ORIGINAL ARTICLE

Influence of heat therapy and/or vibration on nonspecific back pain: A prospective, open, randomized, controlled, parallel-group clinical study

Influence de la thérapie par la chaleur et/ou les vibrations sur les rachialgies non spécifiques: une étude clinique prospective, ouverte, randomisée, contrôlée, en groupes parallèles

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Abstract

Introduction-Aim: Traditional heat therapy (HEAT) and emerging vibration therapy (VIB) have shown potential benefits in alleviating nonspecific back pain (NSBP). This randomized controlled study aimed to evaluate the efficacy of HEAT, VIB, and their combination (COMBI) in reducing pain levels and improving cardiovascular parameters in NSBP patients.

Methods: Fifty-nine patients with NSBP were randomly assigned to 3 groups: HEAT (n=19), VIB (n=20), and COMBI (n=20). The study included three visits (V_1 to V_3) with interventions in V_2. Pain visual analogue scale scores (ie; primary outcome, with a minimal clinically important difference (MCID) set at 10 mm on a 100 mm scale), oxy-haemoglobin saturation (SpO^2), heart-rate, blood-pressure, and perfusion-index were evaluated before (V_{2b}) and after (V_{2a}) each intervention. During V_3 (ie; telephone call one day after the intervention) only pain score was evaluated. Changes (ie; V_{2a}-V_{2b}, V_3-V_{2b}) were calculated.

Results: All 3 therapies were clinically effective, with mean pain changes exceeding the MCID. The COMBI group showed the greatest pain reduction in mm (17 at V_2, 23 at V_3) compared to the VIB (15 at V_2, 10 at V_3) and HEAT (11 at V_2, 10 at V_3) groups. In comparison to the COMBI group, the VIB one exhibited a higher change in heart-rate (-2±4 vs. 3±5 bpm; -1±3 vs. 1±3 % of predicted maximum hear-rate, respectively). SpO^2 change under COMBI decreased significantly by 1±1%. No significant changes were observed in blood-pressure or perfusion-index across the groups.

Conclusions: COMBI-therapy provides superior pain relief for NSBP compared to each therapy alone. RCT registration. ISRCTN registry (https://www.isrctn.com/); Trial Number: ISRCTN15769490 (https://doi.org/10.1186/ISRCTN15769490).

Key words: Back Pain; Heat Therapy; Pain Measurement; Randomized Controlled Trial; Vibration

Résumé

Introduction-Objectif: La thérapie traditionnelle par la chaleur (TTC) et la thérapie émergente par vibrations (VIB) ont montré des bénéfices potentiels dans l'atténuation des rachialgies non spécifiques (RNS). Cette étude randomisée et contrôlée visait à évaluer l'efficacité de la TTC, VIB et de leur combinaison (COMBI) dans la réduction des niveaux de douleur et l'amélioration des paramètres cardiovasculaires chez des patients souffrant de RNS.

Méthodes: Cinquante-neuf patients atteints de RNS ont été répartis aléatoirement en 3 groupes: TTC (n=19), VIB (n=20) et COMBI (n=20). L'étude comprenait trois visites (V_1 à V_3) avec des interventions à V_2. Les scores sur l'échelle visuelle analogique de la douleur (critère principal, avec une différence minimale cliniquement significative (DMCS) fixée à 10 mm sur une échelle de 100 mm), la saturation en oxyhémoglobine (SpO^2), la fréquence cardiaque, la pression artérielle et l'indice de perfusion ont été évalués avant (V_{2av}) et après (V_{2ap}) chaque intervention. Lors de la V_3 (appel téléphonique un jour après l'intervention), seul le score de douleur a été évalué. Les changements (V_{2ap}-V_{2av}, V_3-V_{2av}) ont été calculés.

Résultats: Les trois thérapies ont montré une efficacité clinique, avec des changements moyens de douleur dépassant la DMCS. Le groupe COMBI a présenté la plus grande réduction de la douleur en mm (17 à V_2, 23 à V_3) comparé aux groupes VIB (15 à V_2, 10 à V_3) et TTC (11 à V_2, 10 à V_3). En comparaison au groupe COMBI, le groupe VIB a montré une plus grande variation de la fréquence cardiaque (-2±4 vs. 3±5 bpm; -1±3 vs. 1±3 % de la fréquence cardiaque maximale prédite, respectivement). Le changement de SpO^2 dans le groupe COMBI a diminué de manière significative de 1±1 %. Aucun changement significatif n'a été observé pour la pression artérielle ou l'indice de perfusion dans les différents groupes.

Conclusions: La thérapie COMBI, comparée à chaque thérapie prise isolément, offre un soulagement pus marquée de la RNS. Enregistrement de l'essai contrôlé randomisé (RCT). Registre ISRCTN (https://www.isrctn.com/); Numéro d'essai: ISRCTN15769490 (https://doi.org/10.1186/ISRCTN15769490).

Mots-clés: Dorsalgie; Essai contrôlé randomisé; Evaluation de la douleur; Thérapie par chaleur; Vibration

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Introduction

The prevalence of back pain (BP) presents a significant challenge in the fields of epidemiology, medicine and health economics (1). According to a comprehensive study, BP is a widespread medical condition that affects approximately 540 million patients worldwide at any given time (2). The research indicated that BP is a leading cause of disability globally and can hinder patients from engaging in occupational and daily activities (2). In Germany alone, approximately eight million patients suffer from chronic BP (3). While there are objective causes of specific BP, such as pain from vertebral body injuries, nonspecific BP (NSBP) usually lacks clear causes (3). It is estimated that, on average, the ratio of specific BP to NSBP across the entire population is 1:4 (4). This highlights the need to focus particularly on the treatability of NSBP (5).

Chronic low BP (LBP) influences both local and systemic physiological functions. Firstly, it causes structural and functional changes in the paraspinal muscles, including muscle atrophy, fatty infiltration, and impaired motor control (6). These alterations contribute to persistent pain and functional limitations (6). Secondly, chronic LBP can lead to modified movement patterns, resulting in abnormal spinal loading and an increased risk of further degeneration (7). Thirdly, chronic LBP triggers maladaptive neuroplastic changes, leading to central sensitization and heightened pain perception (8). Fourthly, chronic LBP is linked to an enhanced inflammatory response, characterized by elevated pro-inflammatory cytokines (eg; interleukin-6, tumour necrosis factor-α), which contribute to widespread pain hypersensitivity and systemic fatigue (9). Fifthly, autonomic nervous system dysregulation can cause altered cardiovascular responses, increased stress hormone levels (eg; cortisol dysregulation), and impaired thermoregulation (10). Sixthly, patients with chronic LBP frequently experience anxiety, depression, and cognitive impairments, which exacerbate pain chronicity due to shared neural pathways involved in pain and mood regulation (11). Lastly, reduced physical activity as a result of chronic LBP is associated with lower cardiovascular fitness, metabolic disorders, and a higher risk of obesity (12). The progression from acute to chronic LBP is a multifaceted process influenced by biological, psychological, and social factors (8, 9, 11, 13-15). Firstly, repeated nociceptive input from the lower back can lead to both peripheral and central sensitization (8), resulting in hyperalgesia and allodynia. Secondly, persistent pain is associated with structural and functional changes in brain regions such as the prefrontal cortex, amygdala, and anterior cingulate cortex, which enhance pain perception, emotional distress, and impaired pain inhibition (11). Thirdly, psychological factors, including anxiety, depression, and fear-avoidance behaviours, contribute significantly to pain chronification (13). For instance, patients with kinesiophobia may avoid physical activity, further exacerbating muscle deconditioning and disability. Fourthly, chronic LBP is characterized by persistent low-grade inflammation, marked by increased levels of cytokines like interleukin-1β and tumour necrosis factor-α, which play a role in sustaining pain and promoting tissue degeneration (9). Fifthly, genetic predisposition and epigenetic modifications, such as DNA methylation in pain-related genes, have been associated with a heightened risk of chronic pain development (14). Lastly, dysfunction in descending inhibitory pathways from the brainstem, particularly in serotonergic and noradrenergic systems, diminishes the body's natural pain modulation mechanisms, thereby sustaining pain (15).

Various forms of thermal applications are currently used in physical therapy for NSBP (16-18). Heat is one of the earliest therapeutic methods in medicine (19). Its use has been documented for centuries across various conditions, pain being one of the most common indications (20). Recent publications (21, 22) have confirmed that heat therapy (HEAT) is among the most effective interventions for reducing pain intensity in acute and subacute mechanical nonspecific, musculoskeletal LBP (21). The physiological effects of HEAT on tissues include vasodilation, increased blood flow, enhanced metabolism, heightened inflammation, increased tissue extensibility, activation of the transient receptor potential channels, and pain reduction (23).

In comparison, vibration therapy (VIB) is used less frequently for pain treatment (24). However, in recent years (eg; since 2000), partial- and whole- body vibration (WBV) have gained popularity as non-invasive interventions for various health conditions (24). WBV involves using a device that imparts mechanical vibrations to the body, producing various physiological responses (24). Numerous studies have investigated the impacts of WBV on neurological (25), musculoskeletal (26), and cardiovascular (27) disorders. Studies on the impacts of VIB on cardiovascular function have noted transient phenomena such as itchiness (28, 29), redness (28, 30), erythema (30, 31), and oedema (30) during the first few sessions of WBV. Some authors attribute these phenomena primarily to the increase in blood flow (31-35). The vasodilation effects of WBV might be linked to a sudden rise in the production of vasodilatory substances, such as metabolites and nitric oxide (NO) (32, 36, 37). It has been shown that local vibrations lead to increased pulsatile shear stress (PSS) in the tissue, enhancing the bioavailability of NO and other mediators locally (38). Given this, a modified use of vibration technology, originally developed to combat physical inactivity by increasing muscle activity, appears to offer alternative benefits (39). However, to the finest of the authors' knowledge, no controlled study has yet examined the combination (COMBI) of both interventions for NSBP reduction. This approach might also be the closest to a multimodal treatment strategy (40, 41). In therapeutic practice, as of April 2025, most treatment approaches still primarily focus on unimodal, drug-based symptomatic pain therapy, unfortunately continuing to downplay the risks of side effects, chronicity, misuse, and addiction (42, 43). Not all therapists are consistently aware of these side effects, nor of the fact that a significant paradigm shift in the treatment of BP has occurred in recent decades (eg; 2005-2025) (44). New multimodal and multidisciplinary

therapeutic approaches have been developed and are increasingly succeeding in replacing purely unimodal, drug-centered treatments (40, 44, 45). These combined pain treatments—often involving several days of physiotherapy and exercise therapy—enable patients to achieve a significantly more sustainable recovery (40, 44, 45).

With this in mind, in this randomised controlled trial, we selected traditional HEAT and VIB from the physiotherapeutic arsenal as new forms of mechanical loading and investigated their mechanisms of action and synergistic effects (COMBI) on the pain level (ie; the main outcome) and cardiovascular parameters (eg; oxy-haemoglobin saturation (SpO^2), heart-rate, blood-pressure, and perfusion-index) in patients with NSBP. The therapy will be considered clinically 'efficient' if it induces a change (ie; Delta = after minus before intervention) in pain visual analogue scale (VAS) exceeding the recommended minimal clinically important difference (MCID) of 10 mm on a 100 mm scale (46).

Methods

Study design

This was a monocentric, prospective, open-label, randomised, controlled, unblinded, parallel-group clinical study with repeated measurements before ($_b$) and after ($_a$) the interventions. The study was carried out at the Centre for Diagnostics and Health in Munich (study outpatient clinic, Helene-Mayer-Ring 14, 80809 Munich) over a period of eight months (ie; from July 2015 to February 2016). The study followed the principles of the Declaration of Helsinki and was conducted in accordance with the guidelines set by the CONSORT statement (47). The ethics committee of Ludwig-Maximilians University of Munich approved the protocol (approval number 472/14). The study was registered with the International Standard Randomised Controlled Trial Number (https://www.isrctn.com/; ISRCTN15769490, https://doi.org/10.1186/ISRCTN15769490). Written informed consent was obtained from participants prior to each study intervention. Patients participated in the study at no cost. Data collection was pseudonymized, and the collected data was stored electronically on a password-protected computer.

Study population

Patients were recruited through three methods: i) Mailing campaigns targeting patients who had previously visited the private physiotherapy centre mentioned above; ii) Referrals from resident doctors, and iii) New patients presenting with complaints of NSBP for the first time. Interested patients were met by qualified individuals (MH, CH, and DH in the authors' list) who provided them with comprehensive information about the study and led a pre-screening to determine their eligibility for involvement. Eligible patients were given a participant information sheet for careful review. Any questions or concerns were addressed through discussion with two physicians (MH and DH in the authors' list). Subsequently, both the physician and the patient signed an informed consent form, officially admitting the patient to the study and inviting them to the screening visit. During this visit, patients were informed about the potential benefits and risks of the investigation, including blistering at contact points with the therapy platform, itching in the treated areas of the body, and nausea and dizziness from rapid, brief drops in blood pressure.

During the second visit, often on the same day as the screening visit, patients were randomly allocated to one of three groups: HEAT, VIB, or COMBI therapy (ie; receiving both therapies). Blinding was not feasible due to the nature of the intervention, so an open intervention approach was used. All patients were instructed to continue their conventional medical therapy, such as nonsteroidal anti-inflammatory drugs or antidepressants, throughout the study.

Inclusion, non-inclusion, and exclusion criteria

Only patients aged 18 to 80 years with NSBP within the past 24 hours, as determined by the VAS, were included. Patients with BP that could not be clearly explained by simple clinical means and convincingly accounted for the current symptoms were eligible for inclusion. The applied non-inclusion criteria were: contraindications in specific BP (eg; ankylosing spondylitis) (48), conditions identified as "red flags" (49), specific spinal diseases, inflammatory spondylopathies, internal organ diseases such as renal pelvic inflammation, vertebral collapse due to osteoporosis or accident, malignant tumours, diseases with specific origins such as muscles, intervertebral discs, and nerve roots, acute inflammatory diseases (48), patients with implanted metallic or electronic objects such as pacemaker, defibrillator, and pumps, pregnancy, and large tattoos. Exclusion criteria included occurrence of any adverse event such as abnormal laboratory finding, symptoms, or diseases temporally associated with the use of a medicinal product; and absence during a session.

Device description

The therapy table comprises a base plate, two fixed bases, a fixed pillow, and the vibration plate (Figure 1). The therapy was administered using a prototype "spintrac-couch" manufactured by Kurperle GmbH, Bad Füssing.

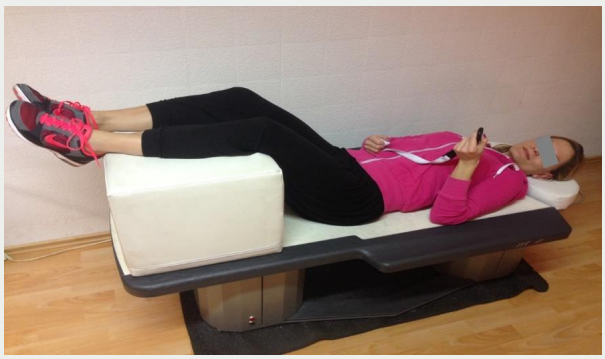

Figure 1. Therapy table.

The patient lies on the vibration plate with their back and positions their head on the pillow, which is securely anchored independently of the vibration plate. Infrared lights are positioned on the inside in the middle of the vibrating plate. These lights emit light with a wavelength of 780-1000 nanometres, heating up a metal field integrated into the vibration plate to 40°C accordingly. Subsequent models of vibration plates incorporate red light intended to directly affect the patient's skin. The vibration plate itself vibrates horizontally and clockwise at a frequency of 20 Hz with an amplitude of 6 mm. Additionally, the therapy table features a setting that enables simultaneous operation of light/heat and vibration. The duration of treatment was 10 minutes.

Study protocol and procedures

Box 1 outlines the study procedures. The procedures consist of three visits (V):

Visit 1 (V_1)
During V_1, we:

- Assigned a screening number for each patient;
- Conducted an anamnesis;
- Performed a physical examination focusing on the musculoskeletal system;
- Measured anthropometric data (ie; height, weight);
- Measured vital parameters (ie; systolic blood-pressure (SBP), diastolic blood-pressure (DBP), heart-rate, SpO_2, perfusion-index); and
- Recorded pain VAS (50).

Once all inclusion and non-inclusion criteria were met, the dates for the randomization visit (V_2) and the first intervention were programmed. V_1 and V_2 usually took place on the same day.

Visit 2 (V_2)
During V_2, patients were randomly assigned to receive their first intervention, either HEAT, VIB or COMBI therapies. Randomization was conducted using a random list generated online through the random group generator of PubMed available at http://www.pubmed.de/tools/zufallsgenerator/?no_cache=1. A randomization schema determined the assignment of patients to HEAT, VIB, or COMBI therapies' groups. A list was created with a chronological sequence ensuring the clear assignment of each patient to one of the three therapy groups. The physicians responsible for randomization (MH and DH in the authors' list) entered each new patient's name, along with the time, date, and randomized number, into the patient's folder. Due to economic considerations, the physicians were not blinded. Before the first intervention (V_{2b}), we performed the following evaluations: medical history review, physical examination, assessment of vital signs, recording of pain VAS scores and pulse oximetry. After the first intervention (V_{2a}), heart-rate, SpO_2, blood-pressure, perfusion-index and pain VAS scores were re-evaluated.
The variation between the values obtained after and before the intervention (ie; Delta = V_{2a} minus V_{2b}) was calculated for each parameter.

Visit 3 (V_3)
One day after the final intervention, a follow-up phone call was made to assess patient safety, the sustainability of effects, and pain VAS scores. The difference between the values obtained after the final intervention and before the first intervention (ie; Delta = V_3 minus V_{2b}) was calculated.
During subsequent physiotherapy visits, patients were informally asked about their willingness to use the therapy table and provided with an opportunity to share their feedback regarding the therapies.

Box 1. Study procedures.

Visits (V)	V_1	V_2		V_3
		V_{2b}	V_{2a}	
Therapies (interventions)			Yes	
Informed consent	Yes			
Screening	Yes			
Randomization		Yes		
Medical history	Yes	Yes		Yes
Physical examination	Yes	Yes		
Anthropometric data (***ie***; height, weight)	Yes			
Vital signs (***ie***; systolic and diastolic blood pressure)	Yes	Yes	Yes	
Pain: Visual analogue scale	Yes	Yes	Yes	Yes
Pulse oximetry (***ie***; heart-rate, oxy-hemoglobin saturation, perfusion index)		Yes	Yes	

$_a$: After therapy. $_b$: Before therapy. V_1: Visit 1. V_2: Visit 2. V_3: Visit 3 (Telephone call).

NSBP diagnosis and localization

The criteria from the Federal health report by the Robert Koch institute (48), aligned with the European clinical guidelines on chronic NSBP (49), were applied. Diseases marked with "red and yellow flags" were excluded. The location of BP (eg; upper shoulder/cervical spine, middle, lower) was recorded.

Collected data

Height (in meters) was measured using a Harpenden® stadiometer, and weight (in kilograms) was recorded with a calibrated SECA® 711 mechanical patient scale, which can measure up to 220 k. Body mass index (BMI, kg/m^2) was then calculated, and the following corpulence categories were determined: underweight (BMI < 18.5 kg/m^2), normal weight (BMI: 18.5-24.9 kg/m^2), overweight (BMI: 25.0-29.9 kg/m^2), and obesity (BMI > 30.0 kg/m^2) (51).
SBP and DBP (measured in mmHg) and heart-rate (measured in bpm) were recorded after a 5-minute rest period in a seated position. Heart-rate was also expressed as a percentage of the predicted maximal heart-rate (PMHR) using the formula: PMHR (bpm) = 208 – (0.7 × Age) (52). A digital blood-pressure monitor (model UH-707plus, A&D Co, Ltd. Saitama, Japan) was used on the left upper arm. SpO^2 (measured in %) was determined using a finger pulse oximeter (Beijing Choice Electronic Technology Co., Ltd. Technology Co., Ltd., China). The perfusion-index was assessed with a Wireless pulse oximeter (Gravis Computervertriebs-GmbH, Ernst-

Reuter-Platz 8, 10587 Berlin).
Pain scores were evaluated using the visual analogue scale (VAS), which ranges from 0 to 100 (ie; no pain to unbearable pain) on a 100-mm scale (50).

Sample size calculation and statistical analysis

Sample size
The sample size was estimated using the formula (53):
$\mathbf{N = (2\,(Z_{\alpha/2} + Z_{1-\beta})^2\,\delta^2)/MCID^2}$, where

- "N" is sample size for each group;
- "$Z_{\alpha/2}$" is the normal deviate for type I error (fixed at 5%, $Z_{\alpha/2} = 1.96$);
- "$Z_{1-\beta}$" is the normal deviate for type II error (fixed at 85%, $Z_{1-\beta} = 1.03$).
- "δ" and "MCID" are the pooled standard deviation and the MCID of the main outcome (ie; pain VAS). Given the pioneering nature of this study at the time of its realization, "δ" and "MCID" values were fixed at 10 mm on a 100 mm scale (46).

Inserting the aforementioned data into the formula resulted in a sample size of 18 patients in each group. Considering a potential power loss of 10% due to possible adverse effects, the revised sample size was calculated to be 20 patients in each group [20 = 18/(1-0.10)].

Expression mode of data
Categorical data (eg; sex, corpulence status) were presented as number (%), respectively. Quantitative data (eg; age, anthropometric data, heart-rate, blood-pressure, SpO_2, perfusion-index, pain VAS) were presented as mean ± standard deviation) (95% confidence interval). Variations (Delta = after minus before) induced by the therapies were calculated for each set of the aforementioned quantitative data.

Period effect: before vs. after
The Wilcoxon matched pairs test was utilized to compare the quantitative data of the same group before and after the intervention.

Group effect: Comparison between the three groups
One-way analysis of variance (ANOVA) was employed to compare the quantitative data between the three groups. If necessary, the Tukey honestly significant difference test was applied.

Group and period effect: Three groups vs. two periods
Factorial ANOVA was utilized to examine the intervention differences (ie; groups vs. periods) and to analyse the differences between and within the study sessions and groups. The effect size was calculated using partial eta-squared and Hedge's values for effect size measurement (54). An effect size of ≤ 0.20 was described as small, around 0.50 as medium, and around 0.80 as large (55).

Clinical significant approach
Any therapy inducing a change in pain VAS exceeding the recommended MCID of 10 mm on a 100 mm scale was considered clinically 'efficient' (46).

All statistical analyses were performed using statistical software (StatSoft, Inc. (2011). STATISTICA, version 12). The significance level was set at $p < 0.05$.

Results

Figure 2 illustrates the study enrolment. Among the initially recruited 86 patients, data of 26 patients were excluded from the final analysis. The remaining 60 patients were equally randomized into the three groups. One patient from the HEAT group was lost during the follow-up, resulting in a final sample of 59 patients (19 in the HEAT group, 20 in the VIB group, and 20 in the COMBI group) (Figure 2). Patient feedback throughout the study was notably positive.

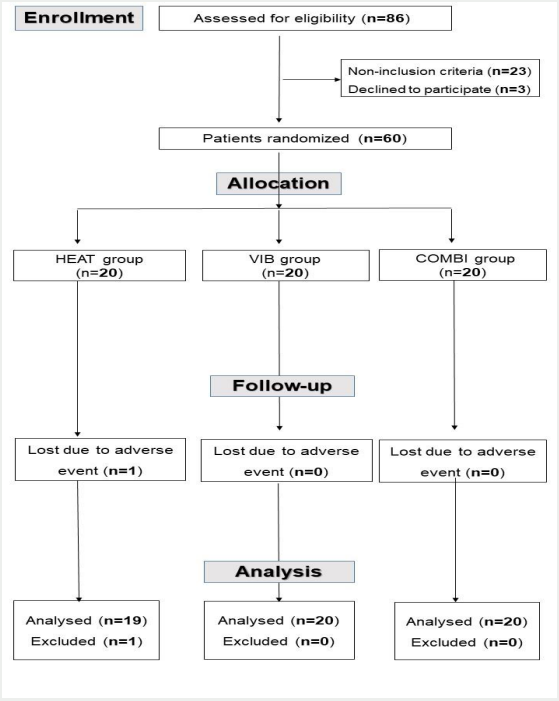

Figure 2. Study flowchart.
COMBI group: Combination group (both therapies). **HEAT group**: Heat therapy group. **VIB group**: Vibration therapy group.

Characteristics of the three groups

Table 1 presents the characteristics of the three groups. The groups were matched for sex, height, weight, BMI, and corpulence status. However, the COMBI group was approximately 15 years younger than the VIB group.

Effects on pain VAS

Table 2 compares pain VAS data between the three groups. One-way ANOVA indicated no statistically significant differences for Delta1 and Delta2. Factorial ANOVA revealed only period effects with lower pain VAS values after the therapy. Comparisons "before vs. after1" therapy revealed statistically significant decreases in pain VAS by 10.8 mm (HEAT group), 15.3 mm (VIB group), and 16.8 mm (COMBI group). Comparison "before vs. $after_2$" therapy identified a statistically significant decrease in pain VAS by 23.4 mm only in the COMBI group. All effect sizes were small.

Table 1. Characteristics of the three groups.

Data	Unit/Category	HEAT group (n=19)	VIB group (n=20)	COMBI group (n=20)	p-value
Sex	Male	5 (26.3)	7 (35.0)	7 (35.0)	0.0805
Age	Year	53±19 (43 to 62)	61±15 (54 to 69)	46±14 (40 to 53)	0.0188†‡
Height	m	1.65±0.08 (1.61 to 1.69)	1.68±0.12 (1.62 to 1.74)	1.73±0.13 (1.67 to 1.79)	0.0934
Weight	kg	72±12 (66 to 78)	77±15 (67 to 81)	80±17 (73 to 88)	0.1711
Body mass index	kg/m²	26.5±3.6 (24.8 to 28.3)	26.3±5.0 (23.9 to 28.6)	27.1±6.0 (24.3 to 29.9)	0.8509
Corpulence status	Underweight	0 (0.0)	1 (5.0)	0 (0.0)	0.5231
	Normal weight	7 (36.8)	7 (35.0)	9 (45.0)	
	Overweight	9 (47.4)	9 (45.0)	5 (25.0)	
	Obese	3 (15.8)	3 (15.0)	6 (30.0)	

Categorical and quantitative data were number (%), and mean±standard deviation (95% confidence interval), respectively.
COMBI group: Combination group (both therapies). **HEAT group**: Heat therapy group. **VIB group**: Vibration therapy group.
p-value (Chi-2 test): Comparison of categorical data between the 3 groups
†p-value < 0.05 (One way analysis of variance): Comparison of quantitative data between the 3 groups.
Tukey HSD test: ‡(p-value < 0.05): VIB group vs. COMBI group.

Table 2. Pain (visual analogue scale) data.

Periods	Groups			ANOVA p-value			
	HEAT group (n=19)	VIB group (n=20)	COMBI group (n=20)	Period effect	Group effect	Period and group effect	Partial eta-squared
Before	51.4±13.5 (44.9 to 57.9)	56.9±17.4 (48.8 to 65.0)	51.0±15.7 (43.6 to 58.3)	0.0009‡	0.3000	0.7788	0.0044
After$_1$	40.5±21.4 (30.2 to 50.8)	41.6±22.0 (31.3 to 51.9)	34.2±22.8 (23.5 to 44.9)				
After$_2$	41.7±24.7 (29.8 to 53.6)	46.9±26.0 (34.8 to 59.1)	27.6±18.7 (18.9 to 36.3)	0.0004‡	0.0675	0.2596	0.0244
Delta$_1$	-10.8±17.3 (-19.2 to -2.5)†	-15.3±13.2 (-21.5 to -9.1)†	-16.8±16.6 (-24.5 to -9.0)†	0.4825			0.0257
Delta$_2$	-9.7±23.6 (-21.1 to 1.7)	-10.0±22.7 (-20.6 to 0.7)	-23.4±18.6 (-32.1 to 14.6)†	0.0861			0.0838

Data were mean±standard deviation (95% confidence interval).
After$_1$: After therapy at visit 2. **After$_2$**: After therapy at visit 3. **ANOVA**: Analysis of variance. **Before**: Before the intervention. **COMBI group**: Combination group (both therapies). **Delta$_1$**: After1 minus before. **Delta$_2$**: After2 minus before. **HEAT group**: Heat therapy group. **VIB group**: Vibration therapy group.
†p-value < 0.05 (Wilcoxon matched pairs test): Before vs. after for each group.
p-value (one way ANOVA): Comparison between the 3 groups for Delta.
‡p-value (factorial ANOVA: Period effect, group effect, period vs. group effect): Comparison between the 3 groups.

Effects on heart-rate

Table 3 compares heart-rate data between the three groups. Comparisons "before vs. after" therapy revealed statistically significant decreases in heart-rate in the VIB group: after therapy, heart-rate decreased by 2±4 bpm and 1±3% of PMHR, respectively. One-way ANOVA indicated significant differences in Deltaheart-rate: Compared to the COMBI group, the VIB group exhibited higher Deltaheart-rate (-2±4 vs. 3±5 bpm, -1±3 vs. 1±3 %PMHR, respectively). However, factorial ANOVA revealed no period vs. group effects.

Table 3. Heart-rate data.

Expression mode	Period	Groups			ANOVA p-value			
		HEAT group (n=19)	VIB group (n=20)	COMBI group (n=20)	Period effect	Group effect	Period vs. group effect	Partial eta-squared
bpm	**Before**	68±9 (64 to 72)	63±7 (59 to 66)	63±9 (59 to 67)	0.9354	0.0099††	0.4629	0.0136
	After	68±8 (64 to 71)	61±9) (57 to 65)	65±10 (61 to 70)				
	Delta	-1±3 (-2 to 1)	-2±4 (-4 to -0)†	3±5 (0 to 5)	0.0037‡§			0.1813
%PMHR	**Before**	40±5 (38 to 42)	38±5 (36 to 41)	36±6 (33 to 39)	0.9263	0.0586	0.5215	0.0115
	After	40±4 (38 to 42)	37±6 (34 to 40)	38±7 (34 to 41)				
	Delta	-0±2 (-1 to 0)	-1±3 (-3 to -0)†	1±3 (0 to 3)	0.0035‡§			0.1824

Data were mean±standard deviation (95% confidence interval).
After: After therapy. ANOVA: Analysis of variance. **Before**: Before therapy. bpm: Beats per minute. **COMBI group**: Combination group (both therapies). Delta: After minus before. **HEAT group**: Heat therapy group. **VIB group**: Vibration therapy group. **%PMHR**: heart-rate expressed as a percentage of the predicted maximal heart-rate.
†p-value < 0.05 (Wilcoxon matched pairs test): Before vs. after for each group.
‡p-value < 0.05 (one way ANOVA): Comparison between the 3 groups for Delta. Tukey HSD test: §(p-value < 0.05): VIBRA group vs. COMBI group.
††p-value < 0.05 (factorial ANOVA: period effect, group effect, period vs. group effect): Comparison between the 3 groups.

Effects on blood-pressure

Table 4 compares blood-pressure data between the three groups. No statistically significant differences were observed for SBP and DBP regardless of the statistical approach applied.

Effects on SpO_2 and perfusion-index

Table 5 compares SpO_2 and perfusion-index data between the three groups. Although ANOVA revealed no statistical differences for both data, comparisons "before vs. after" therapy indicated a statistically significant decrease in SpO_2 in the COMBI group: after therapy, SpO_2 decreased by 1±1%.

Table 4. Systolic (SBP) and diastolic (DBP) blood pressure data.

Data (Unit)	Period	Groups			ANOVA p-value			
		HEAT group (n=19)	VIB group (n=20)	COMBI group (n=20)	Period effect	Group effect	Period vs. group effect	Partial eta-squared
SBP (mmHg)	Before	122±19 (113 to 131)	130±18 (122 to 139)	123±15 (117 to 130)	0.8973	0.0555	0.9435	0.0010
	After	121±15 (114 to 128)	131±17 (123 to 138)	125±17 (117 to 133)				
	Delta	-1±7 (-4 to 2)	1±8 (-3 to 4)	2±10 (-3 to 6)	0.6343			0.0161
DBP (mmHg)	Before	74±10 (69 to 79)	78±7 (75 to 81)	78±13 (72 to 84)	0.9757	0.1787	0.9653	0.0006
	After	74±9 (70 to 78)	77±7 (74 to 81)	77±13 (71 to 83)				
	Delta	1±5 (-2 to3)	-1±6 (-3 to 2)	-0±8 (-4 to 3)	0.8413			0.0062

Data were mean±standard deviation (95% confidence interval).
After: After therapy. **ANOVA**: Analysis of variance. **Before**: Before therapy. **COMBI group**: Combination group (both therapies). **Delta**: After minus before. **HEAT group**: Heat therapy group. **VIB group**: Vibration therapy group.
p-value (Wilcoxon matched pairs test): Before vs. after for each group.
p-value (one way ANOVA): Comparison between the 3 groups for Delta.
p-value (factorial ANOVA: Period effect, group effect, period vs. group effect): Comparison between the 3 groups.

Table 5. Oxy-haemoglobin saturation (SpO^2) and perfusion index (PI) data.

Data	Period	Groups			ANOVA p-value			
		HEAT group (n=19)	VIB group (n=20)	COMBI group (n=20)	Period effect	Group effect	Period vs. group effect	Partial eta-squared
SpO_2 (%)	Before	96±3 (94 to 98)	97±1 (96 to 97)	97±1 (96 to 98)	0.3966	0.1465	0.7000	0.0063
	After	96±3 (94 to 97)	97±2 (96 to 97)	96±1 (96 to 97)				
	Delta	-0±3 (-2 to 1)	0±1 (-1 to 1)	-1±1 (-1 to -0)†	0.4331			0.0294
PI (%)	Before	7±4 (6 to 9)	8±4 (5 to 10)	9±6 (6 to 11)	0.5496	0.2403	0.9015	0.0019
	After	7±4) (5 to 9)	7±4 (5 to 9)	9±6 (6 to 12)				
	Delta	-1±2 (-2 to 0)	-1±4 (-3 to 1)	0±4 (-2 to 2)	0.6842			0.0137

Data were mean±standard deviation (95% confidence interval).
After: After therapy. **ANOVA**: Analysis of variance. **Before**: Before therapy. **COMBI group**: Combination group (both therapies). **Delta**: After minus before. **HEAT group**: Heat therapy group. **VIB group**: Vibration therapy group.
†p-value < 0.05 (Wilcoxon matched pairs test): Before vs. after for each group.
p-value (one way ANOVA): Comparison between the 3 groups for Delta.
p-value (factorial ANOVA: Period effect, group effect, period vs. group effect): Comparison between the 3 groups.

Discussion

The main results of the present study were as follows:
i) All three therapies demonstrated clinical efficiency, as evidenced by mean changes exceeding the recommended MCID of 10 mm during V_2 and V_3. The COMBI group exhibited higher mean changes for pain (-16.8 in V_2 and -23.4 in V_3) compared to the VIB (-15.3 in V_2 and -10.0 in V_3), and HEAT (-10.8 in V_2 and -9.7 in V_3) groups.
ii) Compared to the COMBI group, the VIB group showed higher changes in heart-rate; (-2±4 vs. 3±5 bpm, -1±3 vs. 1±3 %PMHR, respectively);
iii) A significant decrease of 1±1% in SpO^2 was observed "before vs. after" COMBI therapy;
iv) No statistically significant difference was noted for blood-pressure and perfusion-index, regardless of the statistical approach applied.

"In the first half of our lives, we sacrifice our health to earn money, in the second half we sacrifice our money to regain health. And during that time, health and life go away" (55). This quote from Voltaire, dating back to the 18th century, remains relevant today. There are fewer reasons to get up from one's chair for work or hobbies (56). Everything can be done from the comfort of one's home, in front of a screen (56).

Effect on pain

The COMBI group exhibited greater improvements than the other two groups (Table 2). Pain reduction in the COMBI group continued to progress on the day after the procedure (ie; at V_3), with a pain reduction of up to 50% compared to the HEAT and VIB groups, which maintained an average pain reduction of approximately 10-15% (Table 2). This finding aligns with previous studies; although they employed different outcome measures (57-59).

In one study, 80 older participants were randomly assigned to four groups (ie; WBV alone, Heat alone, "WBV plus heat", control group) (59). The intervention spanned three months, with an additional three-month follow-up period (59). Assessment focused on balance ability, muscle strength, and flexibility in the waist and lower limb joints (59). After the intervention, both the WBV and "WBV plus heat" groups exhibited improvements across all measured parameters (59). Notably, the "WBV plus heat" therapy group showed significantly greater improvement compared to other groups, aligning with previous studies (59, 60). Some authors (59) suggested that the high level of improvement in the "WBV plus heat" group may be due to the common use of heat therapy as a pre-exercise aid (58), which enhances tissue metabolism and promotes muscle metabolism before exercise (57). Heat therapy also supports glycogenesis and muscle recovery (57). Another study found that heat therapy reduces the risk of tissue damage by increasing tissue flexibility and lowering the energy cost of muscle contraction through reduced internal friction (61). In addition, in a healthy elderly population, some authors reported that skin blood flow was highest during the combination of passive vibration and moist heat (62), with mean skin blood flow increasing to 450% immediately after a 10-minute intervention and 379% 10 minutes post-intervention, compared to baseline measurements (62).

Pain is a hallmark of inflammation, primarily mediated by the sensitization of primary sensory neurons (63). This process is mainly transmitted through a network of these neurons (63). The pharmacological management of inflammatory pain involves two main strategies: i) Non-steroidal anti-inflammatory drugs, that inhibit prostaglandin production; and ii) Opioids and dipyrone, which block nociceptor sensitization by activating the NO signalling pathway (63). Consequently, BP regulation can be quite complex, often involving multiple causes or combinations (63). Many human diseases have an inflammatory component, with NO being a key mediator (64). NO, a gaseous transmitter widely present in the human body, plays a crucial role in regulating vascular relaxation, immune response, inflammation, neurotransmission, and other essential functions (21). NO is synthesized by three isoenzymes (ie; neuronal, endothelial, and inducible NO synthase), all of which are found in diverse human tissues such as skin, nervous tissue, endothelial tissue, and the digestive tract (65). NO could be a crucial factor in explaining the reduction of pain under vibration and/or heat therapy.

NO is a soluble and highly reactive gas that diffuses through cell membranes, and triggering various local processes in other cells (65). It is continuously synthesized from the amino acid L-arginine in endothelial cells by the constitutive calcium (Ca^{2+}) and CaM-dependent enzyme known as NO synthase (65). CaM, a Ca^{2+}-binding regulatory protein highly conserved in all eukaryotes, acts as a second messenger responsible for activating proteins (66). Several auto regulatory functions of blood vessels control local vascular tone and blood pressure (67). A crucial mechanism among them is the endothelium's ability to sense fluid shear stress exerted by flowing blood and respond by releasing vasodilatory factors such as NO (68). Flow-induced vasorelaxation mediated by NO is essential for adapting vessel diameter to blood flow and regulating vascular tone and blood pressure (69). The activity of NO synthase is increased by fluid shear stress through various mechanisms such as vibration and heat (70, 71). An acute increase in flow leads to a transient elevation of intracellular Ca^{2+} and subsequent Ca^{2+}/CaM-dependent activation of endothelial NO synthase (70, 72, 73), while sustained flow-induced NO formation requires phosphorylation of the enzyme (70-72). NO released by endothelial NO synthase contributes to vascular relaxation, increased blood flow, and downregulation of inflammatory cascades, including those involved in pain (74-76).

In summary, our results appear to support previous recommendations at least partially, suggesting that a change in perspective may be necessary for the treatment of NSBP (44). Moving away from purely unimodal approaches toward more multimodal, holistic, and flexible concepts incorporating newer pain mechanisms and musculoskeletal functional pathologies into targeted treatment concepts seems warranted.

Mechanisms and benefits associated with HEAT and VIB therapies

The authors suggested that gaining a comprehensive understanding of how each therapy affects physiological responses, cellular processes, and overall health outcomes will greatly contribute to unravelling the nuanced interplay between heat and vibration.

Heat therapy

HEAT is widely used in clinical practice to manage musculoskeletal pain (20, 62). When the core body temperature exceeds a threshold, typically around 0.4°C above the resting core temperature, active cutaneous vasodilation and sweating are triggered (77). This threshold may be slightly delayed in older patients (78). Additionally, direct heating of the skin induces vasodilation mainly through the local release of NO (79, 80). As a result, skin blood flow may rise more in environments like a Finnish sauna or hot water immersion compared to a far infrared sauna, even at the same core body temperature (81). During passive heat stress, skin blood flow can increase by up to 4.5-7.0 litres above the resting state in the supine position (82). Some authors have conducted a systematic review using network meta-analysis to assess the effectiveness of treatments for

acute and subacute mechanical nonspecific low back pain (22). They reported that heat wraps, manual therapy, and exercise were among the most effective interventions (22). An international multidisciplinary Delphi-based consensus further emphasizes the importance of heat therapy for musculoskeletal pain, while also highlighting the need for stronger scientific evidence to guide its use in clinical practice (20).

Vibration therapy

Compared to HEAT, VIB is utilized even less frequently for pain management (24). To the finest of the authors' knowledge, only three reviews have evaluated the effects of WBV on LBP (24, 83, 84), and even less frequently for BP (24, 35). The most recent review included only seven sufficiently qualified publications (24). As previously described, local regulation of vascular tone occurs in response to physical influences (85). This means that natural stimuli (eg; mechanical shear stress, temperature, and pulsating fields) can significantly increase the pulsation frequency in older people or in patients with diseases (eg; diabetes mellitus). Blood flow during vibration is significantly positively dependent on amplitude and frequency (86). In 2007, Lohman et al. (87) documented that the application of short-duration (3 minutes), high-amplitude (5–6 mm), and high-frequency (30 Hz) vibrations to the posterior calf muscles significantly increased skin blood flow. In a later study, Lohmann et al. (62) observed that skin blood flow in healthy elderly patients increased most markedly with a combination of passive vibration and moist heat. This combination resulted in a mean increase in skin blood flow of 450% (after the 10-minute intervention) and 379% (10 minutes post-intervention), respectively (62). However, the changes were significantly less pronounced in the groups that received only passive vibration or only moist heat (62). This suggests that blood flow increased significantly for longer than just 10 minutes with the combination. However, these observations may be based on similar physiological changes as in the patients we observed. Lohmann et al. (88) also wondered why moist heat and passive vibration alone did not increase skin blood flow and skin temperature to a comparable extent, but did so when combined. They hypothesized that this was due to the mechanical properties of vibration, which released the vapour in the moist heat device more quickly.

Nevertheless, VIB is gaining popularity as a treatment modality for alleviating pain, increasing muscle activity, and enhancing health-related quality of life (89, 90). VIB has been applied in the treatment of various conditions such as osteoporosis (91), osteoarthritis (92), and fibromyalgia (93). Additionally, VIB may enhance motor function, proprioception (94, 95) and cardiovascular function, including aspects like blood flow, arterial stiffness, and blood-pressure (36, 37).

Heat and vibration therapies: potential synergistic interaction

HEAT promotes vasodilation, leading to increased blood flow, improved tissue oxygenation, and enhanced muscle elasticity (96, 97). This helps reduce muscle stiffness, alleviate pain, and promote relaxation (96, 97). On the other hand, VIB activates mechanoreceptors, enhances proprioception, and modulates pain perception via the gate control theory and central nervous system mechanisms (98). When merged, COMBI therapy may exert a synergistic effect by concurrently improving local circulation (through HEAT) and stimulating neuromuscular activation (through VIB) (96-98). This combined approach can enhance pain relief, optimize muscle function, and accelerate tissue recovery (96-98). Such interactions may be particularly beneficial for musculoskeletal disorders, where both enhanced blood flow and neuromodulation contribute to improved therapeutic outcomes (96-98).

Hypotheses explaining the therapeutic mechanisms

Several hypotheses have been proposed to explain the therapeutic mechanisms. First, vibration may act via the "tonic vibration reflex" (99). This occurs when vibration stimulates primary muscle spindles, activating alpha motoneurons and ultimately contracting the extrafusal muscle fibres (99). This reflex response causes a stretch-reflex in the trunk muscles, thereby activating and strengthening muscles in patients with chronic LBP (100). Occasionally, LBP is associated with paravertebral muscle spasms, and WBV at frequencies below 20 Hz has been suggested to reduce LBP by relaxing muscle spasms (101). Second, a 2022-review offered a distinct perspective on the main mechanisms of WBV (39). The authors of the review focused on non-invasive PSS within the vascular wall and endothelial cells, providing a unique contribution (39). Shear stress and PSS are generated by mechanical frictional forces of blood flow and heart contraction, respectively (39). These mechanical signals influence endothelial cell function, morphology, and gene expression (39). PSS promotes endothelial cell homeostasis and cardiovascular health (102). The archetype of PSS triggering is exercise, such as jogging, which induces pulsations into the body depending on the impact of the foot on the ground (39). Mechanical devices like vibration plates can also induce external pulsations into the body, termed enhanced external pulsation (39). Endothelial cells, forming a single layer lining the heart and vascular system, respond to these signals, by producing messengers crucial for coagulation, vascular tone, inflammation, and cell signalling (39). Endothelial cell activation transitions endothelial cells from a quiescent state to a prothrombotic, proinflammatory, and permeable phenotype, enabling repair and leukocyte trafficking at injury sites (39).

Study limitations

The primary limitation of this study was the absence of intermediate or long-term follow-up. Additional limitations include the exclusive use of the VAS scale, the lack of alternative methods for assessing microcirculation, and the brief duration of the intervention. Nevertheless, further research into the use of HEAT and/or VIB for NSBP is justified, as clinical use has shown few or no side effects. Lastly, the authors acknowledge that COMBI

therapy serve as pain-relief modalities rather than standalone treatments. To maximize its therapeutic benefits, COMBI therapy should be integrated into a comprehensive rehabilitation program that includes active exercise and core muscle strengthening (103). Active exercise plays a crucial role in restoring mobility, improving muscle function, and preventing recurrence by addressing the underlying causes of musculoskeletal pain (103). Core muscle strengthening, in particular, enhances spinal stability and postural control, reducing the risk of future injuries (103). By merging COMBI therapy with structured exercise programs, patients can achieve long-term improvements in pain management, functional recovery, and overall musculoskeletal health. If COMBI therapy proves effective in the future, it could lead to the development of new treatment regimens with expanded options for both doctors and patients.

Conclusion

The rapid effect of COMBI therapy on NSBP observed in our randomized clinical trial is promising and justifies further, larger-scale studies to validate the impact of combined HEAT and VIB on pain in other conditions. In the interest of sustainability, multimodal concepts should also be used more in the future, merging the possibilities of COMBI therapy with active training to strengthen the core muscles. Our results suggest that the NO release is involved in the local biochemical metabolic pathway. Consequently, future assessments should include parameters related to microcirculation and inflammatory markers in the serum. It is also recommended to investigate whether, and to what extent, heat and vibration signals influence other body parts and organs.

Declaration. The authors wish to disclose that an artificial intelligence tool (**ie**; ChatGPT ephemeral) was utilized to enhance the clarity and coherence of the manuscript' writing. The tool was utilized for language refinement purposes only, ensuring the text was clear and coherent without altering the scientific content or generating any new text (104).

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Abbreviations' list
$_a$: After intervention
ANOVA: Analysis of variance
$_b$: Before intervention
BMI: Body mass index
BP: Back pain
COMBI: Combination therapy
DBP: Diastolic blood-pressure
HEAT: Heat therapy
LBP: Low back pain
MCID: Minimal clinically important difference
NO: Nitric oxide
NSBP: Nonspecific back pain
PSS: Pulsatile shear stress
SBP: Systolic blood-pressure
SpO_2: Oxy-haemoglobin saturation
V: Visit
VAS: Visual analogue scale
VIB: Vibration therapy
WBV: Whole body vibration

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