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Laser Therapy for Musculoskeletal Pain Management: A Preliminary Network Meta-analysis Comparing High-intensity and Low-level Protocols

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Abstract: Musculoskeletal disorders are a leading cause of pain and disability worldwide. Among the non-invasive interventions commonly used in physical therapy, laser therapy – specifically high-intensity laser therapy and low-level laser therapy – has emerged as a promising approach for pain management in rehabilitation. This preliminary network meta-analysis aimed to compare the analgesic effectiveness of both modalities with and without other physical therapy treatments in individuals with musculoskeletal pain. An electronic search was conducted in PubMed, Scopus, Web of Science, CINAHL, ScienceDirect, and the Physiotherapy Evidence Database (last updated 22 June 2025). The methodological quality of the included randomized controlled trials was assessed using the Physiotherapy Evidence Database scale. Pain intensity was the primary outcome, measured with instruments such as the Visual Analog Scale, the Numeric Pain Rating Scale, or equivalent tools. Standardized mean differences were calculated to pool results across studies and determine the overall effect size. A network meta-analysis was conducted to estimate the relative effectiveness of each intervention and generate treatment rankings. A total of 20 studies were included, with a mean PEDro score of 5.9 (SD = 1.5), and lower ratings were commonly observed for allocation concealment and therapist blinding. Substantial heterogeneity was observed across studies ($I^2 > 50$ %). HILT appears more effective than LLLT when applied as a standalone intervention (SMD = 0.9; 95 % CI: 0.1, 1.7). However, when combining either modality with exercise or conventional physical therapy, there were no significant differences. Notably, physical therapy alone outperformed both laser modalities (SMD = 3.3; 95 % CI: 0.9, 5.7). Further high-quality RCTs are needed to evaluate long-term outcomes and patient-centered outcomes.

Keywords: Pain management, Musculoskeletal pain, High-intensity laser therapy, Low-level light therapy, Physical therapy modalities.

1. Background

Musculoskeletal disorders represent one of the most prevalent health challenges globally, affecting over 1.7 billion individuals and contributing significantly to chronic pain, disability, and reduced quality of life [1]. Conditions such as low back pain, neck pain, and osteoarthritis impose a substantial socioeconomic burden due to increased healthcare utilization, prolonged absenteeism, and decreased productivity [1, 2]. Many of these disorders, particularly those of a degenerative nature, tend to become chronic, leading to persistent symptoms and long-term functional impairment. Chronic musculoskeletal pain – defined as pain persisting for more than three months – affects approximately 20 % to 33 % of the adult population and remains a principal cause of disability worldwide [3]. Addressing this growing public health concern requires comprehensive, multimodal treatment approaches, among which laser therapy has emerged as a promising non-invasive modality within the field of physical rehabilitation [4-6].

Laser therapy exerts its therapeutic effects through photobiomodulation (PBM), a process in which specific wavelengths of light are absorbed by intracellular photoacceptors such as cytochrome c oxidase, water molecules, and membrane-bound

chromophores [5, 7]. This photonic interaction triggers a cascade of biological responses, including mitochondrial activation, increased adenosine triphosphate (ATP) production, modulation of gene expression, and regulation of inflammatory pathways [8]. These mechanisms collectively contribute to pain relief, tissue repair, and attenuation of oxidative stress and inflammation, which are critical in managing musculoskeletal pain [5, 7, 8].

Among the available laser modalities, low-level laser therapy (LLLT) and high-intensity laser therapy (HILT) have been widely employed in the management of musculoskeletal conditions [4, 5]. Low-level laser therapy operates with power outputs below 500 milliwatts and relies exclusively on PBM mechanisms. These include enhanced microcirculation, reduction of oxidative stress, decreased nociceptive transmission, stimulation of cellular metabolism, and modulation of inflammatory mediators, all of which promote analgesia and tissue regeneration [5, 6].

In contrast, HILT operates at higher power levels (greater than 500 mW), with wavelengths around 1064 nanometers [4, 9]. The high power ensures faster energy delivery to the tissues (energy [Joules] = treatment time [sec] * output power [W]), allowing for shorter treatment durations. Importantly, HILT combines PBM with photothermal effects, which may further enhance therapeutic outcomes by stimulating collagen synthesis, increasing vascular perfusion, and promoting muscle relaxation. While both modalities have demonstrated efficacy in reducing pain and improving function in musculoskeletal disorders, HILT may offer additional advantages due to its thermal and PBM effects and is considered theoretically superior because of its dual mechanism of action [4, 10]. Nevertheless, its higher cost and limited accessibility may restrict its clinical application compared to LLLT [4].

Despite encouraging evidence supporting the use of both interventions, direct comparative studies remain scarce [11-13]. Therefore, this preliminary network meta-analysis aims to critically evaluate and synthesize current evidence from randomized controlled trials (RCTs) to compare the analgesic effectiveness of HILT and LLLT in individuals with musculoskeletal pain. The analysis considers both the isolated application of each modality and their combination with other therapeutic strategies – such as exercise or conventional physical therapy (PT) – to clarify their role within integrated, multimodal approaches to musculoskeletal pain management.

2. Methods

2.1. Review Design and Study Eligibility

This non-experimental, quantitative systematic review involved a secondary analysis of RCTs and was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14].

The review was structured using the PICOS framework, focusing on individuals with musculoskeletal pain who received HILT, either as a standalone intervention or in combination with other PT treatments [15]. Comparators included LLLT, administered alone or in conjunction with conventional PT interventions. The primary outcome was the change in pain intensity, assessed using validated instruments such as the Visual Analog Scale (VAS), the Numeric Pain Rating Scale (NPRS), or other pain assessment tools. Only RCTs were eligible for inclusion. Exclusion criteria comprised studies investigating non-musculoskeletal conditions or musculoskeletal disorders with neurological involvement, absence of a direct comparison between HILT and LLLT, lack of pain-related outcomes, or insufficient data for analysis. No language restrictions were applied during the screening process.

2.2. Electronic Database Search

An extensive literature search was conducted across eight electronic databases – PubMed, Scopus, Web of Science, CINAHL, Cochrane Library, ScienceDirect, and the Physiotherapy Evidence Database (PEDro) – with no language restrictions applied. The search strategy combined Medical Subject Headings (MeSH) and free-text terms related to laser-based interventions and musculoskeletal disorders. Keywords included *"Lasers," "Laser Therapy," "Low-Level Light Therapy," "High-Intensity Laser Therapy," and "Class IV Laser," along with condition-specific terms such as "Musculoskeletal Pain," "Musculoskeletal Diseases," "Neck Pain," "Myofascial Pain Syndromes," "Low Back Pain," "Osteoarthritis," and "Pain Management."* Boolean operators ("OR" within thematic categories and "AND" across categories) were used to construct comprehensive search strings and maximize sensitivity. No filters or date restrictions were applied to ensure exhaustive retrieval of relevant studies. Study selection was performed using the Rayyan web tool [16].

2.3. Methodological Quality of RCTs

The methodological quality of the included RCTs was assessed using the PEDro scale, which is specifically designed to evaluate the internal validity of RCTs [17]. The scale comprises 11 criteria; however, only criteria 2 to 11 contribute to the total score, as the first item – concerning the specification of eligibility criteria – is not scored [17, 18]. Initially, PEDro scores were retrieved from the official PEDro database. For RCTs not indexed in the database, methodological quality was assessed using the PEDro scoring criteria: (1) Eligibility criteria specified; (2) Random allocation; (3) Concealed allocation;

(4) Baseline comparability; (5) Blinding of participants; (6) Blinding of therapists; (7) Blinding of outcome assessors; (8) Adequate follow-up; (9) Intention-to-treat analysis; (10) Between-group comparisons; and (11) Point estimates and measures of variability. Trials scoring above 5 were considered high quality, while those scoring 3 or below were classified as low quality [17].

2.4. Statistical Methods

Meta-analyses of pain intensity outcomes – assessed using VAS, NPRS, or comparable instruments – were conducted using standardized mean differences (SMDs) and the inverse variance method [19]. Statistical heterogeneity was evaluated using the Chi-squared test and the I^2 statistic ($\alpha = 0.05$), with $I^2 \geq 50$ % indicating substantial heterogeneity [20]. Based on the degree of heterogeneity observed, analyses were conducted using either the DerSimonian and Laird random-effects model or the Mantel-Haenszel fixed-effects model, as appropriate [20, 21].

A network meta-analysis was performed to estimate and rank the relative efficacy of interventions involving HILT and LLLT, whether administered alone or in combination with other therapies [22]. Transitivity was assessed by examining the comparability of populations, interventions, and outcomes across studies. Network connectivity was ensured by verifying that all interventions were linked through direct or indirect comparisons [22, 23].

In the network geometry, each node represented a distinct intervention, with node size proportional to the number of participants assigned to that treatment. The thickness of connecting lines reflected the number of direct comparisons between interventions [22, 23]. Treatment ranking was based on the surface under the cumulative ranking curve (SUCRA), with higher values indicating greater relative efficacy. SUCRA values were graphically represented using radial plots.

3. Results

The initial database search yielded 9433 records (last updated on June 22, 2025). After removing duplicates, 3130 articles were screened, resulting in the selection of 28 studies for full-text review. Eight randomized controlled trials comparing HILT and LLLT were subsequently excluded: five due to the absence of pain intensity outcomes and three because they addressed non-musculoskeletal conditions (e.g., Bell's palsy, osteoporosis, and dysmenorrhea). Ultimately, 20 RCTs were included in the analysis [24-43]. Fig. 1 displays the PRISMA flowchart summarizing the study selection process. Table 1 outlines the search strategy, including individual keywords and combinations with Boolean operators.

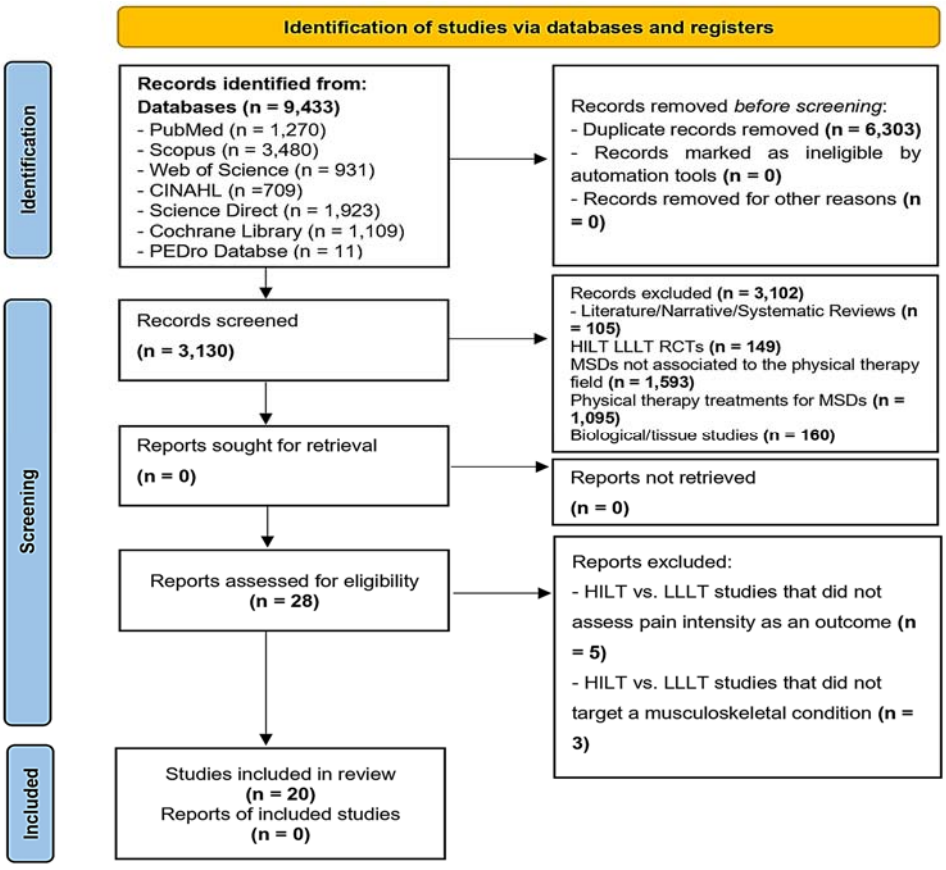

Fig. 1. PRISMA flowchart.

Table 1. Search strategy.

Keywords		Identification of studies via databases and registers							
		PubMed	**Scopus**	**Web of Science**	**CINAHL**	**ScienceDirect**	**Cochrane Library**	**PEDro Database**	**Total**
Search 1	*"Lasers"*	100083	1722446	300449	10732	1000000	26215		3159925
Search 2	*"Laser Therapy"*	51379	49032	17284	12267	23190	7752		160904
Search 3	*"Low-Level Light Therapy"*	8560	5173	730	328	443	1807		17041
Search 4	*"High-Intensity Laser Therapy"*	193	259	206	101	124	226		1109
Search 5	*"Class IV laser"*	29	59	40	18	161	32		339
Search 6	S1 OR S2 OR S3 OR S4 OR S5 OR S6	137869	1722589	314150	20613	1023918	26417		3245556
Search 7	*"Musculoskeletal Pain"*	12672	21700	16257	5409	24723	3297		84058
Search 8	*"Musculoskeletal diseases"*	19786	52146	10761	13178	14431	5759		116061
Search 9	*"Neck Pain"*	18335	36141	16554	10671	32126	5821		119648
Search 10	*"Myofascial Pain Syndromes"*	2288	3344	356	1779	3102	1845		12714
Search 11	*"Low Back Pain"*	47697	85682	61344	29649	68835	15114		308321
Search 12	*"Osteoarthritis"*	129690	182669	154022	50180	175277	26294		718132
Search 13	*"Pain Management"*	89533	71073	62224	41201	91653	26267		381951
Search 14	S8 OR S9 OR S10 OR S11 OR S12 OR S13 OR S14	302660	418910	293688	141712	349452	17535		1523957
Search 15	S7 OR S14	1270*	3480*	931*	709*	1923*	1109*	11*	9433

* Search algorithm used for selected databases: *("Lasers" OR "Laser Therapy" OR "Low-Level Light Therapy" OR "High-Intensity Laser Therapy" OR "Class IV laser") AND ("Musculoskeletal Pain" OR "Musculoskeletal Diseases" OR "Neck Pain" OR "Myofascial Pain Syndromes" OR "Low Back Pain" OR "Osteoarthritis" OR "Pain Management").*

3.1. Methodological Quality Assessment

The included RCTs had a mean PEDro score of 5.9 (SD = 1.5), indicating moderate methodological quality (Table 2). Four studies were rated as high quality (9/10) [34, 36, 40, 41], while six scored below 5/10 [24, 25, 29, 31, 42, 43], primarily due to the absence of blinding – particularly therapist blinding – and lack of concealed allocation. Most trials fell within the 5- to 8-point range, suggesting methodological limitations that may affect internal validity. At the item level, full adherence (100 %) was observed for criteria 10 and 11 (between-group comparisons and criterion and point estimates with measures of variability). High fulfillment (95.5 %) was also recorded for random allocation and baseline comparability (criteria 2 and 4). In contrast, the lowest adherence was noted for therapist blinding (18.2 %) and criterion and concealed allocation (27.3 %). Moderate fulfillment (50–55 %) was observed for participant blinding and assessor blinding (criteria 5 and 7).

3.2. Characteristics of Included Studies

Table 3 presents an overview of the included studies, outlining the country of origin, group allocation, participant characteristics, interventions, assessment time points, and outcomes related to pain intensity. The included RCTs were conducted between 2012 and 2024 in Poland (n = 3) [24, 25, 28), Saudi Arabia (n = 2) [26, 32], Iran (n = 5) [29, 31, 33, 34, 37], Turkey (n = 4) [30, 36, 38, 41], Egypt (n = 2) [27, 39], Indonesia (n = 2) [42, 43], Lithuania (n = 1) [35], and Malaysia (n = 1) [40]. A total of 1310 participants were enrolled, with a mean age of 49.8 years (SD = 9.5). Sex was specified in most studies (460 males and 547 females), although three trials did not report this information. The studies investigated various musculoskeletal disorders, with the most frequently studied conditions being knee osteoarthritis (n = 6) [24, 26, 29, 40, 42, 43], lumbar disc herniation (n = 3) [28, 38, 39], and chronic neck pain (n = 1) and nonspecific low back pain (n = 1) [27, 32]. Other conditions included carpal tunnel syndrome [33, 34], plantar fasciitis [30, 35], lateral epicondylitis [31, 36], delayed onset muscle soreness [25], subacromial impingement syndrome [37], and frozen shoulder [41].

Of the total sample, 621 participants were assigned to experimental groups, 613 to control groups, and 235 to placebo groups. Within the experimental groups, 130 participants received HILT as a standalone intervention, while 360 received HILT combined with adjunct therapies, including exercise and PT modalities such as transcutaneous electrical nerve stimulation (TENS) [29, 31], therapeutic ultrasound [29, 31], cryotherapy [31, 35], hydrocollators packs [29], manual therapy [40],

stretching [30, 35], kinesiology tape [37], splints [33], insoles [30, 35], and elbow bandages [36]. In the CGs, 88 participants received LLLT alone, while 498 received LLLT combined with similar co-interventions. Eight studies involving 170 participants employed placebo interventions, consisting of sham HILT or LLLT, with or without exercise [24-29, 37-39]. Treatment frequency ranged from one to five sessions per week (average: two to three sessions) over a duration of two to twelve weeks. Participant attrition was minimal, with 13 dropouts reported across two RCTs [26, 30].

Table 2. Summary of Methodological Quality According to PEDro Scale Criteria.

Author	PEDro scale criteria	Total Score
Gworys (2012)** [24]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: No; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10
Zwolińska (2014)** [25]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: No; Blind subjects: Yes; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10
Kheshie (2014)* [26]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	7/10
Alayat (2017)* [27]	Eligibility criteria: No; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: Yes; Blind assessors: Yes; Adequate follow-up: No; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	7/10
Taradaj (2018)** [28]	Eligibility criteria: Yes; Random allocation: No; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	8/10
Dekholsh (2018)* [29]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: No; Adequate follow-up: No; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10
Ordahan (2018)* [30]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: No; Blind therapists: Yes; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	8/10
Fekri (2019)** [31]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: No; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10
Abdelbasset (2020)* [32]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: No; Blind therapists: No; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	7/10
Hojjati (2020)** [33]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	7/10
Ezzati (2020)* [34]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	9/10
Naruseviciute (2020)* [35]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	7/10
Kaydok (2020)* [36]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	9/10
Zaki (2021)* [37]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: No; Blind therapists: No; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	8/10
Al-Kurdi (2022)** [38]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: No; Adequate follow-up: No; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10
Abdelsalam (2022)** [39]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: Yes; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	7/10
Ahmad (2023)* [40]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: No; Blind therapists: Yes; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	9/10
Ordahan (2023)* [41]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: Yes; Baseline comparability: Yes; Blind subjects: No; Blind therapists: Yes; Blind assessors: Yes; Adequate follow-up: Yes; Intention-to-treat analysis: Yes; Between-group comparisons: Yes; Point estimates and variability: Yes.	9/10
Astri (2023)** [42]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: No; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10
Rizky (2024)** [43]	Eligibility criteria: Yes; Random allocation: Yes; Concealed allocation: No; Baseline comparability: Yes; Blind subjects: No; Blind therapists: No; Blind assessors: No; Adequate follow-up: Yes; Intention-to-treat analysis: No; Between-group comparisons: Yes; Point estimates and variability: Yes.	5/10

* A confirmed score in the PEDro database.
** Score determined by researchers (Not available in PEDro database).

Among the included studies, pain intensity was predominantly evaluated using the VAS, applied in 18 studies [24-30, 30-40]. Other validated instruments were used less frequently, including the NPRS [40], the Lattinen Index [24], and condition-specific scales such as the Western Ontario and McMaster Universities Arthritis Index (WOMAC) [26, 29], the pain domain of the Knee Injury and Osteoarthritis Outcome Score (KOOS) [40], and the Shoulder Pain and Disability Index (SPADI) [37, 41]. The characteristics of the laser equipment utilized in HILT and LLLT interventions are thoroughly outlined in Table 4.

Table 3. Study characteristics.

Author (Country, Year)	MSD	Participants (n)	Groups (n)	Sessions	Pain outcomes	Assessment instances	Adverse effects
Gworys (Poland, 2012) [24]	Knee OA	125	HILT (30), HILT mild dose (30), LLLT (34), Placebo (31)	10	VAS, Lattinen Index	Baseline, post-treatment (2 weeks)	None
Zwolińska (Poland, 2014) [25]	DOMS	30	HILT (10), LLLT (10), Placebo (10)	1	VAS (rest, during exercise)	Baseline, post-treatment, Follow-up (2 days)	None
Kheshie (Saudi Arabia, 2014) [26]	Knee OA	53	HILT plus EX (20), LLLT plus EX (18), Placebo plus EX (15)	12	VAS, WOMAC	Baseline, post-treatment (6 weeks)	None
Alayat (Egypt, 2017) [27]	CNP	75	HILT plus EX (25), LLLT plus EX (25), Placebo plus EX (25)	12	VAS	Baseline, post-treatment (6 weeks)	None
Taradaj (Poland, 2018) [28]	Lumbar disc herniation	68	HILT (18), HILT-placebo (17), LLLT (16), LLLT-placebo (17)	15	VAS, LQIP	Baseline, post-treatment, follow-up (4 & 12 weeks)	None
Dekholsh (Iran, 2018) [29]	Knee OA	45	HILT plus PT (15), LLLT plus PT (15), Placebo plus PT (15)	12	VAS	Baseline, post-treatment, follow-up (6 weeks)	None
Ordahan (Turkey, 2018) [30]	Plantar fasciitis	75	HILT plus stretch and insole (37), LLLT plus stretch and insole (38)	9	VAS, FAOS	Baseline, post-treatment (3 weeks)	None
Fekri (Iran, 2019) [31]	Lateral epicondylitis	30	HILT plus PT (15), LLLT plus PT (15)	10	VAS	Baseline, post-treatment (2 weeks)	None
Abdelbasset (Saudi Arabia, 2020) [32]	Chronic nsLBP	60	HILT plus EX (20), LLLT plus EX (20), EX (20)	24	VAS	Baseline, post-treatment (12 weeks)	None
Hojjati (Iran, 2020) [33]	CTS	45	HILT plus splint (15), LLLT plus splint (15), Splint (15)	1	VAS	Baseline, post-treatment, follow-up (12 weeks)	None
Ezzati (Iran, 2020) [34]	CTS	98	HILT mild dose plus EX (20), HILT High dose plus EX (19), LLLT mild dose plus EX (20), LLLT High dose plus EX (19), EX (17)	6	VAS	Baseline, post-treatment (3 weeks)	None
Naruseviciute (Lithuania, 2020) [35]	Plantar fasciitis	102	HILT plus PT and insole (51), LLLT plus PT and insole (51)	9	VAS (first step, walking)	Baseline, post-treatment, follow-up (3–4 weeks)	None
Kaydok (Turkey, 2020) [36]	Lateral epicondylitis	60	HILT plus bandage (30), LLLT plus bandage (30)	9	VAS	Baseline, post-treatment (3 weeks)	None
Zaki (Iran, 2021) [37]	SAIS	30	HILT plus KT (10), LLLT plus KT (10), Placebo plus KT (10)	6	VAS, SPADI	Baseline, post-treatment (2 weeks)	None
Al-Kurdi (Turkey, 2022) [38]	Lumbar disc herniation	60	HILT plus EX (20), LLLT plus EX (20), Placebo plus EX (20)	9	VAS	Baseline, post-treatment (3 weeks)	None
Abdelsalam (Egypt, 2022) [39]	Lumbar disc herniation	60	HILT plus EX (20), LLLT plus EX (20), Placebo plus EX (20)	12	VAS	Baseline, Intermediate (2 weeks), post-treatment (4 weeks)	None
Ahmad (Malaysia, 2023) [40]	Knee OA	34	HILT plus PT (17), LLLT plus PT (17)	12	NPRS, KOOS	Baseline, post-treatment (12 weeks)	None
Ordahan (Turkey, 2023) [41]	Frozen Shoulder	40	HILT plus EX (20), LLLT plus EX (20)	9	VAS, SPADI	Baseline, post-treatment (3 weeks)	None
Astri (Indonesia, 2023) [42]	Knee OA	61	HILT plus EX (31), LLLT plus EX (30)	6	VAS	Baseline, during treatment, post-treatment (3 weeks)	None
Rizky (Indonesia, 2024) [43]	Knee OA	27	HILT (14), LLLT (13)	8	KOOS	Baseline, post-treatment (4 weeks)	None

Abbreviations: CNP (chronic neck pain), CTS (carpal tunnel syndrome), DOMS (delayed onset muscle soreness), EX (therapeutic exercise), HILT (high-intensity laser therapy), KT (kinesiotaping), KOOS (Knee Injury and Osteoarthritis Outcome Score), LBP (low back pain), LLLT (low-level laser therapy), LQIP (Laitinen Questionnaire Indicators of Pain), MSDs (musculoskeletal disorders), nsLBP (nonspecific low back pain), OA (osteoarthritis), PI (pain intensity), PG (placebo group), PT (physical therapy), NS (not specified), SAIS (subacromial impingement syndrome), SPADI (Shoulder Pain and Disability Index), TENS (transcutaneous electrical nerve stimulation), US (therapeutic ultrasound), VAS (Visual Analog Scale), and WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index).

3.3. HILT Protocols

Most HILT protocols employed wavelengths centered around 1064 nm [25, 26, 28-30, 32, 33], although alternative or combined wavelengths such as 808 nm [31, 34], 808/905 nm [24, 27], and 810/980 nm [37] were also reported. Emission modes included continuous [28, 29, 33, 35, 38], pulsed [25, 26, 31, 34, 39], or combined modes [24, 27, 30, 36, 37, 40, 42, 43].Peak power ranged from 1 W to 3000 W, with 12 W being the most frequently used [28-30, 32, 33, 35, 40, 42, 43], and a mean power output of 6 W (SD = 3.4).

Regarding application technique, 16 RCTs used a single-phase protocol, with scanning being the most common [25, 28, 31-33, 36, 40-43] followed by punctual application [13, 24, 29, 34], and four trials combining both techniques [26, 27, 35, 37]. The most reported spot size was 3.14 cm², corresponding to a 2 cm diameter probe, used in approximately 62 % of studies. Other reported sizes included 0.2 cm², 0.8 cm², 1 cm², and 6.25 cm², while four studies did not specify this parameter.

The total energy delivered ranged from 100 J [30] to 3750 J [41], with average session doses between 1000 and 1200 J. Punctual applications ranged from 6.6 J [24] to 25 J per point [27] (mean: 19 J), while scanning doses ranged from 150 J to 3750 J [30, 41] (mean: 1776 J). Treatment duration ranged from 36 to 900 seconds, with an average of 618 seconds.

3.4. LLLT Protocols

LLLT parameters were typically within the infrared spectrum, ranging from 775 [33] to 905 nm [43]. The most frequently used wavelengths were 810 nm [24, 25, 31, 37] and 830 nm [26, 27, 29, 40, 42], with one study employing a dual-wavelength device (810/980 nm) [37]. Emission modes were predominantly pulsed [13, 26, 27, 29, 30, 33, 35-38, 41], while a few studies used continuous wave lasers [24, 25, 28, 42, 43]. Peak power varied from 0.065 W [28] to 45 W [33], although most studies reported values between 0.4 and 0.8 W [13, 24, 29, 30, 32, 38, 41, 42]. Three studies used cluster-type lasers with outputs up to 1.05 W [26, 27, 35]. In LLLT protocols, spot sizes ranged from 0.028 cm² to 1.5 cm², with 1 cm² being the most frequently reported. Several studies used 0.5 cm², 0.19 cm², or 1.5 cm², while over one-third did not specify this parameter.

Punctual application was the predominant technique [13, 24, 26, 27, 29-31, 34, 36-38, 41], while seven studies used scanning exclusively [25, 28, 32, 35, 40, 42]. The total energy per session ranged from 9 J to 2000 J, with 300 J being the most frequently delivered dose. In punctual technique protocols, energy per point ranged from 1.5 J [43] to 36 J [36], with a mean of approximately 8 J. The total energy for scanning applications varied between 60 J [42] and 1200 J [32].

Table 4. Comparative Summary of Laser Parameters in HILT and LLLT Protocols in the Included Studies.

Laser Parameters	HILT	LLLT
Laser model	MLS, HIRO, BTL-6000, OptonPro, HC YAG Pagani	DORIS MICRO - CTL 1106M, BTL-5000 Cluster Laser, LAS Expert, Endolaser 422, Diode Laser (Chattanooga Group), Lasermed 4098
Wavelength (nm)	808–1064 nm	775–905 nm (frequent: 810 nm, 830 nm; combined: 810/980 nm)
Emission mode	Continuous, pulsed, or both (multi-phase protocols)	Pulsed (most studies), Continuous (few studies)
Output power (W)	1–3000 W (peak); most commonly up to 25 W in practical protocols	0.065–45 W (peak)
Mean power (W)	1–12 W (mean: 6 W ± 3.4)	0.1–0.64 W (most commonly ~0.4 W)
Frequency (Hz) / Duty cycle (%)	5–2000 Hz; duty cycle 25–100 %	0–6500 Hz; 50–80 % duty cycle
Spot size (cm²)	0.2–6.25 cm² (frequently 3.14 cm²)	0.028–1.5 cm² (most commonly between 0.5–1 cm²)
Energy density (J/cm²)	0.61–6.4 J/cm²; up to 150 J/cm² in some protocols	0.2–50 J/cm²
Total energy (J)	12–3750 J (depending on duration and application mode)	8–2000 J per session; 1.5–36 J per point
Treatment duration	36 seconds to 15 minutes	36 seconds to 32 minutes

Abbreviations: HILT (High-Intensity Laser Therapy); LLLT (Low-Level Laser Therapy); MLS (Multiwave Locked System); BTL (BTL Medical Technologies); HC YAG (High Current Yttrium Aluminum Garnet laser); CTL (Ceramic Technology Laser); LAS (Laser Analgesia System); nm (nanometers); W (watt); Hz (hertz); cm² (square centimeters); J/cm² (joules per square centimeter); J (joules).

The meta-analysis examined the comparative effectiveness of HILT and LLLT when applied as standalone treatments, in combination with exercise, or alongside other PT modalities such as TENS, therapeutic ultrasound, manual therapy, kinesiology taping, hydrocollator packs, and cryotherapy (Fig. 2).

SMDs were calculated to quantify between-group effects on pain intensity [19]. Given the substantial heterogeneity across studies (I^2 > 50 %), a random-effects model was applied [20].

Across all comparisons, HILT yielded more pronounced analgesic effects than LLLT. When used as monotherapy, HILT significantly outperformed LLLT (SMD = −0.90; 95 % CI: −1.7 to −0.1), and a similar advantage was observed when HILT at mild doses was combined with exercise (SMD = −2.32; 95 % CI: −4.6 to −0.1). In contrast, no significant differences emerged between HILT and LLLT when both were integrated with other PT techniques or when compared against placebo. Notably, the intervention with the greatest impact on pain reduction was the use of PT modalities – representing a multimodal approach – which showed the largest effect size (SMD = −3.33; 95 % CI: −5.7 to −0.9).

The network meta-analysis incorporated 976 participants (Fig. 3A). The model exhibited a good fit ($\bar{D}$ = 47.1; observed = 45) and showed no signs of inconsistency (p > 0.05), despite high between-study heterogeneity ($\tau^2 \geq 50$ %). A total of 28 direct and 91 indirect comparisons were analyzed across 14 intervention types. Based on SUCRA rankings derived from radial plots (Fig. 3B), the highest probability of effectiveness was associated with PT interventions (SUCRA = 98.4 %), followed by HILT at mild doses combined with exercise (SUCRA = 90.7 %). Conversely, exercise alone had the lowest probability of effectiveness (SUCRA = 10.4 %), though this strategy was assessed in a limited number of trials. Table 5 presents the ranking probabilities and SUCRA values for each intervention based on their effectiveness in reducing pain intensity [22, 23].

4. Discussion

This preliminary network meta-analysis compared the analgesic effectiveness of HILT and LLLT, applied either as isolated or in combination with exercise or PT modalities, in individuals with musculoskeletal pain. Overall, HILT demonstrated superior analgesic effects compared to LLLT – both when applied alone and when combined with exercise. However, it was less effective than the broader category of conventional PT modalities, such as TENS, ultrasound, cryotherapy, manual therapy, stretching, and kinesiology taping. Importantly, no adverse events were reported across studies, supporting the safety profile of both laser modalities.

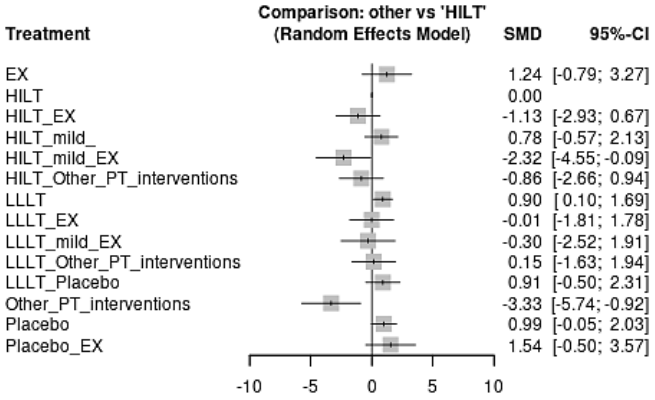

Fig. 2. Forest plot of SMD for pain intensity using a random-effects model: comparison of all treatments versus HILT.

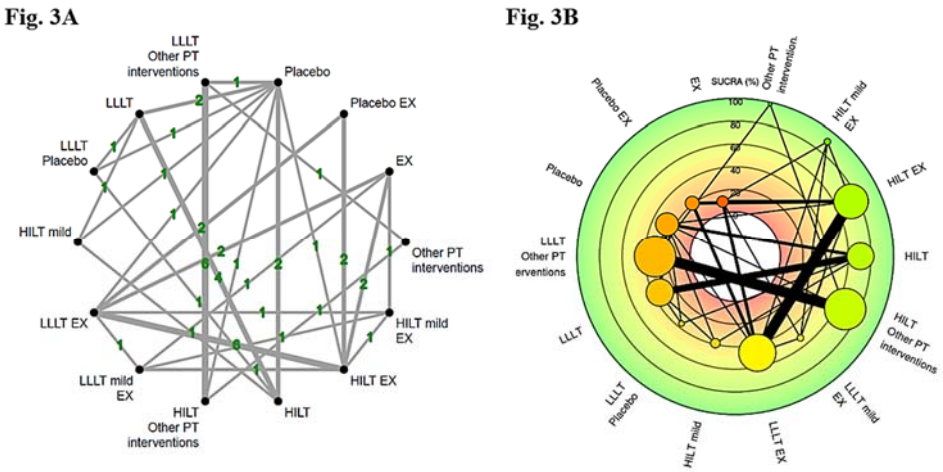

Fig. 3. Network plot and SUCRA-based radial ranking of interventions for pain intensity.

Table 5. Ranking Probabilities and SUCRA Values of Interventions for Pain Reduction Based on Network Meta-Analysis.

Treatment	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8	Rank 9	Rank 10	Rank 11	Rank 12	Rank 13	Rank 14	SUCRA
Other PT interventions	0.85	0.13	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	98.40
HILT (mild) plus EX	0.15	0.68	0.09	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	90.66
HILT plus EX	0.00	0.03	0.33	0.26	0.18	0.10	0.05	0.03	0.02	0.01	0.00	0.00	0.00	0.00	73.63
HILT	0.00	0.06	0.21	0.22	0.19	0.13	0.09	0.05	0.02	0.01	0.00	0.00	0.00	0.00	70.74
HILT plus other PT interventions	0.00	0.08	0.21	0.18	0.15	0.12	0.09	0.06	0.04	0.03	0.02	0.01	0.01	0.00	67.87
LLLT (mild) plus exercise	0.00	0.01	0.08	0.12	0.13	0.13	0.11	0.09	0.07	0.06	0.06	0.07	0.04	0.01	52.50
LLLT plus exercise	0.00	0.00	0.00	0.04	0.11	0.16	0.17	0.14	0.12	0.10	0.09	0.06	0.01	0.00	47.61
HILT (mild)	0.00	0.01	0.03	0.05	0.07	0.09	0.10	0.11	0.11	0.10	0.09	0.09	0.08	0.07	38.92
LLLT placebo	0.00	0.01	0.02	0.04	0.06	0.08	0.10	0.11	0.11	0.10	0.10	0.10	0.09	0.09	36.25
LLLT	0.00	0.00	0.00	0.01	0.03	0.07	0.10	0.13	0.15	0.14	0.13	0.11	0.08	0.05	34.08
LLLT plus other PT interventions	0.00	0.00	0.01	0.02	0.04	0.07	0.08	0.10	0.11	0.11	0.11	0.12	0.11	0.12	30.94
Placebo	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.14	0.20	0.23	0.18	0.09	0.03	26.94
Placebo plus exercise	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.08	0.09	0.10	0.15	0.28	0.14	21.07
Exercise	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.09	0.21	0.49	10.38

Abbreviations: HILT (High-Intensity Laser Therapy); LLLT (Low-Level Laser Therapy); EX (Therapeutic Exercise); PT (Physical therapy modalities apart from laser therapy or exercise, such as electrotherapy, cryotherapy, kinesiotaping, therapeutic ultrasound, or manual therapy).

4.1. Laser Modalities and Analgesic Mechanisms

Although HILT outperformed LLLT in terms of pain relief, neither modality showed significant additional benefit when used alongside other PT interventions. These findings support the clinical value of multimodal strategies, particularly in chronic musculoskeletal conditions, where the combination of therapeutic techniques is widely advocated [44, 45]. Notably, conventional PT interventions demonstrated the highest effect sizes, underscoring their central role in pain management. These findings suggest that laser therapies are best utilized as adjuncts within multimodal treatment strategies, rather than as stand-alone interventions.

Both HILT and LLLT exert their effects through PBM mechanisms, including the modulation of inflammatory mediators, enhancement of local circulation, reduction in nociceptive conduction velocity, and stimulation of endogenous opioid (beta-endorphins] release [4–6]. However, the greater power output of HILT enables the delivery of higher energy in shorter durations, potentially accelerating anti-inflammatory, analgesic, and tissue repair processes [4, 5, 8, 33, 34]. Additionally, its thermal effects may further enhance vascular and neuromuscular responses – such as improved blood flow and muscle relaxation – thereby disrupting the pain–spasm cycle and enhancing pain relief [46, 47].

Several studies applied HILT not only to the primary pain site using a point-by-point technique but also to adjacent periarticular or muscular regions through scanning applications [26, 27, 35, 37]. This combined approach may enhance therapeutic outcomes by simultaneously eliciting FBM and thermal effects across a broader treatment area. Such a strategy appears particularly appropriate in chronic conditions like knee osteoarthritis [24, 26, 29, 40, 42, 43] and spinal pain [27, 28, 32, 38, 39], where thermal modalities are commonly recommended as part of standard physiotherapeutic care [46, 48].

Although HILT – like LLLT – has demonstrated favorable effects on pain intensity, its impact is primarily limited to symptom relief and does not directly improve functional impairments. In contrast, structured physical therapy programs and therapeutic exercise are more effective in enhancing physical function and reducing disability [2]. Therefore, laser therapy should be integrated into comprehensive rehabilitation protocols to optimize overall clinical outcomes.

4.2. Dosimetry and Clinical Implications

The effectiveness of laser-based interventions is not solely dependent on the modality (HILT or LLLT) but rather on the interplay of several technical and dosimetric parameters, including total energy dose (J), energy density (J/cm²), laser wavelengths, duty cycle (%), treatment duration, and spot size [4-6]. These factors collectively determine the quantity and distribution of energy delivered to the target tissue, thereby influencing both FBM and thermal effects. For instance, the higher power output and larger spot sizes characteristic of HILT enable broader and more efficient tissue coverage, which may enhance anti-inflammatory, analgesic, and reparative effects [5, 6]. Conversely, LLLT's lower output and smaller spot sizes often necessitate longer application times to achieve equivalent doses, potentially reducing practicality and contributing to variability in outcomes [49].

Furthermore, wavelength is a critical parameter in laser therapy, influencing both penetration depth and interaction with tissue chromophores [49, 50]. In this review, all protocols used infrared wavelengths between 808 and 1064 nm. Although differences in penetration between these wavelengths appear

clinically negligible [51], those closer to 1064 nm may offer advantages in HILT, as they align with water absorption peaks – potentially enhancing thermal effects [4, 52]. Additionally, individual patient characteristics – such as skin pigmentation, tissue composition, and the chronicity of symptoms – may influence treatment response, reinforcing the need for individualized treatment planning [53].

A key challenge in the clinical use of laser therapy is the substantial heterogeneity in dosing protocols, particularly among LLLT studies, where energy delivery is generally lower than in HILT. This difference often reflects practical constraints, as LLLT require significantly longer durations to reach therapeutic doses, complicating both standardization and comparability across studies.

According to the Arndt-Schulz law, both insufficient and excessive energy doses may attenuate biological effects, thereby compromising therapeutic efficacy and reinforcing the need to identify optimal therapeutic ranges [54]. While LLLT dosimetry is supported by recommendations from the World Association for Photobiomodulation Therapy (WALT) [55], no comparable consensus-based guidelines currently exist for HILT. Only a limited number of authors have proposed dosage frameworks for HILT, and the lack of standardized posology remains a significant gap in the current literature [56, 57]. Therefore, although both modalities demonstrate clinical potential, further research is warranted to establish optimal HILT dosimetry and develop standardized, evidence-based protocols that ensure treatment consistency, safety, and effectiveness.

Based on available pooled data, a minimum cumulative dose of approximately 300 joules per session over 6–8 sessions may serve as a preliminary reference for HILT protocols, although further validation is needed. Although HILT demonstrated superior short-term effects on pain, its substantially higher cost raises important questions about cost-effectiveness [13]. On average, HILT devices are more than twice as expensive as LLLT units. However, the limited availability of long-term follow-up data restricts our ability to determine whether these benefits are sustained over time or ultimately converge with those of LLLT. This prompts a critical question: are HILT's superior outcomes attributable to its technical advantages – such as the combined FBM and thermal effects – or simply a consequence of delivering higher energy doses due to its greater output power? If treatment efficacy is primarily dose-dependent, it is plausible that LLLT, when optimized to match energy delivery, could achieve comparable clinical outcomes at a significantly lower cost. Future research should aim to standardize energy parameters and report dosimetry comprehensively to better assess both the therapeutic and economic value of each modality – especially in resource-limited healthcare settings. In such contexts, cluster-type LLLT devices, which allow higher energy delivery across larger treatment areas, may serve as a practical and cost-effective alternative. Optimizing LLLT dosimetry through cluster emission could help approximate the clinical benefits of HILT and improve accessibility without compromising efficacy.

4.3. Limitations

This preliminary network meta-analysis presents several limitations that should be acknowledged when interpreting its findings. First, substantial methodological and clinical heterogeneity was observed across the included studies, stemming from differences in intervention protocols, patient populations, dosimetric parameters, and outcome measures. While the use of SMDs allowed for data pooling, this metric reduces clinical interpretability, particularly in determining whether treatment effects surpass established thresholds for minimal clinically important differences.

Second, the analysis focused exclusively on pain intensity, without incorporating other relevant clinical outcomes such as physical function, disability, range of motion, or health-related quality of life. Although several included trials assessed these variables, the heterogeneity in measurement tools and reporting prevented their inclusion in the meta-analysis. Future reviews should aim to integrate these endpoints to provide a more comprehensive evaluation of therapeutic effectiveness.

Third, the long-term efficacy of laser therapy remains uncertain. Few trials have incorporated follow-up assessments beyond the immediate post-intervention phase, and those that did exhibited substantial variability in duration (ranging from 3 to 12 months). This inconsistency in follow-up assessments and outcome reporting limits the ability to determine whether the benefits of HILT or LLLT are sustained over time. To address this gap, future randomized controlled trials should employ standardized outcome measures and longer follow-up periods to better inform clinical practice.

5. Conclusion

This preliminary network meta-analysis, focused on pain intensity, suggests that HILT may provide superior analgesic effects compared to LLLT, particularly when administered as a standalone intervention or in combination with exercise. However, conventional PT interventions – such as transcutaneous electrical nerve stimulation, ultrasound, cryotherapy, and manual therapy – demonstrated even higher probabilities of pain reduction than either laser modality alone. These findings indicate that laser-based therapies may be most effective when used as adjuncts within comprehensive, multimodal rehabilitation programs, rather than as stand-alone treatments.

Nonetheless, these results should be interpreted with caution due to substantial heterogeneity among

the included studies, especially in laser parameters and dosing regimens. The lack of clearly established therapeutic windows – particularly regarding optimal energy delivery – remains a significant limitation. Although HILT demonstrated greater potential for analgesia, its high cost and the lack of standardized treatment protocols may limit its widespread clinical adoption. Conversely, optimizing LLLT dosimetry using technologies such as cluster emitters may offer a cost-effective alternative, particularly in low-resource settings.

Future research should prioritize the standardization of intervention parameters, exploration of dose–response relationships, and inclusion of broader clinical outcomes – such as functional improvement, disability reduction, and quality of life – to better define the role of laser therapy in musculoskeletal rehabilitation.

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