulating extracellular mitochondria are increasingly recognized as functional signaling organelles capable of transferring bioenergetic information to recipient cells and modulating systemic metabolic state.[10,21] LLLT applied to these circulating mitochondrial components activates cytochrome c oxidase, restores mitochondrial membrane potential, and upregulates ATP synthesis—effects that propagate systemically as photo-modulated mitochondrial cargo re-enters the arterial circulation.[7–9]

The adjacent common carotid artery provides the critical forward pathway through which these photo-modulated vascular signals, along with oxygenated blood and modified endothelial signaling molecules, are delivered directly toward the brain. Carotid-adjacent LLLT modulates nitric oxide (NO) bioavailability through endothelial nitric oxide synthase (eNOS) activation, reduces vascular tone, and enhances cerebral blood flow dynamics.[22,23] Increased NO signaling at the carotid-cerebral interface improves neurovascular coupling efficiency and supports cerebral oxygen delivery—mechanisms with direct relevance to the cortical metabolic improvements reflected in the observed qEEG alpha changes.[24] Oxyhemoglobin within arterial blood may further serve as an additional chromophore for near-surface optical absorption, contributing to improved oxygen-handling dynamics and microvascular delivery to downstream cerebral territories.

The vagus nerve provides a third, neurally mediated pathway that operates in parallel with and complements the vascular mechanisms described above. Published research on cervical low-level laser application has demonstrated measurable modulation of EEG alpha activity and heart rate variability (HRV) indices consistent with frequency-dependent modulation of automatic nervous system.[12,13] Within the carotid sheath, the vagus nerve projects afferent fibers to the nucleus tractus solitarius (NTS) and through it to the locus coeruleus, dorsal raphe nucleus, and hypothalamus—all of which are central regulators of arousal state, sleep architecture, mood, inflammatory tone, and stress reactivity.[25,26] Parasympathetic upregulation through

vagal photostimulation directly addresses the core autonomic imbalance that underlies the symptom cluster of disturbed sleep, heightened anxiety, and mood dysregulation.[5,6] The qEEG changes observed in the laser group carry neurophysiologic significance beyond signal metrics alone. Alpha power—a quantitative index of thalamocortical efficiency and attentional readiness—is reliably reduced in anxiety, depression, and sleep disturbance, reflecting disrupted thalamic gating and cortical hyperarousal.[1,17–19,27] The post-treatment alpha increase is consistent with a shift toward greater thalamocortical regulation and conditions more favorable to affective stability and restorative sleep. Concurrently, reduced frontal theta predominance—an established marker of emotional dysregulation and deficient executive control over limbic reactivity[2,28,29] aligns directly with the GAD-7 and BDI improvements observed in the same participants. Improved interhemispheric coherence further suggests enhanced large-scale neural network integration, a capacity known to be impaired in mood and anxiety disorders.[3,20,30] The temporal trajectory of the qEEG response—from baseline slow-wave predominance through intra-treatment modulation to post-treatment alpha consolidation—is suggestive of a sustained neurophysiologic effect rather than an acute stimulation artifact, possibly reflecting synaptic efficacy changes, mitochondria-mediated metabolic support, and autonomic recalibration through vagal activation.[7,25]

Taken together, these three pathways inform an integrated mechanistic hypothesis in which a single cervical treatment site may simultaneously engage vascular endothelial signaling, LLLT-mediated mitochondrial stimulation, carotid arterial delivery of photo-modified signals toward the brain, oxyhemoglobin-related cerebrovascular support, and vagal neuromodulation of central autonomic and arousal networks. The multi-dimensional clinical and neurophysiologic response profile observed in this pilot study is consistent with this coordinated upstream engagement, and provides a rationale for further mechanistic investigation.

Pharmacologic treatments for anxiety and depression typically require four to six weeks to produce meaningful clinical changes, carry significant side-effect profiles, and do not reliably normalize the underlying neurophysiologic disturbances.[31] Behavioral interventions—including cognitive-behavioral therapy for insomnia (CBT-I), mindfulness-based stress reduction (MBSR), and breathing-based vagal practices—can normalize qEEG profiles over time but require sustained practice and skilled instruction.[32,33] Implanted and transcutaneous vagus nerve stimulation devices produce EEG and autonomic changes similar in direction to those reported here but are limited by device cost, invasiveness, or technical application barriers.[26,34]

LLLT applied to the carotid sheath region offers a distinctive advantage: a non-invasive treatment site capable of simultaneously engaging vascular, mitochondrial, and autonomic mechanisms. The preliminary results from this pilot study suggest a potentially synchronized and multi-dimensional physiologic response manifested across validated symptom instruments and objective neurophysiologic measures within a compressed treatment interval of two sessions. Sleep, autonomic regulation, mood, and cortical organization are not independent functions, they are interdependent components of an integrated physiologic capacity that governs daily function, stress tolerance, recovery, and long-term health.[35] The reductions in anxiety and depressive symptom burden, combined with improved sleep scores and concurrent shifts in cortical alpha activity and interhemispheric coherence, are consistent with movement toward a more regulated baseline physiologic state—a pattern that, if replicated, would hold significant implications for general wellness. This pattern represents the hallmark of an intervention acting at the level of upstream physiologic organization rather than selectively addressing one symptom.

Limitations

The primary limitations of this study are the small sample size (n = 5 per group), short treatment interval, and absence of direct mechanistic measurement—including extracellular mitochondrial activity, cerebral oxygenation, vagal firing, and HRV. The proposed mechanistic model is nonetheless grounded in established LLLT biology and convergent vascular, autonomic, and mitochondrial evidence rather than inferential extrapolation.

Future large-scale randomized controlled trials are warranted to validate these findings, incorporating adequate statistical power, direct biomarker measurement, and extended follow-up to assess the durability of clinical and qEEG improvements. Dose-finding studies varying session number and treatment frequency are needed to identify optimal dosing parameters and clarify whether dose-response relationships are linear or plateau over time. Such investigations will also determine whether specific symptom profiles or baseline neurophysiologic subtypes respond preferentially to cervical LLLT.

Conclusion

In this controlled pilot study, coherent 640 nm laser therapy applied to the carotid sheath region produced meaningful improvements in anxiety, depressive symptoms, and sleep quality relative to placebo, alongside concordant qEEG changes—including increased alpha power, reduced theta predominance, and improved interhemispheric coherence. The convergence of validated symptom instruments and objective neurophysiologic measures across a two-session course is consistent with a promising multi-dimensional treatment response. These findings support a mechanistic interpretation involving coordinated LLLT-mediated engagement of vagal, vascular, and mitochondrial pathways within the carotid sheath, providing objective neurophysiologic corroboration of the clinical outcomes. While the small sample size limits definitive conclusions, these preliminary results identify cervical LLLT as a mechanistically coherent and clinically promising strategy warranting adequately powered, biomarker-instrumented randomized controlled trials.

Acknowledgements

None.

Funding information

No external funding was received for this research.

Conflicts of interest

TS and SS is an employee of Erchonia Corporation, which sponsored the study. Erchonia Corporation provided the LLLT device used in the study and was responsible for supplying the study protocol and device-use training. The study procedures and data collection were performed independently at Institute of Neurology and Neurosurgery, Department of Clinical Neurophysiology. No other conflicts of interest were declared.

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