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CONTENTS

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ORIGINAL ARTICLE

Significance of recreational and sports services for the attractiveness of health resorts stays. Expert assessment*

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ABSTRACT

Aim: The aim of this article was to assess the importance of recreational and sports services in increasing the attractiveness of stays at health resorts.
Materials and Methods: This objective was achieved through an expert survey involving deliberately selected physicians working in sanatoriums, primary care clinics and specialist hospitals; physiotherapists working in sanatoriums and specialist hospitals; individuals from local government administration associated with health treatments; and researchers dealing with health resort issues.
Results: According to the majority of experts (62%), recreational and sports services increase the attractiveness of stays at health resorts. The availability of information about these services was assessed as sufficient by most experts, although nearly a quarter indicated a lack of information. Experts' opinions on the level of these services were divided: responses suggesting that the level of these services is good were balanced with assessments that it is poor (40.5%). The presented expert opinions support the hypothesis concerning the importance of recreational and sports services for the attractiveness of stays at health resorts.
Conclusions: According to experts, recreational and sports services are an important element in the treatment and recovery process of patients because physical activity has a positive effect on mental and physical health. These opinions should reach facility hosts and managers of sanatorium facilities and health centres, as well as doctors and therapists.

KEYWORDS: recreational and sports services, health resorts, expert assessment

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INTRODUCTION

Recreational and sports services – in addition to accommodation, catering, transportation, information, medical services, banking, intermediation and organisation, guiding and piloting, local infrastructure, trade, crafts and insurance – constitute components of leisure and health tourism products [1,2]. At holiday and health resorts, recreational and sports services are most often associated with broadly defined health tourism, the aim of which is to restore, improve or maintain an appropriate level of health through prevention and rehabilitation treatments [3]. In addition to health, recreational and sports services should also be considered as part of wellness services. Health-promoting services are offered at resorts primarily by sports and recreation companies and typical health and rehabilitation businesses, especially sanatoriums.

Recreational and sports activities have not been considered as factors improving treatment quality, likely due to the limited experience of Polish health resort patients with this type of offer at sanatorium facilities. It should be borne in mind that for years, the therapeutic model dominated in Polish health resorts [4]. Consequently, the majority of Polish health resorts pursued only therapeutic objectives. However, the development of other forms of health tourism, related to goals such as improving appearance, anti-aging through psychophysical activity, as well as relaxation and rest, actually occurred in Poland only at the end of the 20th and the beginning of the 21st centuries [5].

Recreational and sports offers at Polish health resorts are gradually becoming a complement to health-promoting tourism, which should include sanatorium and rehabilitation tourism, wellness and leisure tourism. Wellness tourism encompasses elements such as exercise, fitness, cosmetics, beauty, nutrition, diet, ecology, nature, mind development, relaxation, meditation and stress management. Family wellness and on-holiday treatments are emerging trends in leisure tourism.

LITERATURE REVIEW

The significant role of recreational infrastructure and services should be emphasized as one of the elements enhancing the tourist attractiveness of regions. Recrea-

** This article presents the second part of research on the importance of recreational and sports services in health resorts. The first part was published in Acta Balneol. 2025;67(2):102 107. doi:10.36740/Abal202502104* tional activities during holidays or stays at health resorts are becoming particularly popular [6]. Examples include the health resorts of Krynica Zdrój [7] and Świeradów-Zdrój [8], where local governments, seeking to enrich their existing offers for tourists, have undertaken diversification efforts. Diversification of the city's existing tourist offers, primarily associated with treatments, involved its expansion to include recreational products [9]. However, research conducted among patients in the Busko-Zdrój health resort indicates that the most common forms of recreational and sports activity are limited to walks, swimming pool classes and Nordic Walking [10].

By analyzing the opinions of tourists visiting the Sun Moon Lake Swimming Carnival, Yeh, Hua and Huang [11] showed that improving the quality of recreational and sports services will bring significant economic benefits. Studies in Montenegro, on the other hand, indicate a significant role of recreational and sports services in health resorts on the decision to visit it again [12].

However, for most Poles, health resorts are still primarily associated with treatment and not with spending leisure time in an active manner.

This is due to the fact that in sanatorium facilities in Polish, where mainly health treatment services have been improved for years, this type of medical services are usually at a high and very high level. Often higher than the recreational and sports services that are often offered.

The situation in this regard is different in the resorts of Western Europe or the USA, where both in reality and in social perception the achievement of health goals has been and is broadly understood, i.e. not only in relation to treatment, but in a holistic view of the concept of health. This has consequences in the form of paying more attention to the presence of recreational and sports offers among guests of foreign resorts. One of the factors here is often the longer time of introducing this type of offer to the health resorts market than in Poland and the higher quality rating of this type of service. This is confirmed by some results of research on foreign health resorts, where the recreational and sports offer has been built for years. For example, research on the quality of the offer of Slovenian health resorts has shown that local guests rate recreation services at a high level [13]. Factors determining the satisfaction of guests with services in health resorts are also presented in recent studies in Slovakia [14].

Foreign research conducted in European health resorts how s that according to resort managers, especially in Western Europe, there is a strong belief among guests about the need to improve their physical condition during their stay in the health resorts [15]. More than half of the surveyed managers of European facilities stated that meeting the need to improve physical condition through the use of recreational and sports goods and services is important or very important for health resorts guests. This suggests a greater importance of recreational and sports services in Western European treatment companies than in many of our resorts.

The importance of the needs to improve physical condition results from human motivation, where needs are its content [16]. The theory of needs plays an important role in the study of the motives of tourist travel, and the basis is the concepts of „push" and „pull", which can be applied to the analysis of the motivation of health resorts arrivals [17]. The needs related to the term „pushing" include everything that prompts guests to stay at the resorts (the so-called internal factors). In the psychological theory of motivation, a need is often defined as *„a state of feeling the lack of something (a thing, a phenomenon, a process), and at the same time a factor activating functions that motivate actions to change this state accordingly"* [18].

Analyzing foreign research on the motives for trips to Health Resorts & Wellness centers as part of health tourism, it should be stated that the motives of relaxation, recreation and the possibility of participating in many recreational and sports activities are often dominant, this is confirmed by research conducted in Taiwan [19].

AIM

The aim of this study was to assess the importance of recreational and sports services in increasing the attractiveness of stays at health resorts. It was hypothesised that recreational and sports services are an important, yet underestimated, factor influencing the attractiveness of stays at health resorts.

MATERIALS AND METHODS

The study employed an expert survey based on the purposive selection of respondents. Expert methods, also known as heuristic methods, rely on the deliberate selection of participants with relevant knowledge and experience rather than probability sampling. They are useful for examining complex issues that may be difficult to measure directly using quantitative methods [20,21]. Expert opinions may be summarised using statistical methods, and weights may be applied to parameters of particular importance to information users [22].

Expert-based approaches have previously been used to investigate innovation exchange in tourism management in Krakow and Prague [23]. In the field of health tourism, a Delphi study involving 28 selected experts from the Czech Republic, Hungary, Poland and Slovakia assessed experiences related to health tourism [24].

The present study was conducted as a single-round expert survey in July 2024. The experts were purposively selected on the basis of their professional experience and involvement in health resort services, administration or research. The final sample comprised 37 experts: 11 physicians working in sanatoriums, primary care clinics and specialist hospitals; 7 physiotherapists working in sanatoriums and specialist hospitals; 9 representatives of health resort municipal administration; 2 managers of health resort facilities; and 8 university researchers. The experts were from Kraków (n = 16), Busko-Zdrój (n = 7), Muszyna (n = 5) and Krynica-Zdrój (n = 3), among other locations. A link to the questionnaire was distributed to the selected experts via the Forms application.

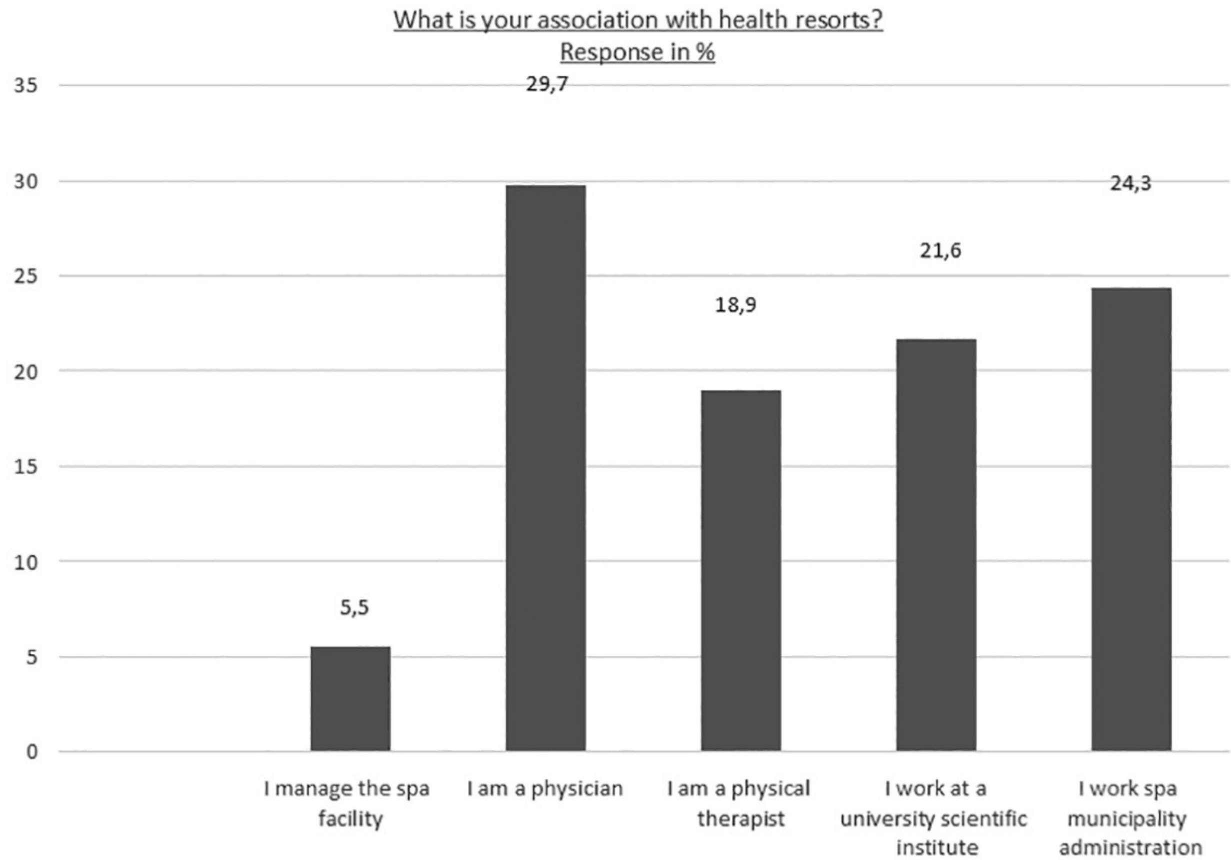

Fig. 1. Selection of experts for the study

Source: own research

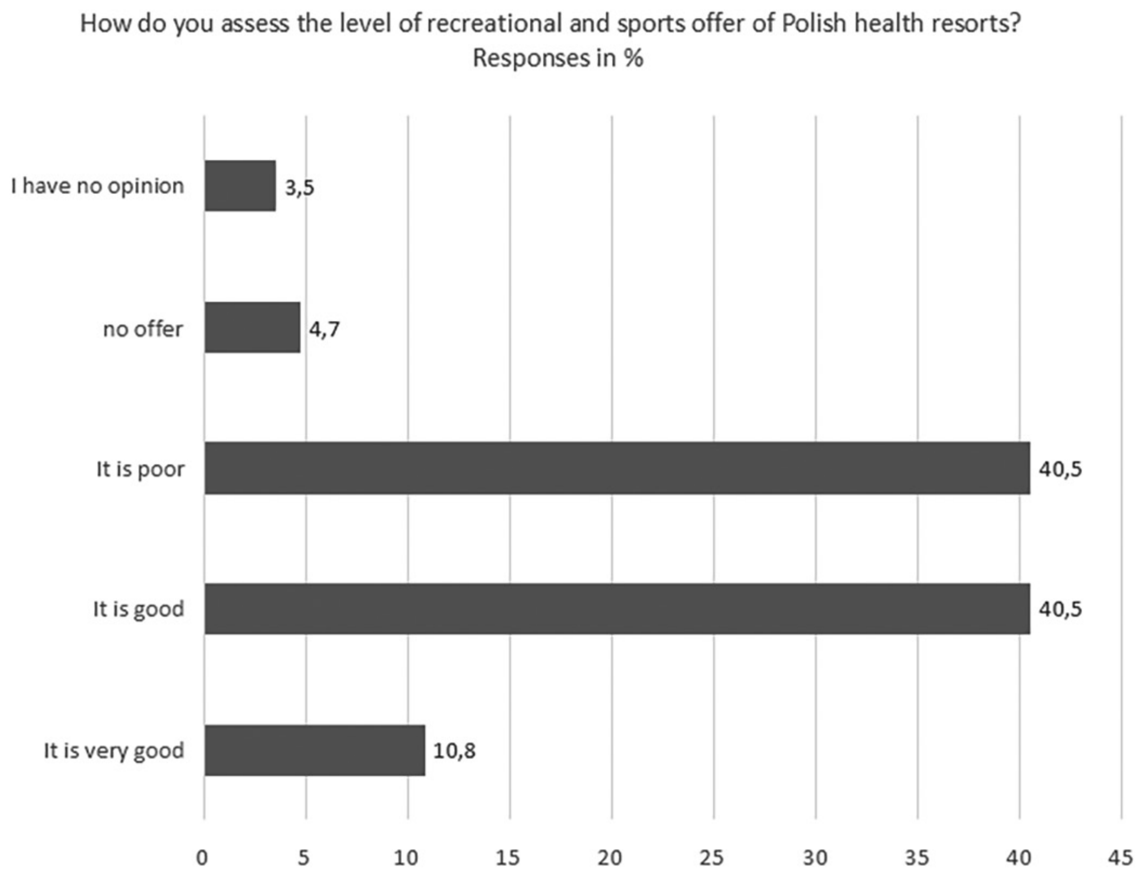

Fig. 2. Experts' assessment regarding the level of recreational and sports services

Source: own research

RESULTS

The final expert sample comprised 37 respondents: 11 physicians working at sanatoriums, primary care clinics and specialist hospitals; 7 physiotherapists working at sanatoriums and specialist hospitals; 9 representatives of health resort municipal administration; 2 managers of health resort facilities; and 8 university researchers (Fig. 1). The experts came from locations including Kraków (n = 16), Busko-Zdrój (n = 7), Muszyna (n = 5) and Krynica-Zdrój (n = 3). As shown in Figure 1, nearly half of the experts were physicians and physiotherapists, i.e. individuals involved in health services. Nearly one third were associated with the administration of health resort municipalities or managed health resort facilities, while one fifth were associated with universities where research on health resorts is carried out and staff for health resorts are trained.

LEVEL OF RECREATIONAL AND SPORTS SERVICES AT POLISH HEALTH RESORTS

The first question concerned the level of recreational and sports services at Polish health resorts. Responses suggesting that these services are good were balanced with experts' assessments that they are poor (40.5% each). Only 10.8% of experts assigned the highest rating (very good), while 4.7% indicated a lack of such services (Fig. 2).

RECREATIONAL AND SPORTS SERVICES AND THE ATTRACTIVENESS OF HEALTH RESORT STAYS

When asked whether recreational and sports services increase the attractiveness of health resort stays, experts were convinced that they do so to a great extent (62.2%), while the remaining experts (37.8%) indicated that they do so in general. None of the respondents indicated a lack of influence (Fig. 3).

The next question concerned the availability of information about recreational and sports services at health resorts. The majority of experts rated this availability as satisfactory (43.2%), but nearly a quarter believed that health resorts lacked such information (24.3%). Only 27.0% of expert responses rated it as good or very good (Fig. 4).

EXPERTS' COMMENTS AND EXAMPLES OF GOOD PRACTICE

The experts were asked to comment on their assessments. According to one physician, recreational and sports services are *important elements in the treatment and recovery process for patients, as physical activity has a positive impact on mental and physical health. Access to a variety of sports activities, thermal pools and other recreational attractions can significantly improve the quality of a stay and the effectiveness of health therapy. I believe that the proper use of recreational and sports services can contribute to faster recovery and better therapeutic outcomes*.

Similarly, one physiotherapist stated that *physical activity promotes good health. In older people, who are most often clients of health resorts, it strengthens and prolongs psychophysical fitness and delays various chronic diseases, including dementia. The recreational and sports offer of health resorts does not always take into account the needs of patients, their health condition or financial resources. Compared to the cultural offer, it is too poorly communicated and omitted in service packages*.

Another expert believed that *the presence of recreational and sports services is of great importance because, for example, when using a swimming pool or performing Nordic walking, we engage a significant number of muscle groups, experience positive fatigue and the release of endorphins, which in turn makes us experience a feeling of satisfaction and happiness*.

Generally, most experts emphasised positive aspects for the health of health resort guests, such as *improving the health habits of health resort patients, supporting the treatment of underlying diseases and the positive psychological as well as social aspects of performing recreational activities in a group*. Other experts commented that *services of this type increase the attractiveness of a stay, have a health-promoting psychological effect, facilitate establishing social contacts*, or that *they are important for increasing the attractiveness of a stay and the intensity of physical and recreational activity, while also having an impact on psychophysical well-being*.

According to another expert, *physical activity is highly recommended. Access to swimming pools and tennis courts is usually available. Tennis is a fairly strenuous sport, requiring good physical condition and at least basic playing skills. Therefore, it is only a sport for a small number of health resort guests. Medical hotels have younger clients, and there is a greater demand there. Fishing can also be a sport. Any additional offer a health resort has is often a factor in a client's choice of a specific facility*.

The experts cited examples of good practices in developing recreational and sports services. A university representative wrote that *a good example of creating a broad range of recreational and sports services is the Muszyna Health Resort, where patients and tourists have access to recreational facilities such as swimming pools, an ice rink, a pitch for team sports and tennis courts. They can also enjoy kayaking and rafting trips on the Poprad River, the longest cross-border cycling route and ski trails in winter. The recreational offer is complemented by walks through sensory and biblical gardens and a visit to the observation tower on Malnik. Travel agencies also offer tours to destinations such as Budapest, Kraków and Łańcut. The extensive recreational and sports infrastructure is undoubtedly thanks to the mayor of Muszyna, Dr. Jan Golba*.

Experts representing health resort municipal administration cited the example of Krynica-Zdrój: *The Krynica-Zdrój Health Resort is a popular holiday destination offering a wide range of recreational and sports services. The town is located in the mountains, which allows for a variety of outdoor activities, such as hiking, cycling and skiing. There are also many recreational facilities, such as swimming pools, tennis courts and sports fields. Access to recreational and sports services in Krynica is broad and varied, so everyone will find something for themselves*.

Another expert confirmed that *recreational and sports services in Krynica are of great importance*, but further stated that *the scope of the offer is limited, and much still needs to be*

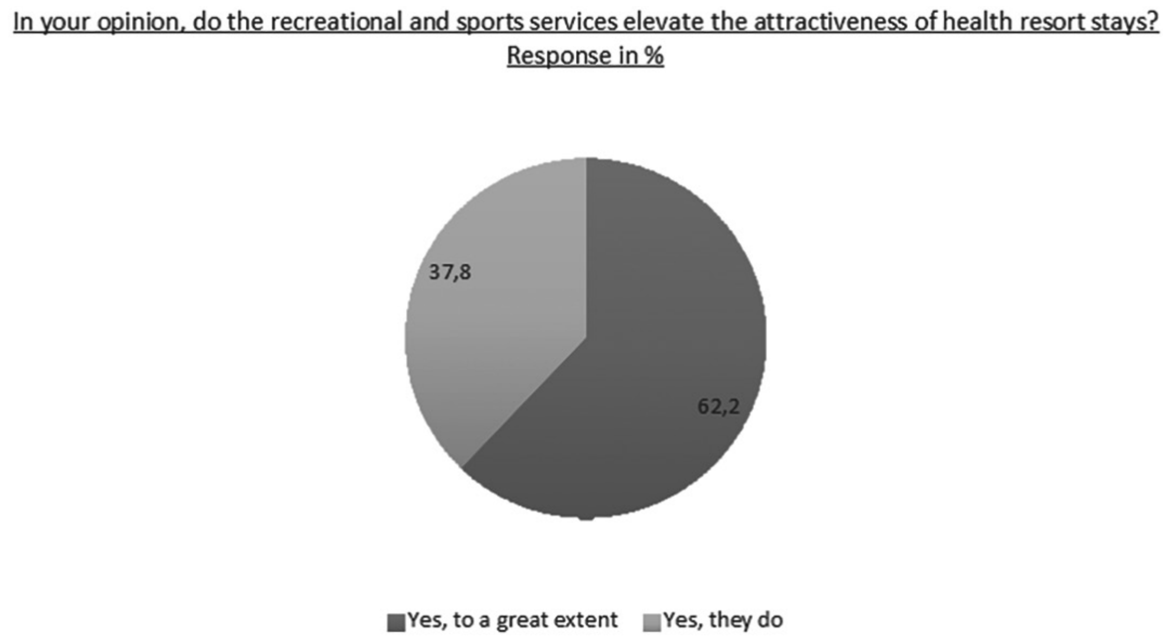

Fig. 3. Distribution of experts' answers to the question regarding the influence of recreational and sports services on the attractiveness of stays at health resorts

Source: own research

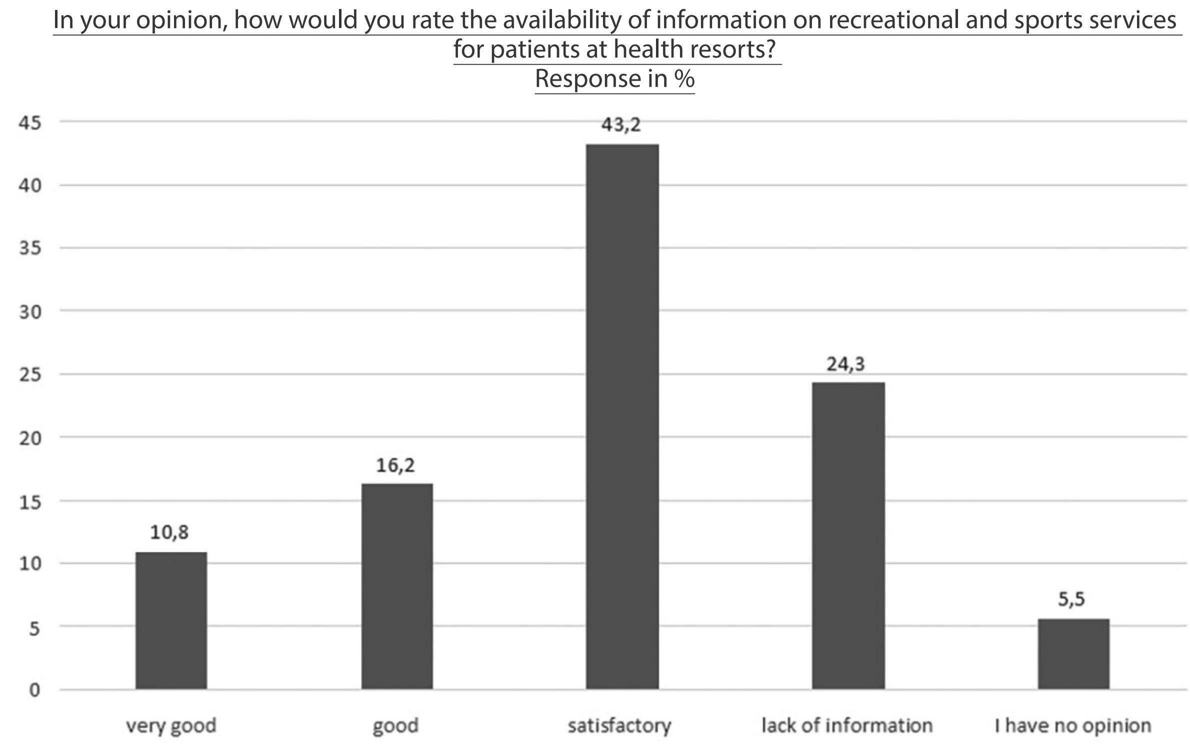

Fig. 4. Availability of information on recreational and sports services at health resorts in expert opinions

Source: own research

done in this area for its development and promotion, to adapt it to the profiles and needs of people visiting health resorts.

A similar opinion applied to Rymanów-Zdrój: *Recreational and sports services in Rymanów-Zdrój are quite well developed. Regular events are noticeable, such as mountain runs, as well as, to a lesser extent, cycling races. Furthermore, the Community Cultural Centre offers a wide range of events, including those with recreational and sports elements. An example is this year's offer of holiday cycling trips by one of the local companies cooperating with the surrounding municipalitie*s.

With regard to Ustka, one expert commented: *There are outdoor gyms, interesting walking routes and bike paths, but there is still a lot to be done, including a comprehensive* *network of bike routes, sports infrastructure and facilities, water playgrounds and outdoor swimming pools. Such infrastructure should be developed at every health resort – both publicly available, by municipalities, and commercial, by companies. This is a very important aspect in creating an offer for patients and tourists, and cooperation with businesses is essential here*.

The Uniejów Health Resort town was also cited as an appropriate example: *Nowadays, wide access to recreational and sports services as well as a wide range of activities are important factors in choosing a health resort. A good example is the Uniejów Health Resort town, which attracts tourists with both therapeutic and recreational and sports options*. Busko-Zdrój was also mentioned *with its very wide range of services for health resort guests, including environmental values, infrastructure and health treatments. It is a highly rated and appreciated town by those who have stayed and received treatment there*.

In their comments, experts pointed to *the lack of access to and information on recreational and sports services, such as chess, bridge and morning outdoor exercise, especially in the afternoon when patients are often recovering from procedures. I believe this should be addressed and developed for the physical and mental well-being of our patients*. They also believed that *we should expand our recreational and sports offerings to people of all ages. Health resorts are not just for retirees. We need more bike paths, botanical gardens, amusement parks, swimming pool complexes and water parks*.

Experts agreed that *additional recreational and sports services add value to a stay and also ensure that patients can spend their free time outside of treatment,* and that *without modern recreational and sports facilities, it is impossible to guarantee a full range of leisure opportunities to a broad group of guests visiting health resort municipalities. Guests expect municipalities to offer a wide range of attractions for every age group, for active people, health resort patients, children and youth. The absence of an appropriate offer causes customers to choose other locations that meet their expectations. Lack of or insufficient funds allocated to the development of services and facilities leads to a decrease in attractiveness and a loss to other, more developed municipalities*.

DISCUSSION

The findings indicate that recreational and sports services are perceived by experts as an important factor increasing the attractiveness of health resort stays. This is consistent with earlier studies showing that recreational activity may enhance the attractiveness of health resorts [6,10] and that the quality of sports and recreational services may influence tourists' satisfaction and intention to revisit a destination [11,12]. The divided assessment of the level of such services in Polish health resorts suggests that their availability and quality vary between individual locations. Similar observations concerning the importance of service quality and customer satisfaction have been reported in studies of health resorts in Slovenia and Slovakia [13,14].

Experts also emphasised the potential role of recreational and sports services in supporting physical activity, psychophysical well-being, social contact and the rational use of free time during a stay. However, they pointed out that the offer should be adapted to the health status, age and financial possibilities of health resort guests and communicated more effectively. This corresponds with research indicating that health and wellness travellers are motivated not only by treatment but also by relaxation, recreation and opportunities for physical activity [19]. As this study reflects expert opinions, the findings should be interpreted as an assessment of the perceived importance of such services rather than evidence of their clinical effectiveness.

CONCLUSIONS

The presented expert opinions, especially the latter, confirm the hypothesis about the great and underestimated importance of recreational and sports services for the attractiveness of health resort stays. Recreational and sports activities make health resort stays additionally desirable and motivate patients to spend their free time more actively.

In the opinion of experts, additional recreational and sports services are an added value to a stay and ensure the rational management of free time. The view was emphasised that without a modern recreational and sports base, it is impossible to provide guests of health resort municipalities with a complete leisure offer.

Experts expect municipalities to offer a wide range of attractions for every age group, including active people, patients, children and young people. The lack of an appropriate offer causes customers to choose a competing health resort.

According to experts, recreational and sports services are an important element in the treatment and recovery process of patients because physical activity has a positive effect on mental and physical health. These opinions should reach health resort hosts and managers of sanatorium facilities and health centres, as well as doctors and therapists.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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ORIGINAL ARTICLE

Effects of post-isometric relaxation and proprioceptive neuromuscular facilitation in older women with neck-related arm pain: a pilot feasibility study

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ABSTRACT

Aim: To compare the preliminary effects of post-isometric relaxation and proprioceptive neuromuscular facilitation, each added to an identical standardised physiotherapy programme, on pain, disability, and cervical mobility in older women with neck-related arm pain.

Materials and Methods: Eight women aged 53–74 years with non-traumatic neck pain radiating to the upper limb were consecutively recruited and allocated, using simple non-randomised sequential allocation, to a post-isometric relaxation group or a proprioceptive neuromuscular facilitation group. Both groups completed ten 60-minute physiotherapy sessions over five weeks; the respective intervention was additionally applied for 10–15 minutes after each session. Outcomes were pain intensity, Neck Disability Index score, and cervical range of motion.

Results: Pain decreased in both groups, disability scores improved, and cervical mobility increased after treatment. The observed changes in several range-of-motion parameters and pain reduction were generally greater in the proprioceptive neuromuscular facilitation group, while post-isometric relaxation was also associated with meaningful within-group improvement.

Conclusions: Both approaches appear feasible and may support pain reduction and improved cervical mobility in older women with neck-related arm pain. Because of the very small, non-randomised pilot sample, the findings are exploratory and require confirmation in adequately powered randomised trials.

KEYWORDS: neck pain, arm pain, proprioceptive neuromuscular facilitation, muscle stretching exercises, range of motion, articular

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INTRODUCTION

Neck pain is a leading cause of disability worldwide, ranking ninth among conditions causing disability in 2017, with an age-standardized prevalence of 3,551.1 and an incidence of 806.6 per 100,000 population [1]. Pain perception involves interactions between peripheral and central neural networks and affects alertness and mental health [2]. Neck pain may arise from injury to cervical muscles, joints, discs, or ligaments [3], and pain radiating into the arm may reflect nociceptive, peripheral neuropathic, or centrally mediated mechanisms, requiring careful clinical differentiation before a 'neuropathic' label is applied [4]. Non-pharmacological approaches are generally preferred for management [5], and exercise plays a central role in the treatment of chronic neck pain [6]. Guidelines recommend multimodal care, including manipulation, mobilisation, soft-tissue therapy, and supervised exercise [7], alongside adjuncts such as heat, cryotherapy, electrotherapy, and dry needling [8]. Post-isometric relaxation (PIR) is a muscle energy technique that uses submaximal isometric contraction followed by relaxation and passive stretching to reduce muscle tone and pain [9]; evidence remains limited but generally favourable [10], although systematic reviews urge cautious interpretation given the small trial sizes [11].

Proprioceptive neuromuscular facilitation (PNF) uses diagonal movement patterns with resistance to improve strength, flexibility, and motor control and is recommended in guidelines for chronic neck pain [12,13]; recent evidence indicates that PNF may improve clinical, physiological, and quality-of-life outcomes in chronic non-specific neck pain [13].

AIM

To our knowledge, no previous study has directly compared the effects of post-isometric relaxation and proprioceptive neuromuscular facilitation in neck-related arm pain, and evidence specifically addressing older adults is particularly scarce. This pilot feasibility study aimed to evaluate, on a preliminary basis, the effects of PIR and PNF interventions on pain intensity, disability, and cervical mobility in older adults with neck pain radiating to the upper limb and to generate effect-size estimates and feasibility data for the design of a future, adequately powered randomised controlled trial.

MATERIALS AND METHODS

STUDY DESIGN

This study followed a prospective, non-randomised comparative pilot design with two parallel intervention arms (PIR and PNF), each combined with an identical standardised physiotherapy programme. Given the exploratory nature and very small sample, and because this was a non-randomised pilot study, the report has been aligned with guidance for non-randomised pilot and feasibility studies, with selective use of relevant CONSORT pilot items where applicable.

ETHICAL APPROVAL

The study was approved by the Klaipeda State University of Applied Sciences Ethics Committee (approval date: 26 September 2024) and was conducted in accordance with the Declaration of Helsinki and the ALLEA European Code of Conduct for Research Integrity. All participants provided written informed consent; confidentiality was ensured, and assessments were performed before and after the intervention in a private, comfortable clinical environment.

PARTICIPANTS AND ALLOCATION

Participants were consecutively recruited from adults referred for outpatient physiotherapy at the Plunge District Municipality Public Health Bureau between October and December 2024. Inclusion criteria were age 53–74 years, non-traumatic neck pain radiating to the upper limb (neck-related arm pain), VAS pain intensity ≥3, a negative Spurling test, and physical activity without severe comorbidities. Exclusion criteria were pain confined exclusively to the cervical region without arm radiation, a history of cervical trauma, radiologically confirmed disc herniation or spondylosis, prior cervical spine surgery, severe headache, movement disorders, congenital cervical deformities, current use of pain medication, and VAS <3 or ≥9 [14]. Because this was a non-randomised pilot study, participants meeting the eligibility criteria were allocated to the PIR or PNF group using simple sequential (alternating) allocation in order of enrolment; no formal randomisation sequence, allocation concealment, or blinding of participants, therapists, or outcome assessors was applied. The study was not prospectively registered in a public trial registry before enrolment, which limits alignment with current interventional study transparency standards and is now acknowledged here; future confirmatory trials will be prospectively registered before enrolment. This represents an important methodological limitation of the study, discussed below. Of the participants who consented, eight women aged 53–74 years (65.6 ± 6.50 years; BMI 25.37 ± 7.95 kg/m^2) completed the full protocol; no participant withdrew or was lost to follow-up. No male patients meeting the inclusion criteria were available for recruitment during the study period; the resulting sample was therefore exclusively female, which substantially limits generalisability to men (see Limitations).

GONIOMETRY

Cervical spine active range of motion (flexion, extension, lateral flexion, and rotation) was measured with a universal goniometer using the neutral zero starting position (0–180° notation), a standardised and validated clinical method that provides objective quantification of range of motion, identifies movement restriction, and allows the tracking of rehabilitation progress [15].

VISUAL ANALOGUE SCALE (VAS)

Pain intensity was assessed using the 11-point (0–10) numerical Visual Analogue Scale (VAS), a validated and responsive measure of pain intensity [16].

NECK DISABILITY INDEX (NDI)

The Neck Disability Index (NDI) is a validated, self-administered 10-item questionnaire assessing pain intensity and its impact on personal care, lifting, reading, headache, concentration, work, driving, sleep, recreation, and social/public life; each item is scored from 0 to 5, with higher scores indicating greater disability [17]. In this study, the 'personal care' item – which assesses the effect of neck pain on activities such as washing, dressing, and self-care – was used as specified in the validated NDI instrument; it does not assess self-esteem.

RESEARCH DESIGN AND INTERVENTION PROCEDURES

This pilot study assessed the feasibility of comparing PIR and PNF protocols, generated preliminary effect-size estimates for future trial design, and evaluated participant tolerance and safety; no formal a priori sample-size calculation was performed because of its feasibility purpose. The 5-week intervention at the Plunge District Municipality Public Health Bureau comprised ten 60-minute sessions delivered twice weekly and was identical in content, duration, and sequence for both groups: warm-up, active and active-assisted neck, shoulder, scapular, and upper-limb mobility exercises, isometric strengthening exercises, and cool-down. The only difference between groups was a supplementary 10–15-minute PIR or PNF technique applied immediately after each physiotherapy session.

GROUP 1 – PIR

Group 1 (PIR, n = 4) received post-isometric relaxation targeting the levator scapulae, upper trapezius, suboccipital muscles (rectus capitis posterior major/minor, obliquus capitis superior/inferior), platysma, deep neck flexors (longus colli, longus capitis), scalene muscles (anterior, middle, posterior), and sternocleidomastoid. The procedure was performed with participants seated and consisted of the following stages: (1) passive stretching of the target muscle to its first resistance barrier (15–20 seconds); (2) submaximal isometric contraction of the muscle against therapist resistance (approximately 20% of maximal voluntary contraction, 5–10 seconds); and (3) relaxation during a deep exhalation, with passive movement to a new stretch barrier (30-second hold). This sequence was repeated three times per muscle group, per session.

GROUP 2 – PNF

Group 2 (PNF, n = 4) received proprioceptive neuromuscular facilitation adapted from the protocols described by Maicki et al. (2024) [18] and Maicki et al. (2017) [19]. Five diagonal, three-dimensional movement patterns were applied [20]: neck flexion–lateral flexion–rotation and neck extension–lateral flexion–rotation patterns; upper-limb patterns (flexion–abduction–external rotation and extension–adduction–internal rotation); scapular patterns (anterior elevation and posterior depression); and postural control re-education. Starting positions included supine, side-lying, and sitting. The PNF modules applied were combination of isotonics, rhythmic stabilisation, hold-relax, and contract-relax; each technique was performed until the individual participant reported local muscular fatigue [18].

STATISTICAL ANALYSIS

Data were entered in Microsoft Excel and analysed using SPSS version 31.0. Descriptive statistics (mean, standard deviation, percentage) were calculated for all variables. Because of the very small sample size ($n = 4$ per group), the primary inferential analysis consisted of within-group paired-samples t-tests comparing pre- and post-intervention scores for each outcome, with exact two-tailed p-values and degrees of freedom ($df = 3$) reported for every comparison. Effect sizes for within-group changes are reported as Cohen's d_z (mean difference divided by the standard deviation of the difference scores), which is appropriate for paired designs and less dependent on sample size than p-values. Between-group comparisons of the magnitude of change using independent-samples Welch's t-tests are reported descriptively as exploratory, hypothesis-generating estimates only, given that with $n = 4$ per group the study has less than 20% power to detect a medium effect size; these between-group results should not be interpreted as confirmatory evidence of superiority of either method. ANOVA and ANCOVA models were not retained in the final analysis because, with only four observations per cell, these models are not statistically identifiable with adequate degrees of freedom for the number of parameters estimated, and their previously reported results could not be reliably reproduced or verified against the raw data; ANOVA/ANCOVA results have therefore been removed from this revised manuscript. The significance threshold was set at $p < 0.05$, acknowledging that, in a sample of this size, this threshold carries a materially elevated risk of both Type I and Type II errors and should be interpreted with caution.

RESULTS

All results presented below are exploratory and derive from a very small pilot sample ($n = 4$ per group). Statistical significance obtained despite the small sample must be interpreted cautiously, and all findings require confirmation in adequately powered studies.

PAIN AND NECK DISABILITY INDEX RESULTS

Baseline VAS scores did not differ between groups (PIR, 4.5 ± 1.0 vs PNF, 6.5 ± 1.73; $p = 0.100$). After the intervention, VAS scores decreased in the PIR group from 4.5 ± 1.0 to 2.75 ± 0.96 ($\Delta = 1.75 \pm 0.04$; $t(3) = 87.50$, $p < 0.001$, $d_z = 43.75$) and in the PNF group from 6.5 ± 1.73 to 3.0 ± 2.45 ($\Delta = 3.50 \pm 0.72$; $t(3) = 9.72$, $p = 0.002$, $d_z = 4.86$). Both within-group changes were significant, although, with $n = 4$ per group, these p-values are highly sensitive to individual variation. An exploratory between-group comparison suggested a greater VAS reduction in the PNF group (Welch's $t \approx -4.85$, $p \approx 0.016$), but this finding is hypothesis-generating only, given the inadequate statistical power. Baseline NDI scores were identical between groups (7.75 points; $p = 1.000$). After the intervention, total NDI scores decreased by 2.5 ± 1.99 in the PIR group ($t(3) = 2.51$, $p = 0.087$, $d_z = 1.26$; not significant) and by 2.0 ± 0.50 in the PNF group ($t(3) = 8.00$, $p = 0.004$, $d_z =$

Table 1. Pain (VAS) and Neck Disability Index (NDI) assessment results (paired ttest, within-group; df=3 for all comparisons; n=4 per group)

Variable	1 GROUP PIR				2 GROUP PNF			
	Before the Research (Mean ± SD)	After Research (Mean ± SD)	Difference Δ	(t-test) results	Before the Research (Mean ± SD)	After Research (Mean ± SD)	Difference Δ	(t-test) results
Visual Analogue Scale	4.5±1	2.75±0.96	1.75±0.04	43.75	6.5±1.73	3±2.45	3.5±0.72	9.72
General Neck Disability Index	7.75 ± 4.35	5.25±2.36	2.5±1.99	2.51	7.75 ± 5.12	5.75±5.62	2±0.5	3.42
Pain	1.25± 0.96	1±0.16	0.25±0.80	0.63	2±1.41	1±0.82	1±0.61	3.28
Personal self care	0.25±0.5	0	0.25±0.5	1.00	1.25±1.89	0.75±0.96	0.5±0.93	1.08
Lifting	1.5±1.73	1±1.41	0.5±0.32	3.13	0.75±0.5	1±0.82	0.25±0.32	1.56
Reading	0.5±0.58	0.25±0.5	0.25±0.08	6.25	0.5±0.58	0.25±0.5	0.25±0.08	6.25
Headache	1±0	1±0.82	0±0.82	0.00	1±0.82	0.25±0.5	0.75±0.32	4.69
Concentration	1±0.82	0.25±0.5	0.75±0.32	4.69	0.25±0.5	0.5±0.58	-0.25±0.08	-5.0
Work	1.25±0.5	1±0	0.25±0.5	1.0	0.5±0.58	0.75±0.96	-0.25±0.38	-1.32
Driving	-	-	-	-	-	-	-	-
Sleep	0.75±0.5	0.5±0.58	0.25±0.08	5.0	1.25±0.96	0.5±0.58	0.75±0.38	3.46
Public life	0.5±1	0.25±0.5	0.25±0.5	1.0	1±0.82	0.75±0.96	0.25±0.14	3.57

Note: Δ = mean pre–post difference (mean ± SD of individual differences).

Paired samples t-test, two-tailed, df=3 for all within-group comparisons (n=4). d_z = Cohen's d_z effect size for paired data (mean difference / SD of differences). Between-group comparisons are not shown in this table because, with n=4 per group, the study is substantially underpowered for between-group inference (see: Discussion/Limitations); exploratory Welch's t-test results for group differences in the magnitude of change are reported narratively in the Results section. Driving item data were not available/applicable for all participants and are reported as missing (N/A).

Source: compiled by the authors of this study

4.00; significant); the between-group difference in NDI change was not significant (Welch's t ≈ 0.49, p ≈ 0.656). Full domain-level statistics (test, df, exact p, and d_z) are presented in Table 1.

CERVICAL SPINE RANGE OF MOTION RESULTS

Both groups showed improved cervical range of motion (Table 2). In the PIR group, all six ROM parameters improved significantly (flexion: +9.5 ± 0.06°, $t(3) = 316.67$, $p < 0.001$, $d_z = 158.33$; extension: +10.75 ± 4.84°, $p = 0.021$; right/left lateral flexion: +8.75 ± 1.58°/+12.5 ± 0.62°, both $p < 0.01$; right/left rotation: +10.0 ± 4.28°/+8.75 ± 2.33°, both $p < 0.02$). In the PNF group, flexion improved by 11.25 ± 11.04° but did not reach statistical significance ($t(3) = 2.04$, $p = 0.134$, $d_z = 1.02$) because of high variability; extension improved by 8.75 ± 5.5° ($p = 0.050$); lateral flexion and rotation improved significantly (all $p < 0.02$). Exploratory between-group comparisons showed no significant difference for any ROM parameter (all $p > 0.05$); the PNF group showed a numerically larger, non-significant gain in flexion, whereas the PIR group showed numerically larger gains in lateral flexion and rotation. Neither method fully restored the normative range of motion, reaching approximately 71–97% of reference values in all directions.

DISCUSSION

This pilot study provides preliminary, exploratory data comparing PIR and PNF, each combined with a standardised physiotherapy programme, in a small, exclusively female sample of older adults with neck-related arm pain. The study is aligned with guidance for non-randomised pilot and feasibility studies; the CONSORT extension for pilot trials is used only where items are applicable. With only four participants per group, these findings should be regarded as hypothesis-generating rather than confirmatory and are intended primarily to inform the design and sample-size calculation of a future, adequately powered randomised controlled trial. The observed within-group effect sizes are reported to support such planning, but their magnitude is inflated by the very small sample and should not be taken as an estimate of the true population effect size.

Comparison with prior literature provides context, although differences in sample age and protocol limit direct comparisons. Khan et al. [8] compared PIR with myofascial release therapy, both combined with cryotherapy and isometric exercise, in a 2-week protocol among younger adults (~32 years), reporting significant improvements in VAS, NDI, and ROM; this differs from our broader 5-week physiotherapy-based protocol. Shady et al. [1] found PIR, combined with infrared therapy, to be superior to passive stretching in 40 younger adults (~26 years) over 4 weeks. Dudoniene et al. [14] reported a VAS reduction of 3.04 ± 1.14 points with PIR plus TENS in 25 working-age adults (~37 years) over 4 weeks. The smaller absolute pain reduction in our older sample (65.6 ± 6.50 years) is consistent with slower tissue regeneration and altered responses to physiotherapy with advancing age [21].

PIR has been reported to be effective in adults with chronic or acute neck pain [14] and in adults with degenerative joint disease [10]; a case report [22] described symptom resolution after PIR in cervical radiculopathy, although single-case evidence cannot support generalisable claims. For PNF, the observed VAS change in our study is directionally consistent with the meta-analysis by Suresh et al. [13]. The proposed mechanism, involving the restoration of impaired feedforward activation of deep and superficial neck flexors, is supported by Falla et al. [23] and Ghaderi et al. [24]; our PNF protocol followed the diagonal movement patterns described by Maicki et al. [18,19], and Boyd-Clark et al. [25] demonstrated the high proprioceptive spindle density of the longus colli that underlies this rationale.

Neither group fully restored the normative range of motion (71–97% of reference values), likely reflecting age-related fascial and musculoskeletal changes and the short 5-week intervention period [26]. PNF hold-relax and contract-relax techniques act through both viscoelastic and neuromuscular mechanisms [18]. O'Riordan et al. [27] recommended at least three sessions per week, lasting 30–60 minutes, for optimal outcomes, and Ylinen et al. [28] showed that 12 months of training produces durable gains; our 5-week protocol, while feasible, may have been too brief to achieve maximal or durable benefit.

Table 2. Cervical Spine active range of motion research assessment results

Variable	1 GROUP PIR				2 GROUP PNF			
	Before the Research (Mean ± SD)	After Research (Mean ± SD)	Difference Δ	(t-test) results	Before the Research (Mean ± SD)	After Research (Mean ± SD)	Difference Δ	(t-test) results
Flexion (°)	23±9.63	32.5±9.57	9.5±0.06	158.33	30±13.54	41.25±2.5	11.25±11.04	2.04
Extension (°)	26.75±13.5	37.5±8.66	10.75±4.84	4.44	35±4.08	43.75±2.5	8.75±5.5	3.18
Right lateral flexion (°)	30±4.08	38.75±2.5	8.75±1.58	11.08	31.25±7.5	38.75±6.29	7.45±1.21	12.31
Left lateral flexion (°)	25±7.07	37.5±6.45	12.5±0.62	40.32	31.25±6.29	41.25±2.5	10±3.79	5.28
Rotation to the right (°)	48.75±21.36	58.75±17.08	10±4.28	4.67	48.75±4.79	57.5±2.89	8.78±1.9	9.24
Rotation to the left(°)	51.25±11.81	60±14.14	8.75±2.33	9.24	48.75±4.79	58.75±2.5	10±2.29	8.73

Note: Δ = mean pre–post difference.

Paired-samples t-test, two-tailed, df=3 (n=4). d_z =Cohen's d_z. Exploratory between-group Welch's t-test comparisons of the magnitude of change showed no statistically significant differences for any ROM parameter (all p>0.05); these are hypothesis-generating only given inadequate statistical power.

Source: compiled by the authors of this study

Recent evidence continues to support these approaches: Tariq et al. (2024) [29] found massage combined with PIR to be more effective than massage alone for cervicogenic headache, and Kaviyarasan et al. (2026) [30], in a pilot RCT comparing myofascial release with isometric relaxation plus stretching, similarly emphasised feasibility and preliminary effect estimation rather than definitive comparative claims – consistent with the pilot framing adopted here.

CONCLUSIONS

This exploratory pilot study suggests that both PIR and PNF, when combined with a standardised physiotherapy programme, are feasible interventions and are associated with within-group reductions in pain and improvements in cervical range of motion in older women with neck-related arm pain. Within-group effect-size estimates (PIR VAS $d_z = 43.75$; PNF VAS $d_z = 4.86$) are reported to inform the design and sample size of future controlled trials and should not be interpreted as evidence of comparative superiority of either method.

Both methods were associated with improved cervical range of motion; the PNF group showed a numerically larger, non-significant gain in flexion, whereas the PIR group showed significant gains in extension, lateral flexion, and rotation. Because between-group comparisons in this pilot study are substantially underpowered, no conclusion regarding the relative effectiveness of PIR versus PNF for improving cervical mobility can be drawn from these data.

A future, adequately powered randomised controlled trial with concealed allocation, blinded outcome assessment, a balanced sex distribution, age stratification, an extended intervention and follow-up period, and multiple recruitment centres is required before any comparative or practice recommendation regarding PIR versus PNF can be made.

LIMITATIONS

Key limitations include: (1) a very small sample (n = 4 per group), well below the level required for reliable statistical inference, producing wide confidence intervals and unstable p-values; (2) non-randomised sequential allocation without concealment or blinding, risking selection and performance bias; (3) an exclusively female sample, limiting generalisability given documented sex differences in pain processing; (4) diagnosis based on clinical history, VAS, and the Spurling test rather than a validated neuropathic pain instrument (painDETECT, DN4, or QST), hence this manuscript refers to 'neck-related arm pain' rather than 'neuropathic pain'; (5) the absence of a standard-care control group, precluding attribution of change specifically to PIR or PNF versus the shared physiotherapy programme or natural fluctuation; (6) a short 5-week intervention with no long-term follow-up; (7) a single recruitment site and an older-adult sample, limiting generalisability to other populations and settings; and (8) the study was not prospectively registered in a public trial registry before enrolment, which limits alignment with current interventional study transparency standards; future confirmatory trials will be prospectively registered before enrolment.

PRACTICAL IMPLICATIONS

Given the exploratory nature of this pilot study and the limitations described above, no definitive clinical recommendation favouring either PIR or PNF can currently be issued. Clinicians may consider that both techniques, delivered alongside a structured physiotherapy programme, were feasible, well tolerated, and associated with within-group improvement in this small sample of older women; practitioners are advised to await the results of an adequately powered randomised controlled trial before adopting either method preferentially over the other for neck-related arm pain in older adults.

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ORIGINAL ARTICLE

Gender-specific differences in cardiac rehabilitation outcomes among obese patients after myocardial infarction

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ABSTRACT

Aim: To assess gender-specific differences in the effectiveness of cardiac rehabilitation among obese patients after a first myocardial infarction and to identify factors influencing functional recovery.

Materials and Methods: A prospective observational study was conducted between 2020 and 2024 at City Hospital No. 1 in Mykolaiv, Ukraine. The main group included 100 inpatients with stage I obesity (BMI 30.0–34.9 kg/m^2) who experienced a first acute myocardial infarction, while the control group consisted of 100 normal-weight patients (BMI 18.0–24.9 kg/m^2) with comparable clinical and anamnestic characteristics. All patients received standardised revascularisation, pharmacotherapy, and a comprehensive rehabilitation programme comprising physical training, dietary modification, psychological support, and education. Functional status was assessed using left ventricular ejection fraction (LVEF) and the 6-minute walk test. The follow-up duration was 6 months. Statistical analysis included variance and correlation analyses.

Results: Obese women more frequently presented with atypical myocardial infarction symptoms and had higher rates of acute heart failure and arrhythmias. At discharge, obese women demonstrated higher VAI values and lower exercise tolerance than obese men and normal-weight women ($p < 0.05$). After rehabilitation, both groups showed improvement; however, obese women exhibited slower recovery of exercise tolerance and a 15% lower increment in LVEF than men. Clinically significant improvement in the 6-minute walk distance was observed less frequently in obese women.

Conclusions: Obesity adversely affects post-infarction recovery, and gender-specific factors may modify rehabilitation outcomes. Obese women demonstrated delayed functional recovery and a smaller improvement in cardiac function. Gender-sensitive rehabilitation strategies and targeted secondary prevention programmes may help optimise outcomes in this high-risk population.

KEYWORDS: cardiac rehabilitation, functional recovery, gender, myocardial infarction, obesity

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INTRODUCTION

Gender differences in the presentation of myocardial infarction are well documented. Women are more likely to present with atypical symptoms, such as fatigue, nausea, and back pain, rather than the classic chest pain more commonly reported by men. Among women with obesity, these atypical presentations may be more prevalent, contributing to delays in diagnosis and treatment initiation [1, 2]. Such diagnostic challenges may lead to delayed enrolment in cardiac rehabilitation (CR) programmes, thereby reducing the potential for optimal recovery.

Psychosocial variables, including depression, anxiety, and perceived social support, differ significantly between genders and may affect participation in rehabilitation. Women with obesity are particularly vulnerable to depressive symptoms after MI, which are associated with lower CR attendance and completion rates [3, 4]. Furthermore, caregiving responsibilities often fall disproportionately on women, potentially limiting their availability for regular participation in structured rehabilitation programmes.

Research indicates that women, especially those with obesity, are less likely to be referred to and enrolled in CR programmes following MI [5]. Factors contributing to this disparity include implicit bias in healthcare referral practices, a lack of gender-specific rehabilitation services, and personal barriers, such as body image concerns and logistical constraints, including transportation and childcare [6]. These factors may collectively reduce adherence to recommended secondary prevention strategies.

Physiological and hormonal differences between women and men may influence the response to exercise interventions. Women generally demonstrate lower baseline exercise tolerance, which may be further diminished by obesity-related physical limitations. Women with obesity may also experience greater discomfort or embarrassment in mixed-gender exercise settings, potentially affecting their engagement with CR programmes [7]. Current CR protocols may not adequately account for these gender-related variations, limiting their efficacy in female populations.

Evidence suggests that women with obesity are less likely than men to receive guideline-directed medical therapy following MI and may have poorer control of cardiovascular risk factors, such as hypertension, diabetes mellitus, and hyperlipidaemia [8]. These disparities in secondary prevention may contribute to suboptimal long-term outcomes and higher rates of recurrent cardiovascular events among women.

Gender differences in post-MI recovery are evident in both functional and psychosocial domains. Women with obesity are more likely to experience reduced physical functioning, persistent symptoms, and lower quality of life in the months following MI than their male counterparts [9]. These disparities underscore the need for a more individualised and gender-sensitive approach to post-MI rehabilitation.However, data on gender-specific differences in cardiac rehabilitation outcomes among patients with obesity after MI remain limited.

AIM

The aim of the study was to assess gender differences in the implementation of rehabilitation programs in obese patients after myocardial infarction

MATERIALS AND METHODS

The study was conducted between 2020 and 2024 at City Hospital No. 1 in Mykolaiv, Ukraine. The rehabilitation outcomes of 100 inpatients with stage I obesity (BMI 30.0–34.9 kg/m^2) who had experienced a first acute myocardial infarction were analysed. These patients formed the main group. The control group comprised 100 patients with normal body weight (BMI 18.0–24.9 kg/m^2) [10] who had also experienced a first acute myocardial infarction and had clinical and medical-history characteristics comparable to those of the main group.

Men predominated among the study participants (57.0% in the main group and 60.0% in the control group). The mean age was 62.3 ± 1.1 years in the main group and 61.5 ± 1.8 years in the control group ($p > 0.05$).

The visceral adiposity index (VAI) was calculated according to Amato et al. [11]:

For men:

$$VAI = [WC / (39.68 + 1.88 \times BMI)] \times (TG / 1.03) \times (1.31 / HDL).$$

For women:

$$VAI = [WC / (36.58 + 1.89 \times BMI)] \times (TG / 0.81) \times (1.52 / HDL),$$

where WC is waist circumference (cm), TG is triglyceride concentration (mmol/L), and HDL is high-density lipoprotein cholesterol concentration (mmol/L).

The severity of acute heart failure was assessed according to the Killip classification [12]. The stage and type of chronic heart failure were determined according to the 2023 European Society of Cardiology classification, and functional class was assessed according to the New York Heart Association classification [13, 14].

The diagnostic, treatment, and clinical management programme was identical in both groups and followed current clinical protocols. All patients underwent revascularisation procedures, including stenting or balloon angioplasty, and received antihypertensive, anticoagulant, antiarrhythmic, lipid-lowering, and inotropic therapy, as well as treatment for concomitant conditions, as indicated.

The rehabilitation programme included physical exercise, dietary modification, psychological support, and education on cardiovascular disease prevention.

The study was conducted in accordance with applicable bioethical requirements. All patients provided written informed consent to participate in the study [14].

All patients underwent assessment of BMI, myocardial systolic function, and exercise tolerance using the 6-minute walk test [15–17]. Gender differences in functional recovery were assessed during a 6-month follow-up period.

Statistical analysis was performed using analysis of variance and correlation analysis in Microsoft Excel software (Microsoft Corp., USA).

RESULTS

Most cases of MI were STEMI, accounting for 64.0% of cases in the main group and 66.0% in the control group. NSTEMI was recorded in 36.0% and 34.0% of cases, respectively. The distribution of complications during the acute phase of MI was comparable between groups (Table 1).

Clinical manifestations of MI included chest pain (72% in the main group and 76% in the control group), shortness of breath on minimal exertion (62% and 42%, respectively), palpitations (22% and 20%, respectively), and general weakness (64% and 66%, respectively). No between-group differences were observed in MI localisation. Posterior MI was the most common localisation, occurring in 58% of patients in the main group and 50%

Table 1. Distribution of patients by the structure of complications

Complications	Main group				Control group			
	STEMI (n=64)		nSTEMI (n=36)		STEMI (n=66)		nSTEMI (n=34)	
	abs.	%	abs.	%	abs.	%	abs.	%
Acute aneurism of left ventricle	4 (3/1)*	6,3	-	-	1 (0/1)	1,5	-	-
Kilip III/IV	9 (6/3)	14,1	3 (3/0)	8,3	2 (1/1)	3,0	1 (0/1)	2,9
Arrhythmias	3 (2/1)	4,7	1 (1/0)	2,8	1 (0/1)	1,5	1 (1/0)	2,9

Note: in the numerator – the number of women, in the denominator – men

Source: compiled by the authors of this study

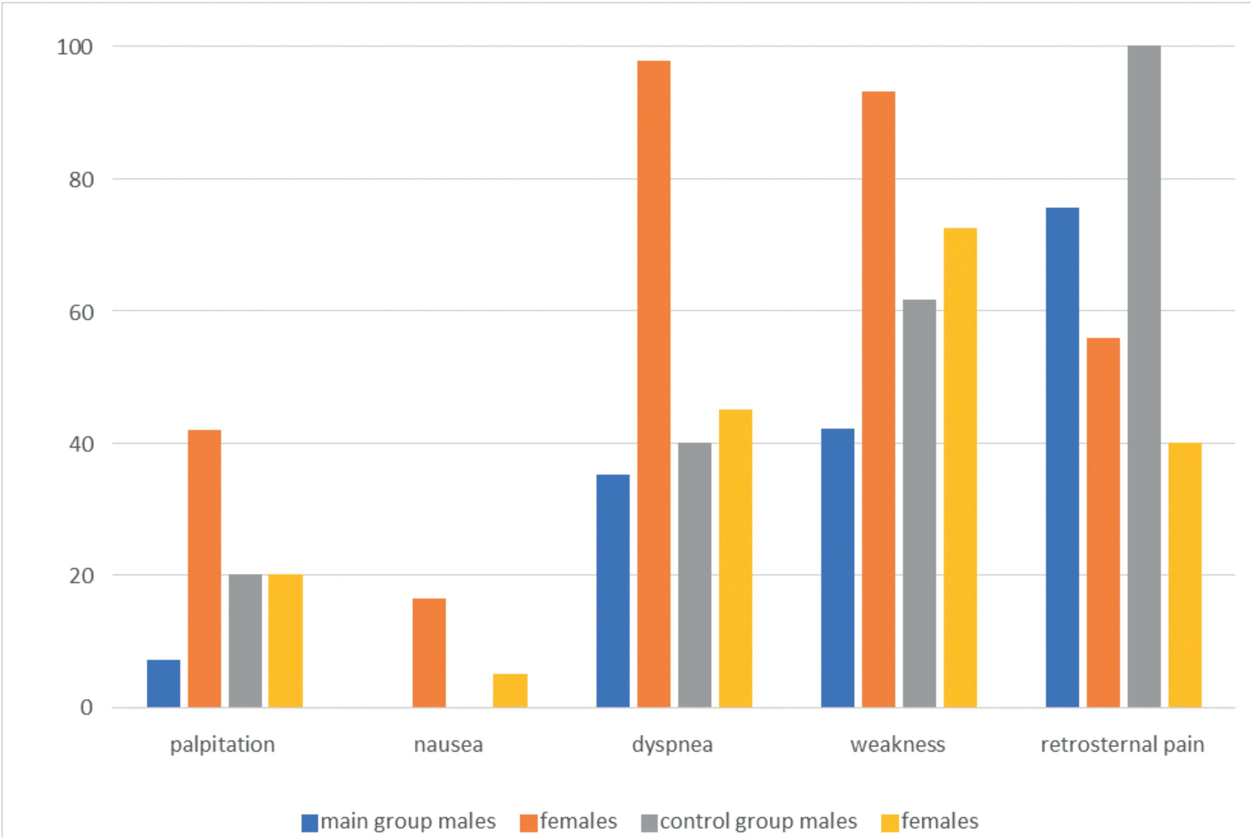

Fig. 1. Gender differences in the course of MI in patients of different clinical groups
Source: compiled by the authors of this study

in the control group. Lateral MI occurred in 36% and 46% of patients, respectively, whereas anterior MI occurred in 6% and 4%, respectively.

Sex-specific differences in the clinical presentation of MI are presented in Fig. 1. In the control group, no significant sex-related differences in the clinical presentation of MI were observed ($p > 0.05$).

Risk factors included arterial hypertension (82% in the main group and 88% in the control group), coronary heart disease (78% and 74%, respectively), type 2 diabetes mellitus (46% and 28%, respectively), dyslipidaemia (78% and 62%, respectively), smoking (46% and 24%, respectively), alcohol misuse (32% and 28%, respectively), previous coronavirus infection (10% and 14%, respectively), and occupational hazards (8% and 12%, respectively).

At discharge, mean LVEF was 51.1 ± 0.3% in the main group and 52.6 ± 0.7% in the control group. Mean BMI was 32.7 ± 0.3 kg/m^2 in the main group and 23.5 ± 0.4 kg/m^2 in the control group. Mean VAI was 1.7 ± 0.1 and 1.0 ± 0.1, respectively ($p < 0.05$). Among patients with obesity, VAI was higher in women than in men (2.1 ± 0.2 vs. 1.3 ± 0.2; $p < 0.05$).

Although all patients demonstrated clinical improvement after treatment, signs of chronic heart failure were still present at discharge. NYHA class II was observed in 58.0% of patients in the main group and 66.0% in the control group, whereas NYHA class III was observed in 42.0% and 34.0%, respectively. The mean 6-minute walk distance was 266 ± 9 m in the main group and 289 ± 11 m in the control group.

Following rehabilitation, systolic function and exercise tolerance improved in both groups. LVEF increased to 53.7 ± 0.4% in the main group, representing a relative increase of 5.1%, and to 56.8 ± 0.6% in the control group, representing a relative increase of 8.0%. The 6-minute walk distance increased by 43 ± 3 m in the main group and by 52 ± 5 m in the control group ($p < 0.05$).

Overall, rehabilitation outcomes were positive in both groups; however, the magnitude of improvement was smaller in the main group than in the control group. A clinically significant improvement in exercise tolerance was observed in 88% of patients in the main group, with the mean 6-minute walk distance increasing to 309 ± 8 m. In the control group, a clinically significant improvement was observed in all patients, with the mean distance increasing to 341 ± 11 m ($p < 0.05$).

DISCUSSION

In the present study, patients in both groups showed improvement following rehabilitation; however, the magnitude of improvement in LVEF and exercise tolerance was smaller in the main group than in the control group.

VAI was higher among women with obesity than among men with obesity. Sex-specific differences in functional recovery should be interpreted cautiously, as detailed sex-stratified outcome data for LVEF and the 6-minute walk test are not presented in the Results section.

The observed sex differences in VAI may reflect the use of sex-specific formulae, as well as differences in fat distribution and hormonal and metabolic profiles. As VAI is a calculated index rather than a direct measure of visceral adiposity, these findings should be interpreted with caution.

The findings of this study suggest that obesity may modify post-MI recovery, with sex- and gender-related factors potentially influencing rehabilitation outcomes. In particular, the observed differences in clinical presentation and VAI support the need for an individualised approach to rehabilitation in patients with obesity. These findings are broadly consistent with the existing literature, which indicates that female patients may experience a more complex recovery trajectory after MI, influenced by both biological and psychosocial factors [1, 5, 9].

One of the key observations was the higher prevalence of atypical clinical manifestations among women with obesity, which may delay diagnosis and initiation of treatment. This, in turn, may negatively affect early engagement in rehabilitation. In addition, the higher VAI observed in women may reflect underlying metabolic disturbances, including insulin resistance and altered lipid profiles, which may further impair cardiovascular recovery [11].

Psychosocial determinants may also be important. Women, particularly those with obesity, are more prone to depression and anxiety after MI, which may reduce adherence to cardiac rehabilitation programmes [2, 3]. Furthermore, social roles and caregiving responsibilities may limit their ability to participate fully in structured rehabilitation interventions. These barriers highlight the need for more flexible and individualised rehabilitation models.

Although all patients demonstrated improvement following rehabilitation, the magnitude of change was smaller in the group with obesity. This suggests that standard rehabilitation protocols may not be sufficiently tailored to address obesity-related limitations.

Overall, rehabilitation after MI requires a comprehensive approach aimed at restoring cardiovascular functional capacity and modifying lifestyle factors, particularly dietary habits and physical activity, while taking into account the individual characteristics of the patient population.

CONCLUSIONS

Obesity may complicate recovery following myocardial infarction, and gender-specific factors may influence rehabilitation outcomes. The interaction between gender and obesity may present particular challenges in the rehabilitation of patients after MI. Addressing these potential disparities may require a multifactorial approach, including gender-sensitive rehabilitation models, mental health support, and attention to social determinants of health. Future research should investigate the mechanisms underlying these differences and develop targeted interventions to optimise outcomes in this population.

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ORIGINAL ARTICLE

Exergaming in the comprehensive rehabilitation of patients with cerebral small vessel disease

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ABSTRACT

Aim: To evaluate the effects of exergaming added to comprehensive rehabilitation on cognitive, motor, balance, emotional, and selected cerebrovascular haemodynamic outcomes in patients with cerebral small vessel disease (CSVD).

Materials and Methods: Sixty-four patients with MRI-confirmed CSVD (mean age, 67.4 ± 5.8 years) were randomized to an intervention group receiving standard rehabilitation plus exergaming or a control group receiving conventional rehabilitation. The exergaming programme consisted of 45–60-minute sessions, three times weekly for 12 months, using a stabilometric platform with motion feedback. Outcomes were assessed at baseline, 6 months, and 12 months using the MMSE, MoCA, Schulte test, Digit Symbol Substitution Test, Berg Balance Scale (BBS), Timed Up and Go (TUG) test, stabilometric indices, Geriatric Depression Scale, Hamilton Anxiety Rating Scale, and transcranial Doppler parameters.

Results: At 12 months, the intervention group showed greater improvements than the control group in MMSE scores (+15.0% vs +5.5%; $p < 0.001$), MoCA scores (+23.1% vs +8.8%; $p < 0.001$), and balance (BBS: +8.8 vs +3.2 points). TUG time decreased by 20.1% in the intervention group, compared with 5.7% in controls ($p = 0.001$). CoP sway area decreased by 30.9% in the intervention group and by 10.9% in controls. Depressive and anxiety symptom scores also decreased more markedly in the intervention group. PSV and EDV increased, whereas PI decreased by 11.1%; lower PI values were correlated with greater improvement in MoCA scores ($r = -0.57$; $p < 0.01$).

Conclusions: Exergaming added to conventional rehabilitation was associated with greater improvements in cognitive function, balance, mobility, postural control, emotional status, and selected cerebrovascular haemodynamic measures in patients with CSVD. It may be a feasible adjunct to comprehensive rehabilitation; larger controlled studies are needed to confirm its long-term effects and underlying mechanisms.

KEYWORDS: cerebral small vessel disease, exergaming, cognitive function, balance, transcranial Doppler ultrasonography

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INTRODUCTION

Cerebral small vessel disease (CSVD) is a major contributor to cognitive decline, gait impairment, and neuropsychiatric symptoms in older adults [1, 2]. Vascular white matter changes are common after the age of 60 and particularly prevalent among patients with cerebrovascular disease [1, 3]. CSVD affects small arterioles, capillaries, and venules, leading to chronic ischaemia of deep brain structures and the development of white matter hyperintensities, lacunar infarcts, and cerebral microbleeds. Its clinical manifestations may include cognitive impairment, motor dysfunction, emotional symptoms, and reduced functional independence, often requiring long-term multidisciplinary rehabilitation [1–3].

Maintaining regular participation in conventional rehabilitation may be challenging because of low motivation and reduced engagement. Exergaming combines structured physical activity with interactive virtual tasks and may increase participation while simultaneously stimulating motor, cognitive, and attentional processes [4–7]. Its use may therefore be relevant to rehabilitation programmes for patients with CSVD, particularly where balance training, motor coordination, and cognitive engagement are required.

However, evidence specifically addressing exergaming in CSVD remains limited. Its potential role should therefore be evaluated using clearly defined cognitive, motor, balance, and emotional outcomes.

AIM

To evaluate the effects of exergaming added to comprehensive rehabilitation on cognitive, motor, balance, and emotional outcomes in patients with cerebral small vessel disease.

MATERIALS AND METHODS

STUDY DESIGN AND PARTICIPANTS

The study included 64 patients with cerebral small vessel disease (CSVD) who underwent treatment and rehabilitation in the neurology department during 2023–2024. The mean age of participants was 67.4 ± 5.8 years; 31 were men (48.4%) and 33 were women (51.6%). The diagnosis of CSVD was established based on clinical–neurological examination and confirmed using neuroimaging criteria.

NEUROIMAGING AND CEREBROVASCULAR ASSESSMENT

Brain magnetic resonance imaging (MRI) in all patients revealed characteristic vascular white matter changes, including periventricular or deep leukoaraiosis, lacunar infarcts, and cerebral microbleeds. These findings were quantified using standardized neuroimaging scales: the Fazekas scale (≥2) [10], the Brain Atrophy and Lesion Index (BALI ≥4) [11], and the Scheltens scale [12].

Cerebrovascular hemodynamics were assessed using duplex ultrasound examination of extracranial and intracranial arteries [13]. The pulsatility index (PI) in the middle cerebral artery was recorded as an indicator of distal vascular resistance.

RANDOMIZATION AND INTERVENTION

Patients were randomized into two equal groups: an intervention group (n = 32) and a control group (n = 32). All participants received standard pharmacological therapy according to national clinical protocols, including antihypertensive, antiplatelet, lipid-lowering, and neurometabolic medications [14].

Both groups participated in conventional physical rehabilitation programmes. In addition, patients in the intervention group underwent an exergaming-based rehabilitation module that combined interactive physical tasks in a virtual environment with objective motion control using a Gea Super stabilometric platform (Medi, Israel) [15].

Exergaming sessions were conducted three times per week for 45–60 minutes over a period of 12 months. Each session included exercises aimed at improving balance, spatial orientation, reaction speed, attention, and motor coordination. Stabilometric parameters—including amplitude, area, and mean velocity of center-of-pressure (CoP) sway—were recorded to provide a quantitative assessment of postural stability and its changes during rehabilitation.

OUTCOME MEASURES

Treatment effectiveness was evaluated at three time points: baseline, 6 months, and 12 months.

Cognitive function was assessed using the Mini-Mental State Examination (MMSE), the Montreal Cognitive Assessment (MoCA) [16], the Schulte test [17], and the Digit Symbol Substitution Test [18].

Table 1. Functional domains in the rehabilitation pathway

Domain	Scales	Intervention group			Control group		
		Initial	6 months	12 months	Initial	6 months	Final
Cognitive Functions	MMSE, scores	23.4 ± 1.7	25.8 ±1.6	26.9 ± 1.4*	23.6 ± 1.8	24.2 ± 1.5	24.9 ± 1.6
	MoCA, scores	21.2 ± 2.3	24.5 ± 2.0	26.1 ± 1.9 *	21.5 ± 2.1	22.8 ± 1.9	23.4 ± 2.0
	Schulte test, s	68.2 ± 9.4	60.5 ±6.8	53.1 ± 7.8 *	69.4 ± 8.9	66.7 ± 7.7	63.7 ± 9.1
	DSST, scores	41.3 ± 7.2	47.8 ± 6.8	54.9 ± 6.6	42.5 ± 6.9	44.4 ± 6.9	47.2 ± 7.1
Motor and Balance Function	Berg Balance Scale, scores	41.8 ± 4.2	45.6 ± 4.7	50.6 ± 3.8*	42.1 ± 4.5	43.8 ± 4.2	45.3 ± 4.0
	Timed Up & Go, s	13.9 ± 2.1	12.6 ± 1.9	11.1 ± 1.8*	14.1 ± 2.3	13.7 ± 2.2	13.3 ± 2.0
Stabilometric Indices	CoP sway amplitude, mm	9.8 ± 2.3	8.3 ± 1.9	6.2 ± 1.7*	9.6 ± 2.4	9.0 ± 2.2	8.2 ± 2.0
	CoP sway area (S), mm^2	185.6 ± 42.1	164.4 ±44.4	128.3 ± 31.7*	182.2 ± 39.8	173.6 ± 35.4	162.4 ± 34.6
	Mean sway speed (Vmean), mm/s	14.2 ± 2.7	12.7 ± 2.4	10.3 ± 2.1*	13.8 ± 2.5	13.1 ± 2.2	12.7 ± 2.4
	Coordination index (CIN)	0.42 ± 0.08	0.35 ± 0.07	0.29 ± 0.06*	0.43 ± 0.09	0.41 ± 0.08	0.39 ± 0.07
	Load asymmetry, %	18.6 ± 5.1	14.3 ± 3.7	9.3 ± 3.2*	17.9 ± 5.0	16.2 ± 3.7	14.9 ± 4.8
Cerebrovascular Hemodynamics	PSV (MCA), cm/s	65.3 ± 8.4	67.8 ± 7.4	70.9 ± 7.6*	66.0 ± 8.7	66.6 ±6.7	67.1 ± 8.5
	EDV (MCA), cm/s	27.1 ± 4.3	28.8 ± 3.7	30.5 ± 3.9*	27.4 ± 3.8	27.8 ± 4.2	28.3 ± 4.6
	PI (Pulsatility Index)	1.08 ± 0.09	1.02 ± 0.08	0.96 ± 0.07*	1.07 ± 0.08	1.06 ± 0.08	1.05 ± 0.09
Depression and Anxiety	GDS, scores	6.4 ± 0.8	4.9 ± 1.0	3.9 ± 0.9*	6.2 ± 0.9	5.8 ± 0.9	5.4 ± 0.9
	HARS, scores	10.5 ± 1.4	8.2 ± 1.8	6.7 ± 1.6*	10.3 ± 1.6	9.7 ± 1.2	9.0 ± 1.4

*Note: * – the difference between groups is statistically significant (p<0.05)*

Source: compiled by the authors of this study

Motor function and balance were evaluated using the Berg Balance Scale (BBS) [19], the Timed Up and Go (TUG) test [20], and stabilometric indicators of postural control [21].

Emotional status was assessed using the Geriatric Depression Scale (GDS) [22] and the Hamilton Anxiety Rating Scale (HARS) [23].

STUDY ENDPOINTS

Primary endpoints included improvement in cognitive function, defined as a ≥15% increase in MMSE and MoCA total scores compared with baseline values.

Secondary endpoints included improvement in balance and coordination, defined as a reduction in TUG time, an increase in BBS score, and a decrease in CoP sway area; changes in GDS and HARS scores; and changes in cerebrovascular hemodynamic indices.

ETHICAL CONSIDERATIONS

The study was conducted in accordance with the principles of the Declaration of Helsinki (1964, revision 2024), the Council of Europe Convention on Human Rights and Biomedicine (1997), and the Order of the Ministry of Health of Ukraine No. 690 dated 23.09.2009 regulating clinical trials [24]. All participants provided written informed consent prior to enrollment. The study protocol was approved by the local Bioethics Committee of the Black Sea National University (Protocol No. 9, dated 14.09.2023).

STATISTICAL ANALYSIS

Statistical analysis was performed using the Mann–Whitney U test, Wilcoxon signed-rank test, and Spearman correlation analysis [25]. A p-value < 0.05 was considered statistically significant.

RESULTS

At baseline, the cognitive status of the two groups was comparable (Table 1). Mean MMSE scores were 23.4 ± 1.7 in the intervention group and 23.6 ± 1.8 in the control group, indicating mild cognitive impairment in both cohorts (p = 0.74). After six months, the MMSE score increased to 25.8 ± 1.6 in the intervention group compared with 24.2 ± 1.5 in the control group (p = 0.021). At 12 months, mean MMSE reached 26.9 ± 1.4 in the intervention group versus 24.9 ± 1.6 in controls (p < 0.001). Overall, patients who participated in the exergaming programme demonstrated an average increase of 3.5 points (15.0%), whereas the control group improved by 1.3 points (5.5%).

Baseline MoCA scores were comparable between groups (21.2 ± 2.3 in the intervention group and 21.5 ± 2.1 in the control group; p = 0.62). At six months, the intervention group achieved a mean score of 24.5 ± 2.0 compared with 22.8 ± 1.9 in the control group (p = 0.018). At 12 months, mean MoCA scores increased to 26.1 ± 1.9 in the intervention group and 23.4 ± 2.0 in controls (p < 0.001). Both groups improved over time, but the magnitude of change was greater in the intervention group.

Performance on the Schulte test was comparable at baseline (68.2 ± 9.4 s in the intervention group and 69.4 ± 8.9 s in controls; p = 0.59). After six months, the mean completion time decreased to 60.5 ± 6.8 s in the intervention group and 66.7 ± 7.7 s in the control group. At 12 months, the mean completion time was 53.1 ± 7.8 s in the intervention group and 63.7 ± 9.1 s in the control group (p < 0.001).

Digit Symbol Substitution Test scores increased from 41.3 ± 7.2 at baseline to 47.8 ± 6.8 at six months and 54.9 ± 6.6 at 12 months in the intervention group. In the control group, scores increased from 42.5 ± 6.9 to 44.4 ± 6.9 and 47.2 ± 7.1, respectively.

Motor and balance function improved in both groups. At six months, the Berg Balance Scale score increased from 41.8 ± 4.2 to 45.6 ± 4.7 in the intervention group and to 43.8 ± 4.2 in the control group. At 12 months, the score was 50.6 ± 3.8 in the intervention group (p < 0.001) and 45.3 ± 4.0 in the control group (p = 0.037). The final between-group difference was 5.3 points.

Mean TUG time decreased from 13.9 ± 2.1 to 12.6 ± 1.9 s at six months and 11.1 ± 1.8 s at 12 months in the intervention group. In the control group, TUG time decreased from 14.1 ± 2.3 to 13.7 ± 2.2 and 13.3 ± 2.0 s, respectively. The difference between groups at 12 months was statistically significant (p = 0.001). Changes in TUG time were inversely correlated with changes in BBS scores (r = –0.72; p < 0.001).

At six months, CoP sway amplitude decreased from 9.8 ± 2.3 to 8.3 ± 1.9 mm in the intervention group and from 9.6 ± 2.4 to 9.0 ± 2.2 mm in the control group. At 12 months, frontal CoP sway amplitude was 6.2 ± 1.7 mm in the intervention group and 8.2 ± 2.0 mm in the control group. CoP sway area decreased from 185.6 ± 42.1 to 164.4 ± 44.4 mm² at six months and 128.3 ± 31.7 mm² at 12 months in the intervention group. In the control group, the respective values were 182.2 ± 39.8, 173.6 ± 35.4, and 162.4 ± 34.6 mm². Mean sway velocity, coordination index, and load asymmetry showed a similar pattern of change (Table 1).

At baseline, the intervention and control groups demonstrated comparable levels of depressive and anxiety symptoms. In the intervention group, GDS scores decreased from 6.4 ± 0.8 at baseline to 4.9 ± 1.0 at six months and 3.9 ± 0.9 at 12 months (p < 0.05). HARS scores decreased from 10.5 ± 1.4 to 8.2 ± 1.8 and 6.7 ± 1.6, respectively (p < 0.05). In the control group, GDS scores changed from 6.2 ± 0.9 to 5.8 ± 0.9 and 5.4 ± 0.9, while HARS scores changed from 10.3 ± 1.6 to 9.7 ± 1.2 and 9.0 ± 1.4 over the same period.

At six months, PSV in the middle cerebral artery increased from 65.3 ± 8.4 to 67.8 ± 7.4 cm/s, EDV increased from 27.1 ± 4.3 to 28.8 ± 3.7 cm/s, and PI decreased from 1.08 ± 0.09 to 1.02 ± 0.08 in the intervention group. At 12 months, the respective values were 70.9 ± 7.6 cm/s for PSV, 30.5 ± 3.9 cm/s for EDV, and 0.96 ± 0.07 for PI (all p < 0.05). Cerebrovascular parameters changed only slightly in the control group. Lower PI values were associated with greater improvements in MoCA scores (r = –0.57; p < 0.01).

DISCUSSION

The addition of exergaming to a comprehensive rehabilitation programme for patients with CSVD was associated with greater improvements in cognitive, motor, balance, and stabilometric outcomes than conventional rehabilitation alone. Increases in MMSE and MoCA scores, shorter TUG times, reductions in CoP sway area, and lower PI values were observed in the intervention group over the 12-month follow-up. These findings are consistent with the multidimensional nature of vascular cognitive impairment, in which cognitive and motor dysfunction may coexist.

Our findings are broadly consistent with earlier reports by Stanmore et al. [26] and Anderson-Hanley et al. [27], which suggest that interactive exercise may support physical and cognitive functioning in older adults. The reduction in PI observed in the intervention group is also consistent with findings by Akazawa et al. [28] concerning the effects of regular aerobic exercise on cerebral blood flow. However, the present study did not assess endothelial function, cerebral perfusion, or vascular reactivity directly. Therefore, the observed changes in Doppler parameters should be interpreted as changes in selected cerebrovascular hemodynamic indices rather than evidence of a specific vascular mechanism.

The reduction in CoP sway area is in line with the observations of You et al. [21], who reported improved postural control in patients with white-matter lesions following visual-feedback training. The concurrent improvements in balance and cognitive outcomes suggest that feedback-based exergaming may be a useful component of rehabilitation programmes addressing both motor and cognitive deficits in CSVD.

Several limitations should be acknowledged, including the moderate sample size, the absence of neurobiological markers such as BDNF or VEGF, and the lack of follow-up beyond one year. In addition, further studies should provide detailed information on randomization, adherence to the intervention, and the statistical analysis of repeated measurements. The present findings should therefore be interpreted cautiously.

CONCLUSIONS

Exergaming added to comprehensive rehabilitation was associated with greater improvements in cognitive performance, balance, functional mobility, stabilometric measures, emotional outcomes, and selected cerebrovascular Doppler parameters than conventional rehabilitation alone in patients with CSVD. The reduction in PI was associated with improvement in MoCA scores; however, this association does not establish a causal mechanism. Exergaming appears to be a feasible adjunct to rehabilitation in this population. Larger multicentre studies with longer follow-up, clearly reported randomization procedures, and biological markers of neuroplasticity and vascular function are needed to confirm these findings and clarify their underlying mechanisms.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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ORIGINAL ARTICLE

Effectiveness of constraint-induced movement therapy with functional electrical stimulation on improving motor hand function among post-stroke survivors

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ABSTRACT

Aim: To determine the effectiveness of constraint-induced movement therapy with functional electrical stimulation in improving motor hand function among post-stroke survivors.

Materials and Methods: This experimental study involved 60 stroke patients with middle cerebral artery syndrome, selected based on inclusion and exclusion criteria using convenience sampling. Participants were divided into two groups: constraint-induced movement therapy with functional electrical stimulation and conventional therapy with functional electrical stimulation. Both groups underwent interventions five days per week for four weeks, with sessions lasting 45-50 minutes. The interventions included task-specific exercises such as reach and grasp, object manipulation, and buttoning practice. Functional electrical stimulation targeted the wrist and finger muscles with specific stimulation parameters. Hand function was assessed using the Jebsen-Taylor Hand Function Test before and after treatment.

Results: Participants demonstrated significant improvement in hand function following the interventions. In the CIMT group, the JTHFT mean score decreased from 96.73 ± 1.55 at pre-test to 93.37 ± 2.98 at post-test ($p < 0.001$). The CT group also showed improvement, with scores decreasing from 96.00 ± 1.62 to 95.40 ± 1.77 ($p = 0.010$). Between-group comparison of post-test values revealed significantly greater improvement in the CIMT group ($p = 0.0021$). Baseline values did not differ significantly ($p = 0.0785$), indicating comparability of the groups prior to treatment.

Conclusions: Combining constraint-induced movement therapy with functional electrical stimulation improves hand function after stroke more effectively than conventional therapy by promoting use of the affected limb and motor recovery. This approach shows promise for improving motor hand function and functional use of the affected upper limb among post-stroke survivors; however, further research is needed to evaluate its long-term effects and effectiveness across diverse patient populations.

KEYWORDS: stroke, constraint-induced movement therapy, functional electrical stimulation, upper extremity, neuroplasticity, quality of life

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INTRODUCTION

Motor dysfunction is a common consequence of stroke, mainly affecting the upper limbs (UL). Over 80% of stroke patients experience UL impairment, often leading to long-term disability and reduced quality of life [1]. Constraint-induced movement therapy (CIMT) is a stroke rehabilitation method that improves hand function by restraining the healthy limb and encouraging use of the affected limb, thereby promoting neuroplasticity and functional recovery [2]. Functional electrical stimulation (FES) supports post-stroke rehabilitation by using electrical pulses to induce muscle contractions and facilitate functional movements such as grasping. It may contribute to both short-term functional improvement and long-term motor recovery, particularly in patients with severe impairment [3]. By enhancing neural plasticity and neuromuscular activation, combining CIMT and FES may overcome some limitations of either intervention alone: FES facilitates muscle activation in patients with limited voluntary movement, while CIMT promotes motor recovery [4]. CIMT combined with FES may improve post-stroke motor recovery, including grip, dexterity, and neuroplasticity [5]. Although combining CIMT and FES offers potential benefits, challenges remain, including adherence, equipment requirements, and therapist training [6].

Technological advances have made CIMT and FES more accessible and adaptable to individual patient needs [7]. Conventional physiotherapy, including passive range-of--motion (PROM) exercises and stretching, also contributes to hand recovery after stroke. Combining CIMT and FES may further enhance motor function and accelerate recovery [8]. Further research is needed to optimize CIMT and FES protocols and improve post-stroke recovery [9]. Yang et al. reported that optimizing the timing and dosage of CIMT improved upper-limb recovery after stroke [10]. Tedla et al. reported that CIMT improved balance and upper-limb function, thereby enhancing daily activities [8]. de Azevedo et al. reported improvements in activity and participation following CIMT after stroke [1]. FES may improve upper-limb motor function, including reaching and grasping, during post-stroke rehabilitation [11]. Stroke rehabilitation requires appropriate patient selection and individualized treatment based on motor and cognitive capacity and treatment tolerance [12]. Adherence to intensive upper-limb rehabilitation may also be influenced by motivational and emotional factors and treatment protocols. Stroke frequently impairs UL function; combining CIMT and FES may enhance recovery, but the effects of this combined approach require further investigation.

AIM

To determine the effectiveness of CIMT combined with FES in improving motor hand function among post-stroke survivors.

MATERIALS AND METHODS

Study design: Experimental study.

Subjects: Patients with middle cerebral artery (MCA) stroke.

Sampling technique: Convenience sampling.

Sample size: 60 participants.

STUDY PROCEDURE

The study included 60 participants recruited using convenience sampling according to predefined inclusion

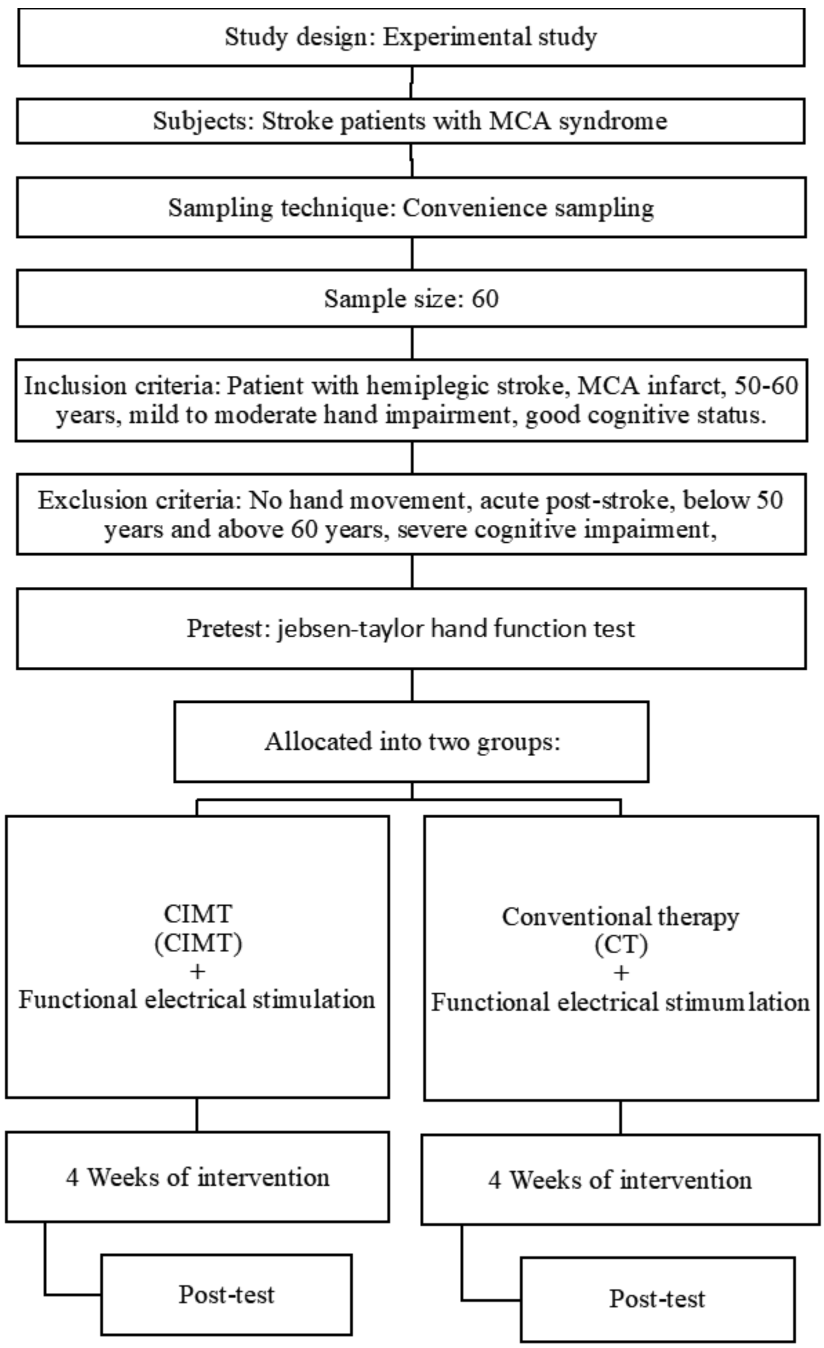

Fig. 1. Methodology – Flowchart

Source: compiled by the authors of this study

Table 1. CIMT: Exercise protocol

EXERCISE	DESCRIPTION	SETS & REPETITIONS
Reach & Grasp	Reach and grasp objects (e.g., a cup or ball) with the affected hand.	2 sets of 10 reps
Object Manipulation	Manipulate objects (e.g., flip cards, stack blocks, roll balls) to enhance fine motor skills.	2 sets of 10 reps
Buttoning Practice	Practice buttoning, unbuttoning, or fastening Velcro with the affected hand.	3 sets of 5 reps
Ball Squeeze	Squeeze a stress or foam ball to strengthen grip.	3 sets of 5 reps
Simulated Eating	Use the affected hand with utensils (e.g., fork or spoon) to pick and transfer small objects like beans or marbles.	3 sets of 5 reps
Wrist Flexion/Extension	Do active wrist flexion and extension against light resistance (e.g., band or wrist weights).	3 sets of 5 reps
Functional Task Practice	Practice daily tasks (e.g., opening jars, pouring water, tying shoelaces) with the affected hand.	2 sets of 5 tasks

Source: compiled by the authors of this study

and exclusion criteria. An information sheet was provided, and informed consent was obtained from all participants. Hand function was assessed using the Jebsen-Taylor Hand Function Test (JTHFT). The participants were subsequently randomly allocated into two groups using simple randomization: the CIMT + FES group (n = 30) and the CT + FES group (n = 30). Following baseline assessment, both groups underwent their respective interventions. The CIMT group received CIMT, including reach and grasp, object manipulation, buttoning practice, ball squeezing, simulated eating, wrist flexion and extension, and functional task practice, combined with FES. The CT group received conventional therapy (CT), including passive range-of-motion exercises, active-assisted range-of-motion exercises, isometric strengthening exercises, and functional gripping practice, combined with FES.

The Jebsen-Taylor Hand Function Test (JTHFT) demonstrates good validity and reliability in assessing hand function in individuals with neurological conditions. It evaluates both fine and gross motor skills, with criterion validity supported by correlations with other established hand function assessments. However, the test may be unsuitable for individuals with severe motor or cognitive impairments because of the complexity of its tasks. Although the JTHFT simulates activities of daily living, it does not assess all aspects of hand function, which may limit its comprehensiveness in some clinical settings. The study methodology is presented in the flowchart in Figure 1.

Functional electrical stimulation (FES)

Surface electrodes were placed over the wrist and finger flexor and extensor muscles (flexor digitorum superficialis, flexor carpi radialis, extensor digitorum, and extensor carpi radialis) to facilitate functional grasp and release.

Stimulation parameters

Pulse width: 200-300 µs

Frequency: 20-40 Hz

Intensity: adjusted to produce visible, comfortable muscle contractions.

Mode: cyclic stimulation with alternating contraction-relaxation phases during task-specific activities Duration: 15 minutes

Constraint-induced movement therapy (CIMT) The exercise protocol is presented in Table 1.

Both groups received treatment for 4 weeks, 5 days per week, with one session per day lasting approximately 45-50 minutes. Pre- and post-intervention data were collected and statistically analyzed.

Inclusion criteria:

age 50-60 years;
middle cerebral artery stroke;
3 months post-stroke;
mild to moderate hand impairment;
willingness to participate;
no significant cognitive impairment;
no severe comorbidities.

Exclusion criteria:

severe impairment;
acute stroke (<3 months);
cognitive impairment;
other neurological disorders;
implanted devices (e.g., pacemaker);
recent CIMT or other therapy.

Outcome measure: Jebsen-Taylor Hand Function Test (JTHFT).

STATISTICAL ANALYSIS

The collected data were analyzed using descriptive and inferential statistics and are presented as mean ± standard deviation (SD). Paired and unpaired t-tests were used to assess within-group and between-group differences, respectively. A p value < 0.05 was considered statistically significant. Statistical analyses were performed using SPSS software. The results are presented in Tables 2 and 3 and illustrated in Figures 2 and 3.

RESULTS

Participants demonstrated a significant improvement in JTHFT scores. In the CIMT group (Group A), the mean score decreased from 96.73 ± 1.552 at pre-test to 93.37 ± 2.977 at post-test. In the CT group (Group B), the mean score decreased from 96.00 ± 1.619 at pre-test to 95.40 ± 1.773 at post-test. The paired t-test showed significant differences between pre- and post-test scores in both groups ($t = 7.827$, $p < 0.001$ for Group A; $t = 2.757$, $p = 0.0100$ for Group B) (Table 2, Fig. 2).

Table 2. Pre-test and post-test values of paired t-test

OUTCOME MEASURE	GROUPS	TEST	MEAN	SD	t value	p value
Jebson-Taylor hand function test	CIMT + FES (GROUP A)	Pretest	96.73	1.552	7.827	<0.001
		Post test	93.37	2.977		
	CT + FES (GROUP B)	Pre test	96.00	1.619	2.757	0.0100
		Post test	95.40	1.773		

Source: compiled by the authors of this study

Table 3. Pre-test and post-test values of unpaired t-test

OUTCOME MEASURE	GROUPS	TEST	MEAN	SD	t value	p value
Jebson-Taylor hand function test	Pre test	96.73	1.552	1.7909	0.0785	<0.001
	Pre test	96.00	1.619			
	Post test	93.37	2.977	3.2142	0.0021	0.0100
	Post test	95.40	1.773			

Source: compiled by the authors of this study

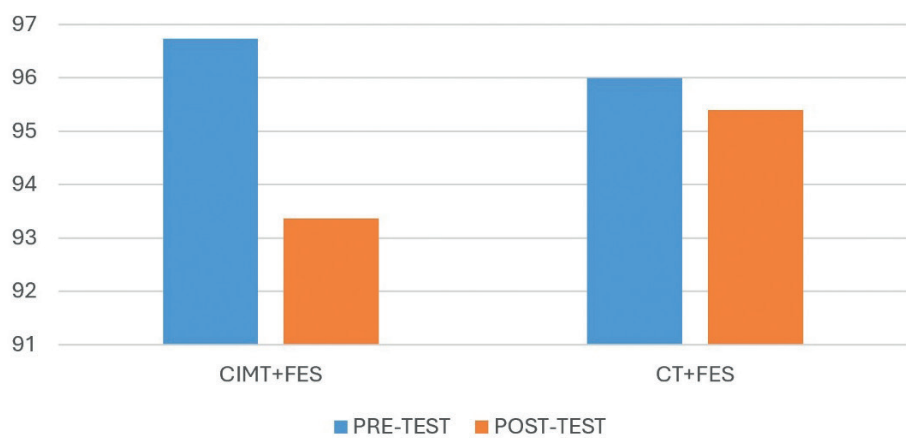

Fig. 2 . Pre-test and post-test values of paired t-test

Source: compiled by the authors of this study

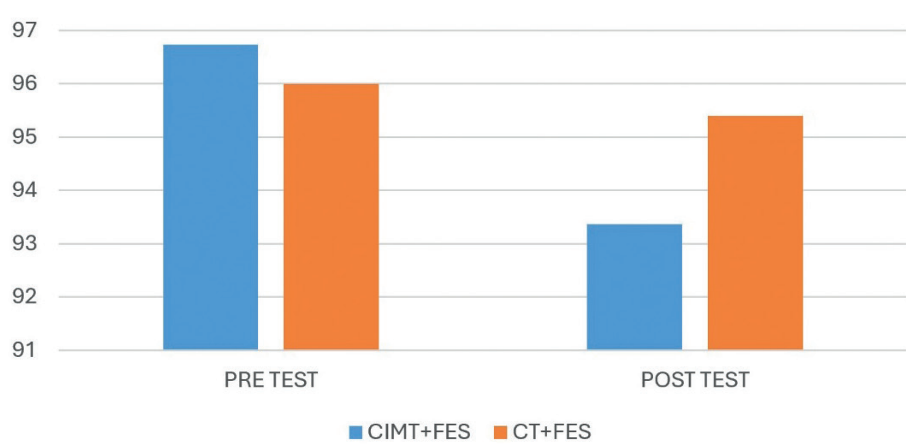

Fig. 3. Pre-test and post-test values of unpaired t-test

Source: compiled by the authors of this study

The between-group comparison showed no significant difference at pre-test (t = 1.7909, p = 0.0785). At post-test, however, a significant difference was observed between the groups (t = 3.2142, p = 0.0021) (Table 3, Fig. 3). These findings indicate that CIMT combined with FES was more effective than CT combined with FES in improving motor hand function.

DISCUSSION

In this study, CIMT combined with FES (Group A) was more effective than conventional therapy combined with FES (Group B) in improving motor hand function among post-stroke survivors. CIMT may improve fine motor skills, grip strength, and functional use of the affected upper limb. Zhang et al. (2023) found that CIMT improved motor function after stroke [13]. Liu et al. reported that modified CIMT improved upper-limb function following stroke rehabilitation [14]. Brunner et al. (2012) found no significant difference in upper-limb motor improvement between CIMT and bimanual training [15]. de Azevedo et al. reported beneficial effects of CIMT on upper-limb activity and participation after stroke [1].

Eraifej et al. reported that functional electrical stimulation improved upper-limb motor function and activities of daily living after stroke, supporting its use as an adjunctive intervention in stroke rehabilitation [16]. Khan et al. reported beneficial effects of FES-based rehabilitation systems on upper-limb motor recovery after stroke [17]. Jonsdottir et al. reported that task-oriented FES improved upper-limb function during post-stroke rehabilitation [18]. Halawani et al. reported beneficial effects of contralaterally controlled functional electrical stimulation (CCFES) compared with conventional neuromuscular electrical stimulation (NMES) on upper-limb function after stroke [19].

Conventional rehabilitation approaches may also contribute to functional recovery. Prabhu et al. (2013) reported that passive movements are used to maintain joint mobility and prevent contractures, although evidence regarding their effectiveness remains limited [20]. Park et al. (2019) reported that hand resistance exercises improved hand strength and motor function in patients after stroke [21].

The findings of the present study indicate that CIMT combined with FES is more effective than conventional therapy combined with FES in improving post-stroke hand function. However, the small sample size, short intervention period, and limited participant diversity restrict the generalizability of the findings. Future studies should include larger and more diverse samples, assess long-term outcomes, optimize treatment protocols, explore different stages of stroke recovery, and evaluate strategies to improve adherence [22-24].

CONCLUSIONS

The findings of this study indicate that combining CIMT with FES is more effective than conventional therapy combined with FES in improving motor hand function among post-stroke survivors. The combination of task-specific motor training through CIMT and muscle activation through FES may provide a targeted rehabilitation approach that enhances functional use of the affected upper limb. These results support the potential use of integrated rehabilitation strategies tailored to individuals with upper-limb impairment after stroke. However, further research involving larger and more diverse stroke populations is needed to optimize treatment parameters and assess long-term outcomes.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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ORIGINAL ARTICLE

Effectiveness of early mobilization in enhancing cardiovascular fitness after myocardial infarction: a randomized pilot study

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ABSTRACT

Aim: The aim of this pilot study was to evaluate the effectiveness of early mobilization exercises combined with breathing techniques in improving cardiovascular fitness, quality of life, and functional recovery in patients following myocardial infarction (MI), compared with standard postoperative care.

Materials and Methods: A total of 30 patients aged 18–80 years who had undergone CABG or PCI following myocardial infarction were included in this randomized pilot study and allocated to two groups of 15 participants each (group A: 10 men and 5 women; group B: 10 men and 5 women). All participants were hemodynamically stable. The early mobilization protocol included graded physical activities such as bed mobility, sitting, standing, ambulation within the ward, and light limb exercises performed under the supervision of a physiotherapist. The intervention was conducted for two weeks, with 30-minute sessions five days per week. Functional capacity was assessed using the 6-minute walk test (6MWT), and perceived exertion using the Visual Analogue Scale (VAS). Pre-test and post-test assessments were performed on postoperative days 7 and 30, respectively, and outcomes were compared between the intervention and control groups.

Results: Patients who participated in early mobilization showed significant improvements in 6MWT distance and VAS scores compared with the control group.

Conclusions: Early mobilization appears to be an effective intervention for improving cardiovascular fitness and functional capacity following myocardial infarction. Larger randomized controlled trials are needed to confirm these findings and establish standardized rehabilitation protocols.

KEYWORDS: myocardial infarction, early mobilization, cardiovascular fitness, cardiac rehabilitation, functional capacity, quality of life

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INTRODUCTION

Cardiovascular diseases, particularly myocardial infarction (MI), remain a leading cause of morbidity and mortality worldwide. MI, commonly referred to as a heart attack, occurs when blood flow to a portion of the heart muscle is obstructed, resulting in tissue damage and a subsequent decline in cardiac function [1]. Following myocardial infarction, patients often face numerous challenges, including physical deconditioning, reduced cardiovascular fitness, and impaired functional capacity and quality of life [2]. Early mobilization exercises have emerged as an important component of post-MI rehabilitation. These exercises involve gradually increasing physical activity during the early stages of recovery and aim to improve circulation, reduce the risk of complications, and promote overall physical and cardiovascular health [3]. Recent studies suggest that early mobilization exercises, when tailored to the individual's health status and supervised by healthcare professionals, may lead to improvements in cardiovascular fitness. Potential benefits include increased exercise tolerance, improved circulation, and a reduced risk of complications such as deep vein thrombosis or pneumonia [4].

In 2020, Munir et al. conducted a scoping review of early mobilization following myocardial infarction. The authors found that although earlier studies, primarily from the pre-revascularization era, supported the safety and potential benefits of early mobilization, robust contemporary evidence evaluating its effects in modern post-MI care remains limited. They emphasized the need for more rigorous randomized clinical trials to inform current clinical practice and guidelines [5]. Nakamura et al. examined the effects of early rehabilitation in patients with acute myocardial infarction (AMI) in a nationwide inpatient cohort study. The study included 31,603 adult patients with AMI who underwent coronary revascularization and stayed in an intensive care unit for more than three days. Patients who started rehabilitation within three days of ICU admission were compared with those receiving standard care. Although no significant differences in activities of daily living at discharge were observed between the groups, early rehabilitation was associated with shorter hospital and ICU stays and lower overall hospitalization costs [6, 7].

Another study compared shorter and longer periods of bed rest in patients with uncomplicated AMI. Across 15 trials, 2,958 patients were assessed; 1,487 were randomized to shorter periods of bed rest (median, 6 days), whereas 1,471 were assigned to longer periods (median, 13 days). No significant differences in reinfarction, cardiac mortality, or all-cause mortality were observed between the groups. The authors concluded that shorter periods of bed rest appeared to be as safe as longer periods, suggesting that prolonged bed rest may provide no additional benefit in uncomplicated AMI. However, most of the included trials were of low methodological quality, highlighting the need for further research to determine the optimal timing of mobilization in this patient population [8]. Similarly, a review of 14 studies involving 3,148 participants compared early mobilization with standard care. Although the findings were not statistically significant, a trend towards lower mortality was observed among patients receiving early mobilization. The authors concluded that early mobilization may provide clinical benefits but emphasized the need for further research to confirm these findings [9]. Other research has similarly indicated that, although historical studies support the safety and benefits of early mobilization, contemporary evidence remains limited, particularly in the era of modern revascularization and current post-MI management [10].

Numerous studies have examined the challenges associated with implementing early mobilization after MI. Systematic reviews and meta-analyses evaluating the effects of early mobilization on mortality and reinfarction have identified limitations such as heterogeneous patient responses, the absence of standardized mobilization protocols, and the relatively low methodological quality of older studies conducted before modern MI treatment approaches became established [11, 12]. Several authors have also noted the limited evidence supporting early mobilization in contemporary post-MI care because much of the available research predates modern revascularization techniques. Despite current recommendations, prolonged bed rest and delayed mobilization may still occur in clinical practice [13]. Other studies examining early rehabilitation after acute MI have identified variability in institutional protocols and potential resource limitations that may affect the implementation of early mobilization programmes, although early rehabilitation has been associated with shorter hospital stays and lower hospitalization costs [14, 15].

Further research is therefore needed to assess the feasibility and effectiveness of early mobilization following MI and to optimise early cardiac rehabilitation protocols [16]. Prolonged bed rest following MI may contribute to physical deconditioning and reduced cardiovascular fitness, whereas appropriately supervised early mobilization may help limit these effects. This pilot study addresses current gaps in evidence concerning the effectiveness of early mobilization in improving cardiovascular fitness and functional capacity after MI and may provide useful information for refining rehabilitation procedures and facilitating the transition from hospitalization to longer-term cardiac rehabilitation [17, 18]. Although early mobilization has been shown to reduce complications in intensive care populations, evidence regarding its specific effects on cardiovascular fitness following MI remains limited [19]. Therefore, the present study aimed to evaluate the effectiveness of early mobilization exercises in enhancing cardiovascular fitness and functional recovery in patients following MI [20].

AIM

The aim of this pilot study was to evaluate the effectiveness of early mobilization exercises, in conjunction with breathing techniques, in improving cardiovascular fitness and functional recovery in patients following myocardial infarction (MI), compared with standard postoperative care.

MATERIALS AND METHODS

STUDY DESIGN

This study was designed as a randomized pilot study with two parallel groups and was conducted among patients who had undergone CABG or PCI following myocardial infarction. The study evaluated the effectiveness of an early postoperative rehabilitation program in this population.

SAMPLING TECHNIQUE AND SAMPLE SIZE

A total of 30 participants were recruited using convenience sampling from the cardiac care and postsurgical wards of the hospital.

INCLUSION AND EXCLUSION CRITERIA

Patients aged 18–80 years, with a body mass index ranging from 20 to 30 kg/m², who were medically stable and cleared by the treating physician to participate in mobilization and exercise therapy were included in the study. Patients with respiratory distress or abnormalities that could limit exercise participation, orthopedic impairments or mobility limitations affecting lower-limb movement, uncontrolled hypertension, or other cardiovascular instabilities were excluded. Patients who had undergone CABG or PCI following myocardial infarction were screened for eligibility and recruited after extubation.

RANDOMIZATION PROCEDURE

All enrolled participants were medically stable at the time of inclusion. Participants were allocated to two groups, an intervention group and a control group, using simple random sampling.

STUDY PROCEDURE

The intervention group received a structured postoperative rehabilitation program comprising early active mobilization combined with breathing exercises, while the control group received breathing exercises along with complication-prevention measures, including passive limb movements and the use of compression stockings.

The exercise protocol included exercises common to both groups, comprising breathing exercises and general complication-prevention exercises. These included ankle pumps and ankle circles to promote venous return and prevent lower-limb thrombosis, toe and heel raises to improve peripheral circulation and muscle activation, and gentle knee bends performed in bed to maintain joint mobility and prevent stiffness. Deep breathing exercises were performed to enhance lung expansion, oxygenation, and diaphragmatic movement. Assisted arm and leg movements were also included to prevent muscle atrophy and maintain joint flexibility.

In addition to the exercises common to both groups, the intervention group received early mobilization exercises. These included sitting up in bed with support to improve orthostatic tolerance and trunk control, shoulder shrugs

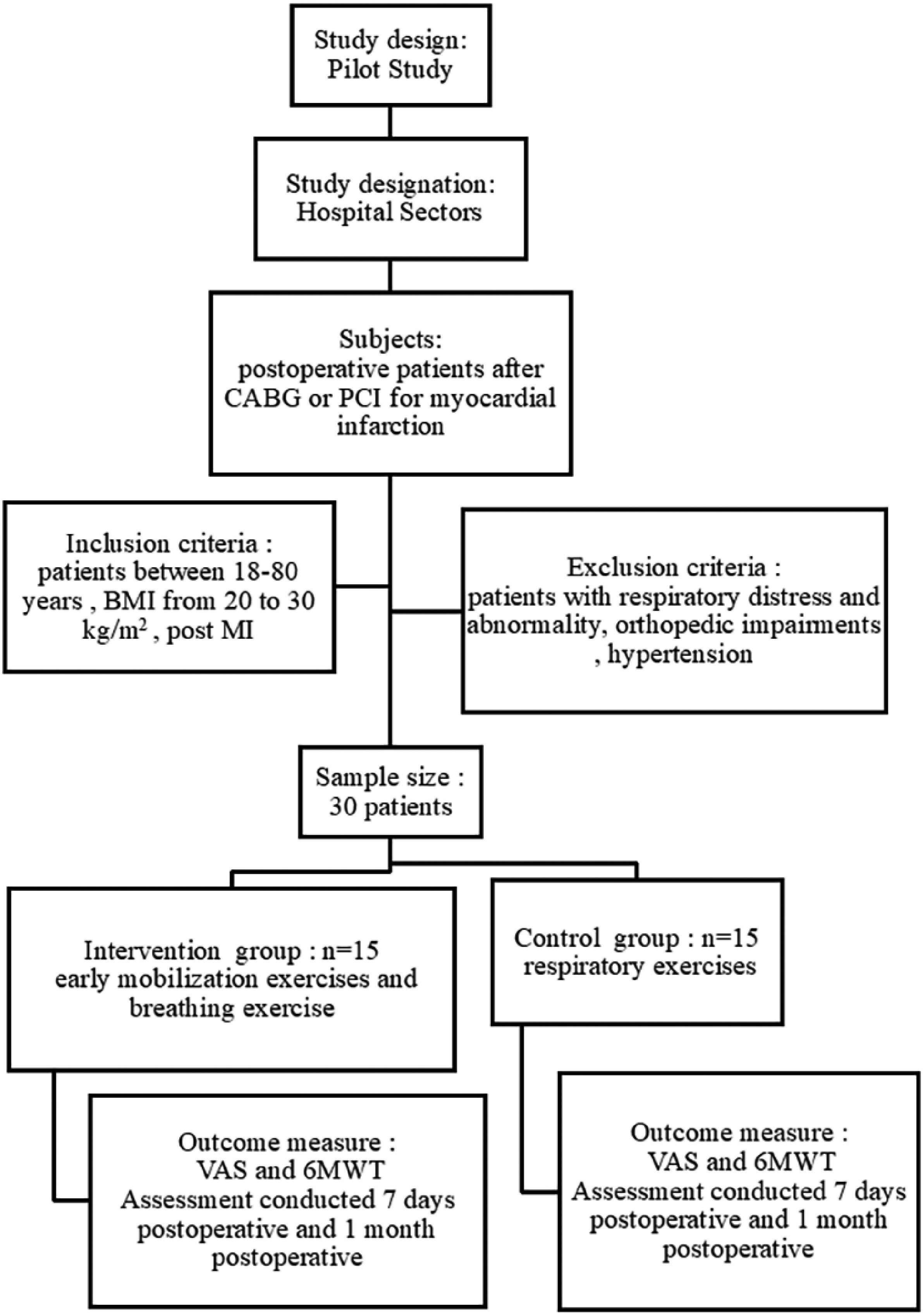

Fig. 1. Methodology – flow chart

Source: compiled by the authors of this study

Table 1. Pre and post-test values for paired t-test

Outcome measure	Groups	Test	Mean	SD	t value	p value
6MWT	Intervention group (Group A n=15)	Pretest	413.47	14.015	-13.110	<0.001
		Post test	431.40	12.944		
	Control group (Group B n=15)	Pretest	410.93	11.405	-9.838	<0.001

Source: compiled by the authors of this study

Table 2. Pre and post-test values for unpaired t-test

Outcome measure	Groups	Test	Mean	SD	t value	p value
6MWT	Intervention group (Group A n=15)	Pretest	413.47	14.015	0.543	0.59
	Control group (Group B n=15)	Pretest	410.93	11.405		
	Intervention group (Group A n=15)	Post test	431.40	12.944	2.590	0.01
	Control group (Group B n=15)	Post test	420.73	9.323		

Source: compiled by the authors of this study

and arm raises to facilitate upper-limb mobility and mild cardiovascular activation, and seated knee extensions to promote quadriceps activation and circulation. Participants subsequently progressed to standing with support for a few minutes to enhance postural control and cardiovascular endurance, followed by short-distance walking within the ward to progressively improve exercise tolerance and cardiovascular fitness. All activities were performed within the patients' comfort level, with continuous monitoring of vital parameters, including heart rate, blood pressure, and oxygen saturation, to ensure safety during mobilization. The duration and intensity of the exercises were progressively increased over the study period according to patient tolerance.

OUTCOME MEASURES

Outcome measures included the Visual Analog Scale (VAS) for perceived exertion and the 6-Minute Walk Test (6MWT) to assess functional capacity [17, 13]. Pre-test assessments were conducted on postoperative day 7, and post-test assessments were conducted on postoperative day 30. The overall methodological flow of the study, including participant allocation, intervention protocol, and assessment time points, is presented in Figure 1.

STATISTICAL ANALYSIS

The collected data were analyzed using descriptive and inferential statistics. All analyses were performed using SPSS software, version 27.0.1.0. Data are presented as mean and standard deviation (SD). A paired t-test was used to assess differences between pre-test and post-test measurements within each group. An unpaired t-test was used to compare the intervention and control groups. The level of statistical significance was set at $p < 0.05$.

RESULTS

Participants demonstrated a significant improvement in 6MWT, with the mean paired pre-test value for the Intervention group (Group A) being 413.47 with a Standard Deviation (SD) of 14.015, and the mean post-test value increasing to 431.40 with an SD of 12.944. The paired pre-test mean for the Control group (Group B) was 410.93 with a Standard Deviation (SD) of 11.405, while the post-test mean increased to 420.73 with an SD of 9.323. The t-values for Group A and Group B were -13.110 and -9.838, respectively, with p-values <0.001 (Table 1, Fig. 2). Furthermore, the unpaired pre-test mean for the Intervention group (Group A) was 413.47 with a Standard Deviation (SD) of 14.015, and the unpaired pre-test mean for the Control group (Group B) was 410.93 with a Standard Deviation (SD) of 11.405. The t-value for both Group A and Group B was 0.543, with a p-value of 0.59. The unpaired post-test mean for the Intervention group (Group A) was 431.40 with a Standard Deviation (SD) of 12.944, and the unpaired post-test mean for the Control group (Group B) was 420.73 with a Standard Deviation (SD) of 9.323. The t-value for both Group A and Group B was 2.590, with a p-value of 0.01 (Table 2, Fig. 3).

Participants also demonstrated a significant improvement in VAS, with the paired pre-test mean for the Intervention group (Group A) being 6.27 with a Standard Deviation (SD) of 0.704 and the post-test mean decreasing to 2.87 with an SD of 0.915. The paired pre-test mean for the Control group (Group B) was 6.20 with a Standard Deviation (SD) of 0.775, while the post-test mean decreased to 3.53 with an SD of 0.640. The t-values for Group A and Group B were 13.360 and 14.270, respectively, with p-values <0.001 (Table 3, Fig. 4). Furthermore,

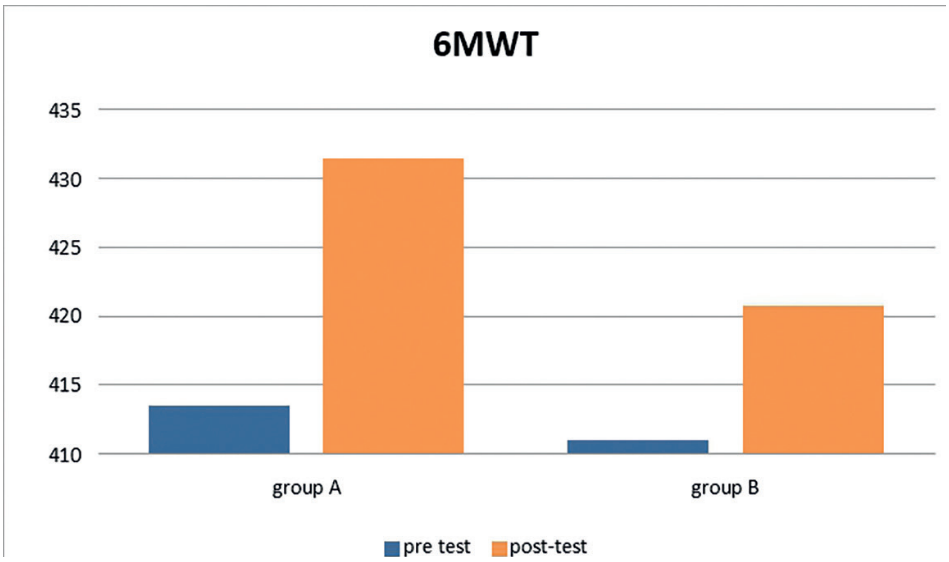

Fig. 2. Pre and post-test values for paired t-test

Source: compiled by the authors of this study

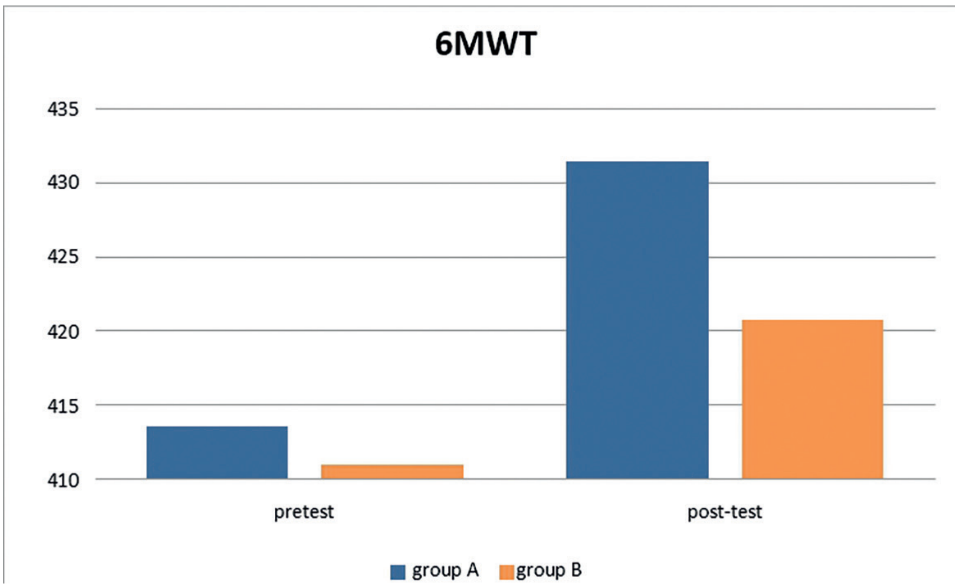

Fig. 3. Pre and post-test values for unpaired t-test

Source: compiled by the authors of this study

Table 3. Pre and post-test values for paired t-test

Outcome measure	Groups	Test	Mean	SD	t value	p value
Visual analogue scale	Intervention group (Group A n=15)	Pretest	6.27	0.704	13.360	<0.001
		Post test	2.87	0.915		
	Control group (Group B n=15)	Pretest	6.20	0.775	14.270	<0.001
		Post test	3.53	0.640		

Source: compiled by the authors of this study

Table 4. Pre and post-test values for unpaired t-test

Outcome measure	Groups	Test	Mean	SD	t value	p value
Visual analogue scale	Intervention group (Group A n=15)	Pretest	6.27	0.704	0.247	0.807
	Control group (Group B n=15)	Pretest	6.20	0.775		
	Intervention group (Group A n=15)	Post test	2.87	0.915	-2.312	0.028
	Control group (Group B n=15)	Post test	3.53	0.640		

Source: compiled by the authors of this study

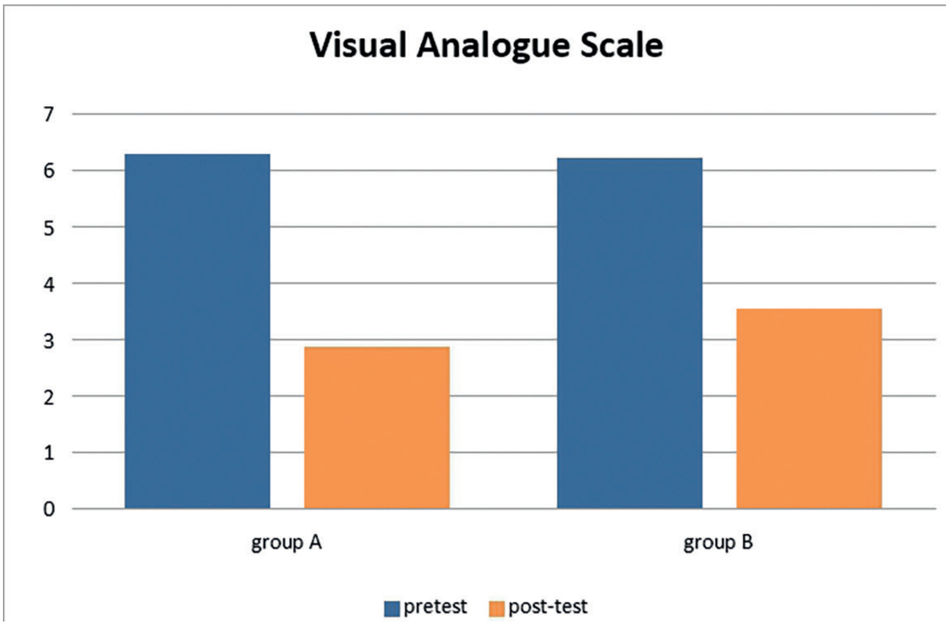

Fig. 4. Pre and post-test values for paired t-test

Source: compiled by the authors of this study

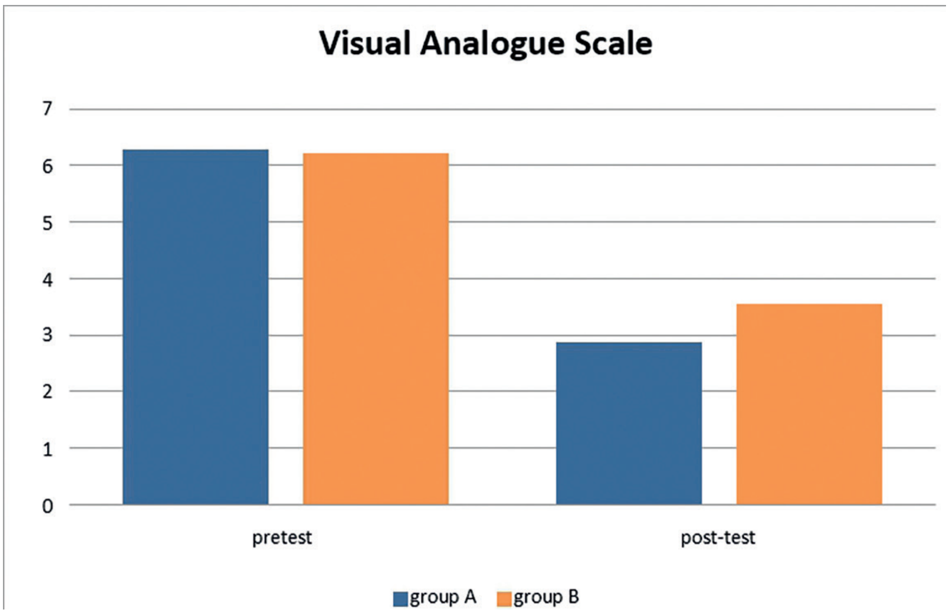

Fig. 5. Pre and post-test values for unpaired t-test

Source: compiled by the authors of this study

the unpaired pre-test mean for the Intervention group (Group A) was 6.27 with a Standard Deviation (SD) of 0.704, and the unpaired pre-test mean for the Control group (Group B) was 6.20 with a Standard Deviation (SD) of 0.775. The t-value for both Group A and Group B was 0.247, with a p-value of 0.807. The unpaired post--test mean for the Intervention group (Group A) was 2.87 with a Standard Deviation (SD) of 0.915, and the unpaired post-test mean for the Control group (Group B) was 3.53 with a Standard Deviation (SD) of 0.640. The t-value for both Group A and Group B was -2.312, with a p-value of 0.028 (Table 4, Fig. 5).

DISCUSSION

Early mobilization after myocardial infarction (MI) is both feasible and beneficial for improving cardiovascular fitness and functional ability in post-MI patients, according to the results of this pilot study [21]. Compared with baseline measurements, patients who participated in organized early mobilization programs reported lower perceived exertion on the Visual Analogue Scale (VAS) and showed increased exercise tolerance, as indicated by longer distances on the 6-Minute Walk Test (6MWT). These findings are in line with previous research indicating that mobilization should be started soon after hemodynamic stabilization to promote autonomic modulation and enhance cardiac output while preventing deconditioning, muscular atrophy, and cardiovascular complications. The study supports the idea that supervised movement is an essential part of post-MI therapy, increasing patient confidence and quality of life in addition to promoting physical recovery [22, 23].

Munir et al. found that early mobility following acute cardiovascular illness significantly improved health-related quality of life in older adults, with improvements in physical functioning and reduced disability [24]. According to Goldfarb and Semsar et al., early mobilization is safe in acute cardiac populations because it enhances mobility, independence, and functional outcomes without provoking adverse cardiac events [25, 26].

The importance of early mobility in enhancing cardiovascular and physical performance is further supported by data from acute hospital and critical care settings. Despite significant logistical and clinical obstacles, Alaparthi et al. found that early mobility is an effective method of minimizing ICU-acquired weakness, increasing cardiopulmonary endurance, and limiting hospital-related complications [27]. According to some studies, early mobilization, when implemented using established protocols and appropriate monitoring, improves overall recovery, reduces deconditioning, and increases cardiovascular efficiency [28]. Although early mobilization presents a temporary hemodynamic challenge following heart surgery, Cassina et al. showed that it is safe and physiologically acceptable under supervision, indicating its relevance to post-MI patients, as shown in the current research [29].

Early mobilization in cardiac patients is strongly supported by systematic reviews and meta-analyses. Following early mobilization after cardiac surgery, Chen et al. found substantial improvements in functional ability, fewer pulmonary complications, and shorter hospital stays, all of which indicate increased cardiovascular efficiency [31]. Early ambulation after uncomplicated MI significantly reduced complications related to prolonged bed rest without increasing mortality, reinfarction, or arrhythmias, according to Cortes and Herkner et al. [30]. These results suggest a paradigm shift from prolonged immobilization to early activity-based recovery and are consistent with previous research by Lopes and Guerci, who supported early mobilization and discharge in clinically stable MI patients [31,32].

Clinical and experimental studies corroborate the physiological processes that underlie the benefits of early mobilization. Bito et al. showed that early initiation of exercise prevents contractile dysfunction, whereas Xu et al. revealed that early exercise training post-MI results in favorable myocardial remodeling and enhanced cardiac function [32]. According to Haykowsky et al., exercise intolerance in older cardiac patients is largely determined by reduced peripheral muscle function and impaired oxygen utilization, which further supports early mobilization to prevent cardiovascular deconditioning [33]. The improvements in cardiovascular fitness observed in the current pilot trial might be explained by these processes.

Preventing subsequent cardiopulmonary complications is another benefit of early mobilization. According to Moradian et al., early mobilization significantly reduced atelectasis and pleural effusions in patients after coronary artery bypass graft surgery, thereby improving oxygenation and cardiac function [34]. Pashikanti and Von Ah emphasized the systemic benefits of early mobilization protocols by showing that they improve functional outcomes and shorten hospital stays in medical-surgical populations [35]. To increase abdominal strength and respiratory performance, which may further improve cardiovascular function during early rehabilitation, Indrani et al. recommended using breathing exercises in addition to mobilization [36].

For long-term cardiovascular benefits, the transition from hospital-based mobility to long-term cardiac rehabilitation is essential. In terms of enhancing cardiovascular fitness and quality of life, Dalal et al. showed that home-based cardiac rehabilitation programs are as effective as center-based programs [37]. Following outpatient cardiac rehabilitation, a home walking intervention was found to significantly improve health-related quality of life in women. Studies have also shown that adherence to cardiac rehabilitation programs is influenced by organizational and patient-related factors, emphasizing the importance of initiating mobility early to promote long-term participation. To reduce cardiovascular morbidity and mortality after coronary events, early physical activity and organized rehabilitation are strongly recommended in the American Heart Association scientific statement by Leon et al. [38].

Early mobilization strategies are further enhanced by adjunct interventions and technology-assisted monitoring. Howie-Esquivel and Zaharias showed that physical activity levels in hospitalized heart failure patients can be accurately measured using mobility-monitoring devices, facilitating the objective evaluation of early mobilization outcomes [22,23]. Furthermore, studies by Divya et al. and Ramachandrana et al. on lower-limb and balance-related exercises demonstrated improvements in gait, balance, and functional mobility, which may indirectly contribute to improved cardiovascular endurance and exercise tolerance in post-MI patients [39,40]. These findings support the use of basic limb and trunk exercises as part of the early mobilization regimen implemented in the present study.

Overall, the results of this pilot trial are in line with a large body of research showing that early mobilization after myocardial infarction is a physiologically beneficial, safe, and effective intervention. Early mobility is a key component of contemporary cardiac physiotherapy because it enhances cardiovascular fitness, prevents deconditioning, reduces complications, and facilitates progression to long-term rehabilitation [40].

LIMITATIONS

The present study has certain limitations that should be considered when interpreting the findings. As this was a pilot study, the relatively small sample size may limit the generalizability of the results to the broader population of post-myocardial infarction patients. Additionally, the short observation period permitted assessment only of the short-term effects of early mobilization, restricting the ability to evaluate long-term outcomes or sustained improvements in cardiovascular fitness. Although standardized protocols were followed, minor variations in the timing and intensity of mobilization sessions among participants may have influenced individual responses to the intervention. Furthermore, potential confounding factors such as medication use, dietary patterns, and pre-existing comorbidities were not strictly controlled in this preliminary study design, which may have had a subtle impact on the observed outcomes. Lastly, the limited follow-up duration prevented assessment of long-term safety, adherence, and maintenance of benefits associated with early mobilization, indicating the need for future studies with larger samples and extended follow-up periods.

CONCLUSIONS

Within the limitations of the study, the intervention group showed significantly greater improvement than the control group. Following myocardial infarction, early mobilization exercises may contribute to improving cardiovascular fitness and functional capacity. Supervised and structured mobilization promotes the recovery of physical endurance and may facilitate subsequent cardiac rehabilitation. Therefore, early mobilization may be an important component of cardiac rehabilitation programs aimed at optimizing recovery following myocardial infarction.

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ETHICS STATEMENT

This study was approved by the Institutional scientific review board of the University. (467/07/2024/ISRB/UGSR/SCPT).

CONFLICT OF INTEREST

The Authors declare no conflict of interest

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REVIEW ARTICLE

The importance of statistical methods in research on the effects of spa treatment

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ABSTRACT

Aim: This paper outlines the basic principles of designing and statistically analysing studies on spa interventions and describes the key steps from formulating a research question to conducting the final statistical analysis. It also highlights common methodological errors that may affect the validity of conclusions in balneological research.

Materials and Methods: This narrative review covers hypothesis formulation, study design – including randomisation and control groups – data collection, and the selection of appropriate statistical tests. It also discusses the role of the statistician during the design phase and the need to verify the assumptions underlying statistical models. The review is based on a non-systematic selection of published systematic reviews, meta-analyses, methodological studies, and statistical textbooks concerning clinical research methodology and balneological research. These sources repeatedly identify problems such as inadequate randomisation, poorly defined outcome measures, and insufficient statistical power.

Conclusions: Statistical methods are an essential component of clinical research and a key tool for the objective assessment of spa treatment effects. Appropriate study design, adequate statistical analysis, and verification of statistical assumptions are necessary to obtain valid and clinically relevant results. A stronger role for statistics in balneological research can support evidence-based clinical practice and further methodological development in spa medicine.

KEYWORDS: research design, statistics as topic, balneology, evidence-based medicine, clinical trials as topic

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INTRODUCTION

Spa care represents a significant component of comprehensive healthcare and, in many regions, an important element of health prevention and rehabilitation. Traditional spa procedures, based on the use of natural healing resources, have well-documented beneficial effects in numerous chronic diseases. With advances in medicine and emerging innovative approaches, such as the use of virtual reality in rehabilitation [1], the scope of spa care is expanding to include new therapeutic elements and procedures. At the same time, healthcare faces new challenges, including an increased need for mental health care [2] and the consequences of emerging diseases such as COVID-19 [3]. In these areas, spa care can play a significant role, not only as part of traditional rehabilitation but also as part of a comprehensive approach to supporting physical and mental health.

To objectively evaluate the effectiveness of spa treatment procedures, it is essential to use scientifically validated clinical research methods and apply appropriate statistical approaches [4]. Only on the basis of valid data can the effectiveness of therapies be assessed, treatment programmes optimised, and their broader implementation in modern medicine supported in accordance with the principles of evidence-based medicine (EBM). EBM emphasises the systematic and critical use of clinical research findings when making decisions about the treatment of individual patients [5].

International meta-analyses and systematic reviews of clinical studies in balneology repeatedly highlight methodological deficiencies in the studies analysed, including considerable variation in study design quality and statistical analysis. Kamioka et al. [6] analysed 19 systematic reviews on balneotherapy and identified recurring problems, including inadequate descriptions of randomisation, inconsistent outcome measures, and low-quality primary studies. In their review of 33 randomised controlled trials (RCTs) on the effects of balneotherapy on pain in patients with chronic low back pain, knee osteoarthritis, and fibromyalgia, Roques and Queneau [7] reported favourable therapeutic effects but highlighted the generally low methodological quality of these studies – particularly the lack of statistical power due to limited sample sizes, insufficient follow-up duration, and treatment heterogeneity. The review by D'Angelo et al. [8] confirmed the clinical benefits of balneotherapy in patients with osteoarthritis but also highlighted methodological deficiencies in randomisation, blinding, the description of statistical procedures, and the selection of outcome variables. García-López et al. [9], in their meta-analysis, confirmed the significant effects of balneotherapy on pain relief and functional limitations but criticised inconsistent intervention definitions, inadequate blinding, and insufficient information on randomisation and sample size calculations. They advocated the need for more high-quality RCTs in clinical balneological research, including standardised treatment protocols, long-term follow-up, and rigorous blinding measures, to increase the validity and reliability of study results. A recent review by Szendi et al. [10] analysed 109 clinical balneological studies published between 1990 and 2025, focusing on the types of interventions used in the experimental and control groups and on different forms of blinding (open-label, single-blind, and double-blind). The authors reported that 74% of these studies were categorised as low quality, lacking both blinding and control groups, while only 11% attempted a double-blind design.

These reviews consistently highlight recurring deficiencies in the planning and evaluation of clinical studies in balneology. The absence of randomisation, poorly defined outcome variables, inadequate assessment of effect size, and a lack of sample size calculations significantly reduce the validity of results and limit their applicability in clinical practice and systematic reviews. This situation persists across various indications and time periods, despite the growing emphasis on EBM principles.

AIM

This paper aims to outline the fundamental principles of using statistical methods in studies assessing the effects of spa treatment and to describe the key steps from formulating a research question to conducting the final statistical analysis. To obtain valid and clinically relevant results, studies must be carefully planned and implemented with appropriate statistical design and analysis in mind.

MATERIALS AND METHODS

This article is presented as a narrative review summarising current knowledge on the statistical methodology of spa treatment research. The review is based on a non-systematic selection of published systematic reviews, meta-analyses, methodological studies, and statistical textbooks focused on clinical research methodology and balneological research.

The methodological framework presented in this review draws on established principles of clinical trial design and statistical analysis, as outlined in recognised statistical textbooks and evidence-based medicine guidelines. The review also covers international publications on common methodological deficiencies in spa treatment studies, focusing on statistical design issues identified in recent meta-analyses of balneotherapy interventions.

The recommendations are based on standard statistical practice in clinical research, established protocols for randomised controlled trials, and current guidelines for EBM implementation. The review includes examples from published spa treatment studies to illustrate appropriate statistical methodology and highlight areas for improvement.

This narrative review aims to provide practical guidance for researchers planning spa treatment studies, with an emphasis on appropriate statistical methods from study conception through data analysis and interpretation.

REVIEW AND DISCUSSION

Planning studies to assess the effects of spa treatment includes formulating research questions and related hypotheses, selecting an appropriate study design, and determining a sample size sufficient to provide adequate statistical power [11].

Research questions, hypothesis formulation, and the selection of appropriate statistical tests are interconnected activities that cannot be addressed separately. Test selection schemes found in some statistical textbooks (e.g., [12]) can be helpful during the design process. By systematically considering factors such as the number of groups involved, whether the data are continuous, and whether a normal distribution can be assumed, researchers can select an appropriate statistical test. The answers to these questions help define the overall study design.

RESEARCH QUESTIONS AND HYPOTHESES

The foundation of every clinical study is a clearly defined research question and related hypotheses. When formulating these, it is advisable to use the four-component PICO framework – population, intervention, comparison, and outcome [13]. This framework includes a precise definition of the study population (e.g., adult patients with a specific disease), a detailed description of the intervention (e.g., a selected comprehensive spa treatment and rehabilitation programme), the definition of a comparator (e.g., a control group receiving no treatment or usual care), and the specification of outcomes (e.g., improved quality of life or reduced levels of monitored parameters).

Hypotheses are equally important for subsequent stages of the study, including study design and the selection of statistical methods. Sample size calculations depend directly on these factors. Hypotheses must be formulated so that they can be statistically tested. An example of an appropriately formulated research hypothesis is as follows:

Patients who completed the innovative spa programme differ from patients who completed the standard spa programme with respect to the change in parameter A at the end of treatment.

The hypothesis is crucial not only for designing the study but also for selecting appropriate statistical methods. Each research hypothesis must be reformulated as null and alternative statistical hypotheses, which can then be tested using appropriate statistical methods. For the above research hypothesis, these would be:

H_0: The mean change in parameter A at the end of spa treatment is the same in both groups.

H_1: The mean change in parameter A at the end of spa treatment differs between the two groups.

Furthermore, it is essential to precisely define the monitored parameters, measurement methods, and characteristics of the study population. Parameters may include, for example, pain intensity, quality of life, or a specific parameter such as the controlled attenuation parameter (CAP), which is used in patients with hepatic steatosis.

STUDY DESIGN

The selection of an appropriate study design has a fundamental impact on study validity. Key elements include randomization, i.e., the random allocation of patients to groups to minimize selection bias; the use of a control group, which enables comparison of spa treatment effects with standard care or placebo; and, where feasible, blinding (single-blind or double-blind), aimed at reducing subjective bias in outcome assessment [14].

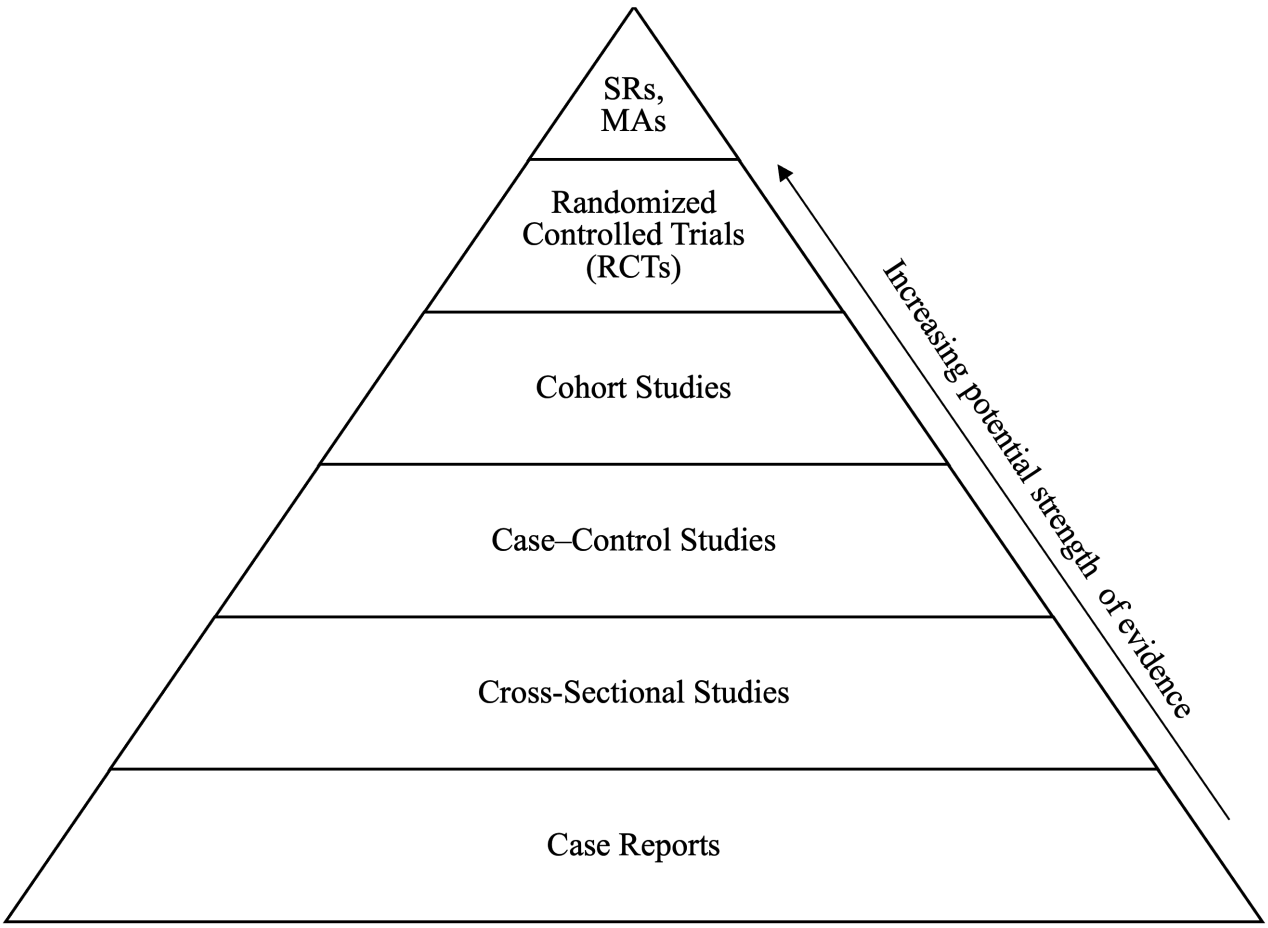

Fig. 1. Hierarchy of clinical evidence.
Source: authors' own elaboration based on [4,5]

Within EBM, study types are distinguished according to their potential to provide reliable information for clinical practice. Figure 1 shows the traditional hierarchy of evidence according to study design. Systematic reviews and meta-analyses of randomized controlled trials (RCTs) are traditionally placed at the highest level because they synthesize findings from multiple studies and may reduce the risk of random error. However, the overall strength of evidence from such reviews also depends on the methodological quality of the included studies, the risk of bias, and the consistency of findings.

In RCTs, patients are randomly allocated to experimental and control groups. For example, in the study by Pérez-Fernández et al. [15], which evaluated the effectiveness of baths using mineral medicinal water from As Burgas in patients with fibromyalgia, patients were assigned to two groups: group A underwent 14 baths over one month in combination with standard pharmacological treatment, whereas group B received standard pharmacological treatment only.

At the opposite end of the hierarchy are case reports and case series, which describe individual patients or groups of patients without a control group and without the possibility of comparison. These types of publications may be useful for generating hypotheses but do not provide sufficiently reliable evidence for clinical practice.

More information on study types used in medical research can be found, for example, in the publication by Kalousová and Zima [4].

SAMPLE SIZE AND STATISTICAL POWER

Sample size is crucial for ensuring adequate statistical power to detect a true, clinically meaningful effect. A small sample reduces the probability of detecting such an effect. In contrast, an excessively large sample may lead to the detection of very small effects that are not clinically meaningful. A disproportionately large study would also be unnecessarily costly and time-consuming and could impose an unnecessary burden on patients. It is therefore crucial to select a sample size that provides adequate power to detect clinically relevant effects.

To determine the minimum number of patients required, a power analysis is necessary. The sample size should be planned according to the primary outcome and the clinically meaningful effect that the study is intended to detect. For commonly used parametric and many nonparametric tests, power can be calculated directly. Simulation-based approaches may be useful for complex statistical methods or study designs when standard analytical approaches are unavailable or unsuitable [16].

STATISTICAL EVALUATION

Statistical evaluation commonly includes descriptive statistics for the dataset and for changes in monitored variables. Hypotheses must be tested using appropriate statistical methods, and the assumptions of these methods must be verified. Interpretation should not rely solely on p-values but should also include measures that assess the magnitude of the observed effect.

a) Descriptive analysis

The statistical sample should be described using basic characteristics, such as the mean, median, and standard deviation, as well as graphical representations, such as boxplots. It is also appropriate to present the same characteristics for observed changes, which may serve as a basis for planning subsequent studies and estimating statistical power and the required sample size.

b) Hypothesis testing

In hypothesis testing, it is essential to check test assumptions. A simple example is the paired t-test, which assumes continuous data and normally distributed paired differences. If these assumptions are not met, nonparametric tests may be used. The nonparametric alternative to the paired t-test is the Wilcoxon signed-rank test, which does not require normally distributed differences. However, it assumes paired observations, independence between pairs, and a symmetric distribution of paired differences. Using an inappropriate test can lead to erroneous results and reduced statistical power.

More advanced analyses can also be performed, such as ANCOVA (analysis of covariance), which accounts for the influence of additional variables (covariates) when comparing groups, or linear mixed models, which are suitable for repeated measurements and hierarchical data. These methods allow statistical adjustment for patient characteristics, such as age and baseline values of monitored parameters, when the compared groups differ at baseline, for example in the proportion of women and men or disease severity.

c) Results interpretation

Statistical significance should be supplemented by an assessment of effect size and clinical significance [17]. A p-value alone indicates whether an observed result is statistically significant. However, the larger the study sample, the smaller the differences that may be detected as statistically significant. To illustrate this, consider an extreme example in which thousands of patients are included in a study and changes in six-minute walk test (6MWT) results after a spa stay are assessed. With such a large sample, even a change of only a few decimeters might be statistically significant. Whether such a change is clinically meaningful, however, depends on the minimal clinically important difference (MCID), which varies according to the patient population and clinical condition [17].

It is therefore important to supplement p-values with effect-size measures, which standardize the observed change, often in relation to variability. Examples include Cohen's d for the t-test and the rank-biserial correlation coefficient for the Wilcoxon test. An overview of effect sizes for statistical tests is provided by Tomczak and Tomczak [18]. In the above example, statistical significance might be found (e.g., $p < 0.001$), but the effect size could still be negligible.

As a final step, the observed change should be evaluated in terms of clinical significance, i.e., whether it has a meaningful impact on the patient.

d) Most common errors in the statistical design and analysis of studies

The main errors include imbalances in baseline characteristics between groups, the absence of control groups, an insufficient sample size that may make it impossible to detect clinically meaningful treatment effects, and inappropriate selection of statistical tests that disregard the underlying model assumptions. These errors are repeatedly highlighted by review and meta-analytical studies on the effectiveness of balneotherapy (e.g., [6–10]). Such deficiencies can fundamentally affect the interpretation of results and reduce the study's credibility and applicability to clinical practice.

CONCLUSIONS

Statistical methods are an essential component of high-quality clinical research in the field of spa treatment. Their appropriate use enables the objective assessment of therapeutic effects, supports the development of evidence-based approaches, and contributes to enhancing the role of spa care as a significant component of modern medicine.

The findings and recommendations presented in this article address recurring methodological errors identified in numerous published studies of balneotherapy. These deficiencies fundamentally affect the validity and interpretability of clinical balneological research findings. The successful application of statistical methods requires the involvement of a statistician at the study-design stage and consistent adherence to clinical research principles. Given the growing demand for scientific validation of therapeutic procedures in spa medicine, the consistent use of appropriate statistical methods is a key prerequisite for broader recognition and funding within the healthcare system.

The targeted development of clinical research in spa medicine therefore represents a strategic opportunity to further advance the field and foster interdisciplinary collaboration.

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CONFLICT OF INTEREST

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REVIEW ARTICLE

Neuroimmune regulation of anxiety and stress: perspectives for balneotherapy

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ABSTRACT

Neuroimmune interactions play a fundamental role in the regulation of anxiety and stress responses, particularly in conditions associated with chronic stress exposure and neuropsychiatric dysregulation. Growing evidence indicates that inflammatory signalling pathways, including cytokine activation, oxidative stress, and neuroendocrine imbalance, contribute to altered emotional regulation, autonomic dysfunction, and sleep disturbances. Dysregulation of the hypothalamic–pituitary–adrenal axis and persistent low-grade inflammation may increase vulnerability to anxiety symptoms and impair adaptive stress responses. From a balneological perspective, spa-based therapeutic strategies may support the modulation of neuroimmune mechanisms through combined thermal, hydrostatic, and environmental stimuli. Balneotherapy, hydrotherapy, climatotherapy, and structured spa rehabilitation programmes may influence autonomic balance, promote parasympathetic activation, and reduce inflammatory burden, thereby contributing to improved psychological resilience and stress adaptation. Exposure to natural environments and relaxation-oriented interventions may additionally support neurobiological recovery and emotional stabilisation. Integrating contemporary neuroimmunology with balneological medicine provides a multidisciplinary framework for non-pharmacological rehabilitation targeting both physiological and psychosocial aspects of anxiety and stress-related disorders. This review highlights the potential of balneotherapy as a complementary strategy within environmental neurorehabilitation and emphasises the need for further clinical studies evaluating neuroimmune biomarkers as outcomes of spa-based interventions.

KEYWORDS: balneology, psychoneuroimmunology, stress, psychological, autonomic nervous system, inflammation mediators

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INTRODUCTION

Contemporary research into the pathophysiology of anxiety disorders and stress responses increasingly highlights the crucial role of neuroimmune interactions in regulating emotional processes and facilitating the organism's adaptation to environmental challenges. Chronic stress contributes to activation of the hypothalamic–pituitary–adrenal (HPA) axis, enhanced inflammatory signalling, and disturbances in autonomic balance, which may result in persistent alterations in central nervous system functioning. Recent studies have emphasised the involvement of pro-inflammatory cytokines, oxidative stress mechanisms, and neuroinflammatory pathways that influence neuronal plasticity and behavioural responses associated with anxiety. Dysregulation of these biological systems has been observed in post-traumatic stress disorder, depression, and other stress-related neuropsychiatric conditions [1, 2].

At the same time, increasing attention is being directed towards non-pharmacological strategies that support neurobiological homeostasis, including approaches applied in spa and balneological medicine. Balneotherapy, encompassing mineral baths, hydrotherapy, pelotherapy, and climatotherapy, represents an environmental intervention with potential modulatory effects on neuroimmune processes. Its mechanisms of action are associated with thermal and hydrostatic stimuli, improved autonomic regulation, and a possible reduction in inflammatory burden. Exposure to natural spa environments and structured relaxation-based rehabilitation programmes may promote parasympathetic activation, reduce perceived stress, and improve sleep quality, which are essential factors in the prevention and rehabilitation of stress-related disorders [3, 4].

Despite the growing number of experimental and clinical studies, the integration of neuroimmunological knowledge with balneological practice still requires comprehensive investigation. A better understanding of the biological mechanisms underlying spa-based therapies may contribute to the development of personalised rehabilitation strategies aimed at regulating stress-related pathways and reducing chronic inflammation. Therefore, the aim of this review is to present current evidence regarding the neuroimmune regulation of anxiety and stress and to discuss the potential role of balneotherapy as a complementary environmental approach supporting adaptive physiological and psychological processes [5].

AIM

The aim of this review is to present and integrate current knowledge regarding the neuroimmune mechanisms involved in the regulation of anxiety and stress responses, with particular emphasis on inflammatory signalling, autonomic dysregulation, and neuroendocrine pathways. Furthermore, this paper seeks to evaluate the potential role of balneotherapy as a complementary, non-pharmacological intervention capable of modulating neuroimmune processes through environmental, thermal, and hydrostatic stimuli. By integrating findings from neurobiology, immunology, and spa medicine, this review aims to highlight the clinical relevance of balneological therapies within environmental neurorehabilitation and to identify potential neuroimmune biomarkers that may serve as outcome measures in future clinical studies.

MATERIALS AND METHODS

A narrative review of the literature was conducted using the PubMed/MEDLINE, Scopus, and Web of Science databases. Publications published between 2013 and 2025 were considered. The search terms included "anxiety", "stress", "neuroinflammation", "neuroimmune", "NLRP3", "IL-18", "MMP-9", "cortisol", "serotonin", "balneotherapy", "hydrotherapy", "spa therapy", "pelotherapy", "thermal therapy", and "oxidative stress", used individually and in various combinations.

Peer-reviewed original research articles, clinical and experimental studies, systematic reviews, and meta-analyses published in English were included. Eligible studies addressed the neuroimmune and neuroendocrine mechanisms of stress and anxiety, as well as the biological, immunological, and psychological effects of balneotherapy and related spa-based interventions.

REVIEW AND DISCUSSION

NEUROIMMUNE MECHANISMS OF ANXIETY AND STRESS

Neuroimmune interactions constitute a fundamental biological framework underlying the development and persistence of anxiety and stress-related disorders. Increasing evidence indicates that chronic psychological stress activates inflammatory signalling pathways within both the peripheral immune system and the central nervous system. Elevated levels of pro-inflammatory cytokines and chemokines may influence neuronal function by altering synaptic plasticity, neurotransmitter metabolism, and neuroendocrine signalling. These processes contribute to emotional dysregulation, heightened vigilance, and impaired stress adaptation observed in individuals exposed to prolonged stress or traumatic experiences [6, 7].

One of the key mechanisms linking stress and neuroinflammation involves microglial activation. Under physiological conditions, microglia maintain neuronal homeostasis; however, chronic stress may induce a shift towards a pro-inflammatory phenotype, promoting the release of cytokines, reactive oxygen species, and matrix metalloproteinases. Such alterations may disrupt neuronal connectivity within brain regions involved in emotional processing, including the amygdala, hippocampus, and prefrontal cortex. Additionally, activation of inflammasome-related pathways, particularly the NLRP3 inflammasome, has been implicated in stress-induced neuroinflammatory responses, suggesting a potential molecular link between immune activation and anxiety symptomatology [8].

Oxidative stress represents another critical component of neuroimmune dysregulation. Increased production of reactive oxygen species and impaired antioxidant defence mechanisms may exacerbate neuronal vulnerability and contribute to neurobiological alterations associated with chronic stress exposure. Biomarkers reflecting oxidative imbalance, inflammatory activity, and neuroendocrine alterations have been reported in various neuropsychiatric conditions, highlighting the multifactorial nature of anxiety pathophysiology [9, 10].

Importantly, neuroimmune mechanisms do not function independently but interact with endocrine and autonomic systems. Dysregulation of immune–brain communication may amplify stress responses, leading to persistent activation of neural circuits associated with fear and anxiety. Understanding these complex interactions provides a biological foundation for exploring therapeutic strategies targeting inflammatory pathways and supporting neurobiological resilience, including environmental and rehabilitation-based interventions such as balneotherapy [11].

The main neuroimmune pathways associated with anxiety and stress that may be relevant to balneological interventions are summarised in Table 1.

HPA AXIS DYSREGULATION AND AUTONOMIC IMBALANCE

The hypothalamic–pituitary–adrenal (HPA) axis plays a central role in the physiological response to stress, coordinating neuroendocrine, immune, and autonomic processes that enable adaptation to environmental challenges. Acute activation of the HPA axis promotes the release of glucocorticoids, which regulate energy metabolism and exert anti-inflammatory effects. However, prolonged exposure to stressors may result in maladaptive altera-

Table 1. Neuroimmune mechanisms of anxiety and stress relevant to balneotherapy

Domain	Main mechanisms	Selected biomarkers	Clinical relevance
Neuroinflammation	Microglial activation, inflammasome signaLling	NLRP3, IL-18	Emotional dysregulation, anxiety symptoms
Oxidative stress	Increased ROS production, impaired antioxidant defence	GPX-1, antioxidant enzymes	Fatigue, risk of neurobiological damage
Neuroendocrine response	HPA axis dysregulation	Cortisol, serotonin	Sleep disturbances, impaired stress adaptation
Autonomic imbalance	Sympathetic dominance	Cytokines, HRV-related indices	Chronic arousal, reduced resilience
Extracellular remodeling	Matrix degradation	MMP-9	Neuroimmune communication

Source: compiled by the authors of this study

tions in cortisol dynamics, impaired feedback regulation, and increased susceptibility to anxiety and stress-related disorders. Chronic dysregulation of this system has been associated with emotional instability, sleep disturbances, and reduced resilience to subsequent stressors [12].

In individuals experiencing persistent psychological stress, sustained glucocorticoid secretion may initially suppress immune activity but may eventually contribute to the development of glucocorticoid resistance. This phenomenon may result in a paradoxical increase in inflammatory signalling, linking neuroendocrine imbalance with neuroimmune dysregulation. Altered cortisol rhythms have been observed in individuals with anxiety disorders and post-traumatic stress conditions, suggesting that impaired HPA axis function may influence both emotional processing and physical health outcomes [13, 14].

Autonomic nervous system imbalance represents another important component of stress pathophysiology. Chronic stress is frequently associated with sympathetic overactivation and reduced parasympathetic activity, which may contribute to heightened physiological arousal and impaired recovery following stress exposure. Reduced vagal activity has been linked to enhanced inflammatory responses, indicating a close relationship between autonomic regulation and immune function. These alterations may manifest clinically as cardiovascular strain, fatigue, and disturbances in circadian regulation [15, 16].

Importantly, interactions between the HPA axis and the autonomic nervous system form a dynamic regulatory network that influences both psychological and physiological adaptation. Understanding these mechanisms provides a framework for exploring therapeutic strategies aimed at restoring neuroendocrine balance and improving autonomic flexibility. Environmental interventions, including spa-based therapies, may provide supportive modulation of these systems through relaxation, thermal stimulation, and promotion of parasympathetic activation, thereby contributing to improved stress regulation and emotional stability [17].

BIOLOGICAL BASIS OF BALNEOTHERAPY: THERMAL AND HYDROSTATIC STIMULI

Balneotherapy exerts its biological effects through a combination of thermal, mechanical, and chemical factors, among which thermal and hydrostatic stimuli play a central role. Controlled exposure to heat represents a mild physiological stressor capable of inducing adaptive responses known as thermal hormesis. This process involves the activation of cellular defence mechanisms that enhance tolerance to subsequent stress, contributing to improved homeostasis and resilience. Repeated thermal stimulation during spa treatments, including mineral baths and sauna exposure, has been associated with modulation of inflammatory pathways and enhancement of antioxidant capacity [18, 19].

One of the key molecular mediators of thermal adaptation is the heat shock protein family, particularly HSP70. Increased expression of HSP70 has been observed following passive heat therapy and sauna sessions, suggesting a protective effect against cellular damage induced by oxidative stress and inflammation [20]. Heat shock proteins act as molecular chaperones that stabilise protein structures, facilitate repair processes, and regulate immune signalling, thereby supporting cellular adaptation to environmental stressors. These mechanisms may be particularly relevant in individuals experiencing chronic psychological stress, in whom impaired stress-response systems contribute to neuroimmune imbalance [21].

Hydrostatic pressure generated during immersion in water further enhances the physiological effects of balneotherapy. The pressure gradient improves venous return, supports cardiovascular regulation, and may influence autonomic nervous system balance. Enhanced circulation and tissue oxygenation contribute to metabolic efficiency and may facilitate the clearance of pro-inflammatory mediators. Additionally, buoyancy reduces mechanical loading on the musculoskeletal system, promoting relaxation and reducing sympathetic activation, which may indirectly influence immune–brain communication [22, 23].

Thermal and hydrostatic stimuli have also been associated with the modulation of oxidative stress. Experimental studies indicate that repeated heat exposure may reduce pro-inflammatory responses and alter the expression of stress-related genes, suggesting potential antioxidant and anti-inflammatory effects [24]. Although the precise molecular pathways remain under investigation, these findings support the concept that balneotherapy may induce adaptive biological responses contributing to improved physiological regulation and stress adaptation [25].

Spa-based therapeutic interventions have increasingly been recognised for their potential to modulate immune function through complex biological mechanisms involving thermal exposure, mineral composition, and environmental factors. One of the most frequently reported effects of balneotherapy is the modulation of cytokine profiles. Clinical and experimental studies suggest that repeated spa treatments may reduce the levels of pro-inflammatory mediators while promoting anti-inflammatory signalling, thereby contributing to improved systemic balance and a reduction in inflammatory burden [26, 27]. Such changes may be particularly relevant in individuals experiencing chronic stress, in whom low-grade inflammation is frequently associated with emotional dysregulation and fatigue.

The chemical properties of therapeutic waters play an important role in shaping immune responses. Sulphurous and mineral-rich waters have been investigated for their potential to influence oxidative processes and inflammatory pathways. Sulphur compounds may act as biological modulators by affecting redox balance and cellular signalling, while bicarbonate and other mineral ions have been associated with improved skin barrier function and systemic relaxation responses [28, 29]. Experimental findings indicate that immersion in mineral waters may influence immune cell activity and cytokine production, suggesting biological effects extending beyond the psychological benefits associated with spa environments.

Pelotherapy, involving the application of therapeutic muds or peloids, represents another important compo-

Table 2. Biological and neuropsychological effects of balneotherapy modalities

Modality	Main stimulus	Proposed mechanisms	Neuroimmune effects	Clinical outcomes
Mineral baths	Thermal and chemical stimuli	Hormesis, improved circulation	Reduced inflammatory activity	Stress reduction
Sauna / passive heat	Heat exposure	HSP70 activation	Modulation of oxidative stress	Mood improvement
Hydrotherapy	Hydrostatic pressure	Autonomic regulation	Parasympathetic activation	Improved sleep quality
Pelotherapy	Bioactive compounds from peloids	Anti-inflammatory signaling	Cytokine modulation	Emotional stabilization
Natural spa environment	Environmental exposure	Sensory relaxation and stress reduction	Indirect immunomodulation	Anxiety reduction

Source: compiled by the authors of this study

nent of spa medicine with potential immunological implications. Bioactive substances present in peloids may interact with inflammatory mediators and contribute to the regulation of stress-related immune responses. Studies conducted in patients with musculoskeletal disorders have demonstrated reductions in inflammatory markers following pelotherapy, supporting the hypothesis that similar anti-inflammatory pathways may also contribute to neuroimmune regulation [30, 31].

The anti-inflammatory effects of spa therapy are likely to be multifactorial, involving both direct physiological mechanisms and indirect psychosocial influences. Thermal stimulation may induce adaptive stress responses, while relaxation and exposure to natural environments may reduce sympathetic overactivation, thereby indirectly modulating immune–brain communication. Additionally, preliminary findings suggest that balneotherapy may influence oxidative stress markers, further supporting its potential role as a complementary strategy in conditions associated with chronic inflammation [32]. Although current evidence remains heterogeneous, the growing body of research highlights the importance of integrating immunological perspectives into investigations of spa-based rehabilitation [32].

BALNEOTHERAPY AND NEUROPSYCHOLOGICAL OUTCOMES

Balneotherapy has increasingly been investigated as a complementary intervention supporting psychological well-being and adaptive stress regulation. Clinical observations and systematic reviews suggest that spa-based therapies may contribute to reductions in anxiety and perceived stress through a combination of physiological relaxation, environmental exposure, and structured therapeutic routines. Immersion in mineral-rich waters and participation in hydrotherapy programmes have been associated with reduced muscle tension, improved mood, and enhanced emotional stability, indicating that balneological interventions may influence both psychological and somatic components of stress responses [33].

The main biological and neuropsychological effects of selected spa-based interventions are presented in Table 2.

An important outcome frequently reported in spa rehabilitation studies is the improvement of sleep quality. Sleep disturbances are common among individuals exposed to chronic stress and anxiety and often result from autonomic imbalance and hyperarousal. Hydrotherapy and spa-based treatments have demonstrated beneficial effects on sleep parameters, including reduced sleep latency and improved subjective sleep satisfaction. These effects may be mediated by thermal relaxation, stabilisation of circadian rhythms, and modulation of neuroendocrine activity, supporting the potential role of balneotherapy as an adjunctive approach in stress--related sleep dysregulation [34-36].

Regulation of the autonomic nervous system represents another key mechanism underlying neuropsychological improvements associated with spa therapy. Thermal immersion and hydrostatic pressure may promote parasympathetic activation while reducing sympathetic dominance, thereby facilitating physiological recovery from stress. Improvements in cardiovascular regulation and enhanced vagal tone observed during spa interventions suggest that environmental therapies may contribute to the restoration of autonomic flexibility, which is essential for emotional resilience and adaptive coping [28, 37].

The natural spa environment itself also plays a significant role in shaping therapeutic outcomes. Exposure to calming landscapes, reduced environmental noise, and structured relaxation settings may enhance the psychological benefits of balneotherapy by decreasing cognitive overload and promoting mindfulness-like states. Studies investigating neutral mineral baths have reported improvements in subjective well-being and relaxation, further supporting the hypothesis that environmental and sensory factors contribute to neuropsychological recovery [37]. Together, these findings highlight the multidimensional impact of balneotherapy on mental health, emphasising its potential role within integrative approaches to stress management and rehabilitation [35, 36].

INTEGRATIVE NEUROIMMUNE MODEL OF ENVIRONMENTAL NEUROREHABILITATION

An integrative neuroimmune model of environmental neurorehabilitation provides a useful framework for understanding how chronic stress contributes to persistent anxiety-related symptoms and how spa-based interventions may support recovery. Within this model, prolonged stress exposure initiates a cascade beginning with neuroendocrine activation and progressing towards sustained neuroimmune imbalance. Repeated or severe stressors promote low-grade systemic inflammation and

Table 3. Proposed neuroimmune biomarkers for future balneotherapy clinical trials

Biomarker	Biological domain	Clinical rationale	Expected effect of balneotherapy
NLRP3	Neuroinflammation	Indicator of stress-induced immune activation and inflammasome activity	Reduction of inflammasome signalling
IL-18	Cytokine response	Marker associated with inflammatory activation and emotional dysregulation	Anti-inflammatory modulation
MMP-9	Extracellular matrix remodelling	Indicator of neuroimmune communication and tissue remodelling processes	Stabilisation of inflammatory processes
Cortisol	HPA axis activity	Indicator of stress adaptation and neuroendocrine regulation	Improved circadian regulation
Serotonin	Neurotransmission	Mediator involved in mood regulation and emotional processing	Enhanced stress resilience

Source: compiled by the authors of this study

central neuroinflammation mediated by cytokine signalling, microglial activation, and oxidative stress pathways. Over time, this inflammatory environment contributes to maladaptive changes in neural circuits involved in fear processing and emotional regulation. In parallel, chronic stress is associated with autonomic dysregulation, typically characterised by sympathetic dominance and reduced parasympathetic activity, which may further amplify immune activation and disrupt sleep and recovery processes [37].

A key feature of this model is the bidirectional interaction between neuroinflammation and autonomic imbalance: inflammatory mediators may impair vagal tone and stress resilience, whereas sustained sympathetic activation may enhance inflammatory signalling. Within this feedback loop, the NLRP3 inflammasome represents a mechanistically plausible regulatory point linking cellular stress signals with cytokine maturation and neuroinflammatory amplification. Furthermore, matrix metalloproteinases, particularly MMP-9, may contribute to extracellular matrix remodelling and blood–brain barrier-related processes involved in neuroimmune communication [8, 38]. Additionally, oxidative and inflammatory profiles observed across various mental disorders support the concept that chronic stress may generate a convergent biological signature shared by anxiety-related phenotypes and stress-associated depression, reinforcing the need for biomarker-guided rehabilitation approaches [39].

Balneotherapy may be conceptualised as an environmental modulator capable of influencing several components of this cascade simultaneously. Thermal and hydrostatic stimuli may induce adaptive hormetic responses, promote parasympathetic activation, and reduce inflammatory burden, thereby attenuating the stress–inflammation–autonomic dysregulation loop. From a neurorehabilitation perspective, spa-based interventions combine physiological conditioning (heat and immersion), behavioural regulation (structured routines and relaxation techniques), and environmental enrichment (natural surroundings), providing a multidimensional approach consistent with contemporary concepts of resilience-oriented rehabilitation [40].

To advance this field, future clinical studies should incorporate neuroimmune biomarkers as standardised outcome measures. Candidate markers include NLRP3-related indices, MMP-9, and IL-18 as indicators of inflammasome-associated activity, together with serotonergic measures and cortisol dynamics reflecting neuroendocrine adaptation [8, 38, 39].

The selected biomarkers represent complementary components of the neuroimmune stress response. NLRP3 and IL-18 reflect inflammasome-related neuroinflammatory activity, MMP-9 represents extracellular matrix remodelling and neuroimmune communication, while cortisol and serotonin provide indicators of HPA axis regulation and mood-related neuroendocrine processes. Although established inflammatory markers such as CRP, TNF-α, and IL-6 are widely used, the biomarkers discussed here were selected due to their specific relevance to anxiety, stress adaptation, and neuroimmune mechanisms potentially influenced by balneotherapy.

Integration of biomarker panels with psychometric assessments and autonomic indices may help identify treatment responders, optimise therapeutic protocols, and strengthen the evidence base supporting balneotherapy within environmental neurorehabilitation.

Proposed neuroimmune biomarkers that may serve as outcome measures in future clinical trials of balneotherapy are presented in Table 3.

IMMUNOMODULATORY EFFECTS OF SPA THERAPY

Balneotherapy and related spa-based interventions have attracted increasing scientific attention due to their potential immunomodulatory effects, particularly in the context of chronic stress and anxiety-related disorders. The biological effects of spa therapy are thought to result from a combination of thermal, mechanical, and chemical stimuli that influence both systemic and local immune responses. Repeated exposure to mineral-rich waters, peloids, and controlled heat environments may contribute to the regulation of inflammatory signalling pathways, thereby supporting physiological adaptation to stress [3, 9, 26, 39].

Several studies suggest that balneological treatments may modify cytokine profiles and reduce markers of low-grade inflammation. Thermal stimulation associated with hydrotherapy and sauna bathing has been linked to adaptive cellular responses, including the induction of heat shock proteins and modulation of oxidative stress pathways [11, 20, 22]. These mechanisms may enhance cellular resilience and promote anti-inflammatory processes, which are particularly relevant in individuals exposed to prolonged psychological stress. Furthermore, sulphurous and bicarbonate mineral waters have been investigated for their potential effects on immune cell activity and redox balance, indicating that the chemical composition of therapeutic environments may contribute to shaping biological outcomes [3, 9, 16, 24, 39].

Pelotherapy and mud-based treatments have also demonstrated promising immunological effects. Experimental findings indicate that bioactive compounds present in therapeutic muds may influence inflammatory mediators and support tissue regeneration. Although most available evidence originates from studies investigating musculoskeletal conditions, the observed reductions in pro-inflammatory markers suggest that similar mechanisms may contribute to improved emotional well-being and stress resilience [35, 36].

Importantly, the immunomodulatory properties of spa therapy should be considered within a broader biopsychosocial framework. Relaxation, reduced environmental stressors, and structured rehabilitation programmes may indirectly influence immune–brain communication by decreasing sympathetic activation and enhancing parasympathetic activity. Despite encouraging findings, further well-designed clinical studies incorporating standardised neuroimmune biomarkers are required to clarify the mechanisms underlying these effects and to establish the therapeutic relevance of balneotherapy in stress-related disorders [3, 9, 26].

CONCLUSIONS

Neuroimmune mechanisms play a fundamental role in the regulation of anxiety and stress responses, linking inflammatory signalling, neuroendocrine imbalance, and autonomic dysregulation within a complex biological network. Chronic exposure to stress may promote persistent low-grade inflammation, oxidative imbalance, and altered HPA axis activity, contributing to emotional instability, impaired sleep, and reduced adaptive capacity. Understanding these interactions provides an important framework for developing integrative therapeutic strategies that extend beyond conventional pharmacological approaches.

Balneotherapy represents a promising environmental intervention capable of influencing multiple components of this neuroimmune cascade simultaneously. Thermal and hydrostatic stimuli, together with the chemical properties of mineral waters and the restorative effects of natural spa environments, may support parasympathetic activation, reduce inflammatory burden, and enhance physiological resilience. Available evidence suggests that spa-based therapies may improve neuropsychological outcomes, including stress reduction, emotional stabilisation, and sleep quality, although the precise molecular mechanisms require further investigation.

Importantly, integrating neuroimmunological biomarkers into balneological research may help bridge the gap between basic science and clinical practice. Biomarkers related to inflammasome activation, cytokine signalling, oxidative stress, and neuroendocrine regulation could provide objective indicators of treatment response and support the development of personalised rehabilitation models. Future studies should focus on well-designed randomised clinical trials combining biological, psychological, and environmental assessments to establish stronger evidence for the therapeutic role of balneotherapy in stress-related disorders.

Overall, the integration of contemporary neuroimmunology with spa medicine highlights the potential of environmental neurorehabilitation as a complementary strategy supporting both physiological regulation and psychological well-being in individuals exposed to chronic stress.

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REVIEW ARTICLE

Sleep disturbances and inflammatory markers in post-traumatic stress disorder: implications for balneological rehabilitation

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ABSTRACT

Sleep disturbances are among the most prevalent and clinically relevant symptoms of post-traumatic stress disorder (PTSD) and have been associated with neurobiological and inflammatory dysregulation. Alterations in sleep architecture, circadian rhythm disruption, and insomnia may contribute to heightened stress reactivity, impaired emotional regulation, and the persistence of trauma-related symptoms. Growing evidence suggests that inflammatory mediators, including interleukin-6 and other cytokines, as well as markers of oxidative stress, may be involved in the complex relationship between sleep dysfunction and neuropsychiatric symptom severity. From a balneological perspective, evidence derived predominantly from populations other than patients with PTSD suggests that spa-based interventions may influence sleep-related and psychophysiological outcomes; however, their efficacy in PTSD has not been established. Balneotherapy, hydrotherapy, thermal interventions, and structured spa-based programmes may potentially influence sleep regulation through thermoregulatory, autonomic, neuroendocrine, and inflammatory mechanisms. These mechanisms and their clinical relevance have not been sufficiently evaluated in PTSD-specific trials. Integrating balneological interventions with contemporary understanding of PTSD neurobiology may provide a conceptual framework for future investigation of personalised rehabilitation strategies in patients presenting with sleep disturbances and neuroimmune dysregulation. This narrative review highlights the potential, but as yet insufficiently established, role of balneological rehabilitation in PTSD and underscores the need for well-designed controlled studies evaluating sleep parameters, inflammatory biomarkers, clinical outcomes, and safety.

KEYWORDS: balneological rehabilitation, hydrotherapy, inflammatory markers, post-traumatic stress disorder, sleep disturbances

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INTRODUCTION

Sleep disturbances represent one of the most frequent and clinically significant symptom clusters in post-traumatic stress disorder (PTSD), affecting both psychological functioning and somatic health outcomes. Insomnia, fragmented sleep architecture, and circadian rhythm dysregulation are increasingly recognised not only as consequences of traumatic stress but also as factors contributing to its persistence through impaired emotional processing and altered fear memory consolidation. Contemporary neurobiological research indicates that PTSD is associated with dysregulation of neuroendocrine and neuroimmune mechanisms involved in the stress response, including alterations in cortisol and serotonergic signalling [1, 2], as well as inflammatory pathways involving interleukin-6 (IL-6), chemokine signalling, and cellular mechanisms of neuroinflammation [3, 4]. Neuroimaging findings further indicate that PTSD duration may be associated with volumetric and microstructural alterations in the hippocampus, amygdala, and prefrontal cortex [5]. Together, these findings indicate that sleep disturbances in PTSD occur within a broader context of neuroendocrine, neuroimmune, and neural-circuit dysregulation.

In recent years, non-pharmacological strategies targeting sleep and stress regulation have gained increasing attention within rehabilitation medicine. Balneological interventions, including hydrotherapy, mineral baths, and structured spa therapy programmes, represent a multimodal therapeutic approach combining thermal, hydrostatic, and environmental stimuli. Evidence from a systematic review suggests that hydrotherapy, spa therapy, and balneotherapy may improve sleep-related outcomes across heterogeneous clinical populations [6]. A further systematic review has examined the potential role of balneotherapy, both alone and in combination with exercise, in improving sleep-related outcomes [7]. However, the available studies were conducted predominantly in populations other than patients with PTSD, and their findings should therefore be interpreted as indirect evidence when considering potential applications in PTSD. Accordingly, the integration of balneotherapy with physical activity and relaxation-oriented routines provides a rationale for investigating its possible role in neurorehabilitation rather than evidence of established therapeutic efficacy in PTSD.

Despite increasing interest in spa medicine, the relationship between PTSD-related neurobiological dysregulation and the potential effects of balneological interventions remains insufficiently explored. The available evidence therefore represents two largely separate bodies of research: studies describing neurobiological abnormalities associated with PTSD and studies evaluating balneological interventions predominantly in non-PTSD populations. A direct therapeutic link between these areas has not yet been established. Understanding these interactions may provide a framework for future investigation of personalised balneological rehabilitation strategies for patients presenting with sleep dysregulation and neuroimmune imbalance. Therefore, a translational perspective integrating contemporary neurobiology with traditional spa therapy principles may contribute to the development of hypothesis-driven approaches to environmental neurorehabilitation in PTSD.

AIM

The aim of this review is to present current evidence on the relationship between sleep disturbances, inflammatory markers, and neurobiological dysregulation in post-traumatic stress disorder (PTSD), and to discuss the potential and currently exploratory role of balneological rehabilitation as an integrative, non-pharmacological approach to sleep regulation and environmental neurorehabilitation.

MATERIALS AND METHODS

This narrative review was conducted through a comprehensive analysis of the available literature concerning PTSD, sleep disturbances, inflammatory biomarkers, and balneological rehabilitation. Relevant publications were identified through a literature search conducted in PubMed, Scopus, and Web of Science, with the last search performed on 10 August 2026. The search was intended to identify literature relevant to the scope of this narrative review and was not conducted according to a systematic review protocol. Combinations of Medical Subject Headings (MeSH) and free-text terms were used, including post-traumatic stress disorder, sleep, balneotherapy, hydrotherapy, spa therapy, inflammation, and oxidative stress. Publications were selected on the basis of their relevance to the objectives of the review, with particular consideration given to studies addressing PTSD-related sleep disturbances, inflammatory and oxidative mechanisms, neurobiological dysregulation, and the potential application of balneological interventions. Priority was given to systematic reviews, randomised controlled trials, observational clinical studies, and translational research published in English. No formal meta-analysis, quantitative synthesis, or systematic risk-of-bias assessment was performed. The findings were synthesised narratively to provide an up-to-date overview of the current evidence and to identify potential implications for clinical practice and future research.

REVIEW

The narrative synthesis of the selected literature indicates associations between PTSD, sleep disturbances, and inflammatory and neurobiological dysregulation. Alterations in inflammatory cytokines, oxidative stress-related markers, neuroendocrine signalling, and other neurobiological parameters have been reported in PTSD and related clinical populations. Evidence from studies conducted predominantly in non-PTSD populations suggests that balneotherapy, hydrotherapy, thermal interventions, and structured spa-based programmes may influence sleep-related, stress-related, and selected inflammatory outcomes. However, these findings constitute indirect evidence and should not be interpreted as demonstrating the clinical efficacy of balneological rehabilitation in PTSD. Because this study was designed as a narrative review, the findings were interpreted qualitatively rather than subjected to systematic quantitative comparison or meta-analysis. The available evidence remains heterogeneous, and PTSD-specific studies evaluating balneological interventions are lacking or very limited.

DISCUSSION

SLEEP DISTURBANCES AND NEUROBIOLOGICAL DYSREGULATION IN PTSD

Sleep disturbances represent one of the core clinical features of PTSD and are closely associated with neurobiological dysregulation affecting emotional processing, autonomic balance, and inflammatory pathways. Insomnia, fragmented sleep, and circadian rhythm disruption are frequently reported among individuals exposed to chronic stress and trauma, contributing to impaired recovery and the persistence of psychopathological symptoms. Altered sleep architecture may enhance nocturnal hyperarousal, reduce slow-wave sleep, and interfere with adaptive fear extinction processes, thereby reinforcing traumatic memory consolidation. Beyond PTSD-specific findings, alexithymic traits have been reported in patients with anxiety disorders and may contribute to difficulties in emotional awareness and regulation, supporting the broader relevance of altered affective processing across stress- and anxiety-related psychopathology [8].

From a neurobiological perspective, disturbances in limbic–prefrontal circuitry and dysregulation of the hypothalamic–pituitary–adrenal (HPA) axis are relevant to the sleep-related dysfunction observed in PTSD. Neuroimaging findings further indicate that PTSD duration may be associated with volumetric and microstructural alterations in the hippocampus, amygdala, and prefrontal cortex, supporting the involvement of limbic–prefrontal circuitry in the neurobiological progression of the disorder [5].

Abnormal cortisol secretion patterns and altered serotonergic signalling may disrupt circadian regulation and emotional stability, contributing to heightened stress reactivity and impaired cognitive control. Neurobiological profiling in PTSD has demonstrated alterations in serotonin, cortisol, noradrenaline, and IL-12, with evidence suggesting that these patterns may vary according to disorder chronicity and age [1]. Traumatic stress has also been associated with differences in serotonin, tryptophan, and cortisol concentrations between stress-resilient and stress-susceptible individuals, further supporting the involvement of neuroendocrine and serotonergic mechanisms in individual stress responses [2].

These neurobiological mechanisms may also interact with inflammatory processes, including signalling involving pro-inflammatory cytokines such as interleukin-6 [3]. Growing evidence suggests a bidirectional relationship between sleep and immune processes. Chronic sleep disruption may promote oxidative stress and neuroinflammatory activity, while increased inflammatory activity may, in turn, contribute to poorer sleep quality and psychological functioning [4, 9]. This interaction suggests that sleep disturbances in

PTSD should be considered not only as behavioural symptoms but also within the broader context of neurobiological and immune dysregulation.

From a balneological perspective, recognition of these sleep-related neurobiological mechanisms provides a theoretical framework for investigating environmental neurorehabilitation strategies. Thermal stimuli, hydrostatic pressure, and structured spa-based routines may potentially influence autonomic regulation, circadian processes, and related neuroendocrine and inflammatory pathways. However, whether these effects translate into clinically meaningful benefits in patients with PTSD remains to be established. A better understanding of the interplay between sleep dysfunction, emotional regulation, and biological markers may therefore support future studies evaluating personalised rehabilitation programmes that integrate clinical psychiatry with balneological approaches.

INFLAMMATORY AND OXIDATIVE BIOMARKERS AS THERAPEUTIC TARGETS

Chronic inflammation and oxidative stress are increasingly recognised as relevant pathophysiological mechanisms in PTSD, particularly in patients presenting with persistent sleep disturbances and emotional dysregulation. Alterations in inflammatory signalling have been reported in patients with PTSD, including differences in circulating IL-6 and components of the chemokine system, supporting the involvement of peripheral immune dysregulation in the disorder [3]. Alterations in chemokine signalling and IL-6 concentrations have also been reported in panic disorder and comorbid personality disorders, suggesting that peripheral immune dysregulation may extend across different anxiety- and stress-related psychiatric phenotypes [10].

Recent evidence in PTSD has implicated the NOD-, LRR- and pyrin domain-containing protein 3 (NLRP3) inflammasome, matrix metalloproteinases 2 and 9 (MMP-2 and MMP-9), and gamma-aminobutyric acid (GABA)-related pathways in cellular mechanisms of neuroinflammation, further supporting the involvement of complex neuroimmune processes in the disorder [4]. The NLRP3 inflammasome has also been implicated more broadly in stress-related neuropsychiatric disorders through mechanisms involving neuron–microglia–astrocyte crosstalk, inflammatory signalling, and HPA-axis dysregulation, providing a potential mechanistic link between chronic stress and neuroimmune dysfunction [9].

Oxidative and metabolic abnormalities represent another relevant component of this biological profile. Alterations in biomarkers related to oxidative stress, inflammation, and neuroplasticity, including glutathione peroxidase 1 (GPX-1), tumour necrosis factor alpha (TNF-α), neurotrophin-4/5 (NT-4/5), and L-arginine, have been investigated in patients with depressive disorders with and without comorbid PTSD [11]. Differences in asymmetric dimethylarginine (ADMA), protein carbonyl groups, catalase (CAT), and Na^+/K^+-ATPase (NKA) have also been examined in depressed patients with and without comorbid PTSD, further supporting the relevance of oxidative and cellular stress pathways in this clinical context [12]. In depressive disorders, alterations in antioxidant defence mechanisms have additionally been investigated, with peroxiredoxin-1 and peroxiredoxin-3 proposed as potential indicators associated with sickness behaviour and depression severity [13], while reduced plasma paraoxonase-1 (PON-1) activity has been proposed as a potential trait marker of depression [14]. These latter findings derive from depressive populations and should therefore be regarded as indirect evidence in relation to PTSD.

More broadly, inflammatory and oxidative alterations have been described across a range of mental disorders, supporting the concept that combined inflammatory and redox profiles may contribute to biological heterogeneity and could potentially inform biomarker-based approaches to personalised psychiatric care [15]. Taken together, the available evidence suggests interactions among inflammatory signalling, oxidative stress, neuroendocrine regulation, and neuroimmune processes. However, the clinical utility of these biomarkers for predicting rehabilitation outcomes or selecting specific therapeutic interventions remains uncertain.

From a translational perspective, biomarker assessment may eventually contribute to the development of more individualised rehabilitation strategies. Nevertheless, the relationship between PTSD-related biomarker profiles and responses to balneological interventions has not been established. Evidence from non-PTSD populations provides only indirect mechanistic support. In patients with fibromyalgia, for example, balneotherapy has been associated with changes in serum interleukin-1 (IL-1), prostaglandin E2 (PGE2), and leukotriene B4 (LTB4) levels, suggesting that balneological interventions may influence selected inflammatory mediators [16].

These findings provide a rationale for further investigation of possible interactions between balneological interventions and inflammatory or oxidative pathways. However, evidence linking such mechanisms specifically to clinical outcomes in PTSD remains insufficient. Future studies should therefore determine whether changes in inflammatory, oxidative, or neuroendocrine biomarkers accompany clinically meaningful improvements in sleep, emotional regulation, or PTSD symptom severity following balneological rehabilitation.

BALNEOTHERAPY AND SPA-BASED SLEEP MODULATION

Balneotherapy and spa-based interventions are increasingly investigated as non-pharmacological approaches to improving sleep-related outcomes and psychophysiological regulation across a range of clinical populations. Thermal and hydrostatic stimulation provided by mineral baths, hydrotherapy, and related spa procedures may influence physiological processes relevant to sleep regulation. However, the available evidence derives predominantly from non-PTSD populations, and extrapolation of these findings to patients with PTSD should therefore be undertaken cautiously.

Clinical studies in non-PTSD populations suggest that specific bathing interventions may influence sleep-related outcomes. An assessor-blinded randomised controlled pilot trial evaluating sodium bicarbonate bathing demonstrated improvements in selected subjective and objective sleep-related parameters [17]. A preliminary pilot study in individuals with sleep disorders found that a seven-day balneotherapy programme combined with sleep-promoting measures was associated with improvements in sleep-related outcomes, providing further evidence for the potential role of multimodal spa-based interventions in sleep management [18]. These observations are consistent with a systematic review indicating that hydrotherapy, spa therapy, and balneotherapy may improve sleep-related outcomes across heterogeneous populations [6]. Nevertheless, these findings provide only indirect support for investigating similar approaches in PTSD and should not be interpreted as evidence of efficacy in this disorder.

More recent evidence further supports a possible relationship between balneotherapy, sleep regulation, and neuroimmune processes. In a 2026 prospective pilot study involving adults with sleep disorders, a 10-day residential hot spring balneotherapy programme was associated with improvements in subjective and wearable-assessed sleep parameters, accompanied by changes in inflammatory cytokines, neurotransmitters, and tryptophan-related metabolic pathways [19]. However, the study did not include patients with PTSD and used a single-arm, self-controlled design; therefore, these findings should be regarded as preliminary and indirect in the context of PTSD rehabilitation.

An important aspect of spa-based sleep modulation involves the integration of balneotherapy with physical activity and structured rehabilitation programmes. In a prospective randomised study of patients with ankylosing spondylitis, balneotherapy and exercise-based interventions were evaluated in relation to clinical outcomes, including sleep quality and quality of life, providing indirect evidence for the potential value of multimodal rehabilitation approaches [20]. In patients with osteoarthritis, balneotherapy combined with physical therapy has also been investigated in relation to sleep quality, providing additional clinical evidence that balneological and rehabilitation interventions may influence sleep-related outcomes in non-PTSD populations [21]. In women with morbid obesity, balneotherapy has also been investigated in relation to sleep disturbances and quality of life, providing further indirect evidence that balneological interventions may influence sleep-related outcomes across different non-PTSD clinical populations [22].

More recent evidence from a spa setting suggests that daytime physical activity combined with balneotherapy during a spa stay may be associated with favourable sleep-related outcomes [23]. A systematic review examining sleep and spa therapies further indicates that balneotherapy, both alone and in combination with exercise, may contribute to improvements in sleep-related outcomes across different clinical populations [7]. However, the heterogeneity of the available studies and the absence of PTSD-specific evidence limit direct extrapolation of these findings to patients with PTSD.

Passive body heating represents another potentially relevant mechanism. A systematic review and meta-analysis found that passive body heating by a warm bath or shower before bedtime may improve selected sleep outcomes, including sleep onset and overall sleep quality, supporting a thermoregulatory mechanism for sleep promotion [24]. These findings provide a plausible physiological rationale for investigating whether thermal interventions could contribute to sleep regulation in patients with PTSD. However, such effects have not been established specifically in PTSD, and the available evidence should not be interpreted as demonstrating therapeutic efficacy in this population.

Overall, evidence from systematic reviews, randomised studies, and preliminary clinical investigations suggests that balneological and thermal interventions may influence sleep-related outcomes in selected non-PTSD populations [6, 7, 17, 18, 19, 23, 24]. These findings provide a rationale for PTSD-specific research but do not establish the effectiveness of balneotherapy for sleep disturbances in PTSD. Future controlled studies should evaluate both subjective and objective sleep outcomes and determine whether any observed improvements are accompanied by changes in neuroimmune, neuroendocrine, or autonomic parameters.

MULTIMODAL NONPHARMACOLOGICAL INTERVENTIONS IN REHABILITATION

Multimodal non-pharmacological interventions are increasingly investigated as components of comprehensive rehabilitation strategies for chronic conditions associated with sleep disturbance, fatigue, pain, and psychological distress. However, their specific effectiveness as components of PTSD rehabilitation requires direct evaluation.

Physical therapy represents an important component of multimodal rehabilitation. A systematic review of patients with chronic pain indicates that physical therapy techniques and commonly used non-pharmacological interventions may influence sleep quality, providing indirect support for the inclusion of sleep-related outcomes in multimodal rehabilitation programmes [25]. Although the available evidence primarily concerns chronic pain and musculoskeletal populations rather than PTSD, these findings may inform the design of future multimodal rehabilitation studies in patients with PTSD.

Simple body-based and thermal interventions have also been investigated in relation to sleep and fatigue. Recent evidence from hospitalised patients with cancer indicates that supportive nursing interventions involving foot massage and bed bathing may contribute to improvements in fatigue and sleep quality [26]. A systematic review and meta-analysis evaluating hot foot baths reported beneficial effects on sleep quality, supporting the potential role of simple thermal bathing interventions in sleep management [27]. Similarly, a quasi-experimental study in older adults living in a nursing home reported improved sleep outcomes following a footbath intervention [28]. However, these studies were conducted in non-PTSD populations and did not evaluate balneological rehabilitation specifically; their relevance to PTSD should therefore be considered indirect.

Evidence from fibromyalgia provides an additional, although indirect, clinical model for considering multimodal rehabilitation approaches. A systematic review and meta-analysis of randomised controlled trials indicates that different non-pharmacological interventions may improve selected clinical features of fibromyalgia, supporting the broader role of multimodal non-pharmacological management in a chronic condition characterised by pain, fatigue, sleep disturbance, and psychological symptoms [29]. Comparative clinical research has also investigated balneotherapy and aerobic exercise as non-pharmacological treatment approaches in patients with fibromyalgia [30]. Because fibromyalgia and PTSD differ substantially in their clinical presentation and pathophysiology, these findings cannot be directly extrapolated to PTSD. Nevertheless, they may inform hypotheses regarding the integration of physical activity and balneological interventions in future PTSD-specific rehabilitation studies.

Overall, evidence from chronic pain, cancer care, older adult care, and fibromyalgia suggests that multimodal non-pharmacological interventions may influence sleep, fatigue, pain, and functional outcomes in selected non-PTSD populations [25-30]. These observations provide an indirect rationale for further investigation of multimodal rehabilitation strategies in PTSD, but PTSD-specific controlled studies are required before their clinical effectiveness can be established.

ENVIRONMENTAL NEUROREHABILITATION AND SPA MEDICINE

Environmental neurorehabilitation may provide a conceptual framework for considering the role of structured therapeutic environments within contemporary balneology. Spa-based rehabilitation can combine balneological procedures, physical activity, rest, and structured daily routines within a controlled therapeutic setting. Such an approach may be relevant to conditions characterised by sleep disturbance, fatigue, and stress-related symptoms; however, its specific therapeutic value in PTSD has not been established.

Structured spa routines may provide regular daily schedules and repeated exposure to predictable therapeutic procedures. These characteristics could potentially support behavioural and sleep-related regulation, although the mechanisms and clinical significance of such effects require further investigation. Recent clinical evidence from a non-PTSD population indicates that balneotherapy may contribute to improvements in stress-related symptoms and fatigue, with beneficial changes in sleep-related outcomes also reported following spa-based treatment [31]. These findings provide indirect support for investigating the potential role of balneological rehabilitation in stress-related conditions, while their applicability to PTSD remains to be established.

Environmental components of spa medicine may also include climatotherapy, outdoor activity, and exposure to natural surroundings. These elements have been proposed as potentially relevant components of comprehensive rehabilitation; however, the evidence available in the present review does not allow firm conclusions regarding their specific effects on autonomic regulation, inflammatory activity, or PTSD-related symptoms. Their potential contribution should therefore be regarded as exploratory rather than established.

Within a multidisciplinary rehabilitation framework, spa medicine offers an environment in which balneological procedures, physical activity, structured routines, and supportive therapeutic interventions can be integrated. Such a setting may provide a basis for future investigation of environmental approaches to sleep and stress regulation. At present, however, environmental neurorehabilitation should be regarded as a conceptual and hypothesis-generating approach to PTSD rehabilitation rather than an established evidence-based treatment model.

TRANSLATIONAL PERSPECTIVE: BIOMARKER-GUIDED BALNEOLOGY

The development of translational approaches in rehabilitation medicine highlights the potential future role of biomarker-guided strategies in the personalised management of stress-related disorders. In PTSD, heterogeneity in inflammatory activity, neuroendocrine regulation, oxidative processes, and neurobiological responses provides a rationale for investigating individualised therapeutic models. Inflammatory and oxidative biological profiles have been proposed as potentially relevant to diagnostic and personalised approaches across mental disorders [15]. However, their clinical utility for selecting specific rehabilitation interventions has not yet been established. Recent PTSD-specific research has identified associations between biomarkers including interleukin-18 (IL-18), inositol-requiring enzyme 1 (IRE1), phosphorylated extracellular signal-regulated kinase (pERK), and activating transcription factor 6 (ATF6) and dimensions of emotional control, further supporting the potential relevance of integrating molecular and psychological measures when characterising biological heterogeneity in PTSD [32].

Such findings may contribute to a more detailed understanding of individual neurobiological profiles, but they should not be interpreted as evidence that these biomarkers can currently predict treatment response.

Neuroimaging may provide an additional dimension to future multimodal assessment. PTSD duration has been associated with volumetric and microstructural alterations in the hippocampus, amygdala, and prefrontal cortex [5]. Integrating such neuroimaging findings with molecular biomarkers and clinical assessment may eventually contribute to a more comprehensive characterisation of neurobiological heterogeneity in PTSD. However, the utility of either biomarkers or neuroimaging measures for selecting balneological treatments remains unproven.

Within a translational framework, balneology could potentially evolve towards a model of precision environmental medicine in which spa-based interventions might eventually be tailored according to individual clinical and neurobiological characteristics. At present, however, there is insufficient clinical evidence to recommend specific balneological interventions according to inflammatory, oxidative, autonomic, neuroendocrine, or neuroimaging profiles in patients with PTSD. Biomarker-guided balneology should therefore be regarded as a research hypothesis requiring prospective validation rather than an established therapeutic strategy.

Future research could integrate clinical evaluation, molecular biomarkers, objective sleep measures, and neuroimaging tools to investigate individualised rehabilitation pathways. The convergence of neuroscience, environmental medicine, and spa therapy represents a potential direction for research into personalised interventions targeting sleep disturbances, stress reactivity, and neurobiological dysregulation in PTSD. Prospective controlled studies are required before such approaches can be translated into clinical recommendations.

CLINICAL LIMITATIONS AND CONTRAINDICATIONS OF BALNEOLOGICAL REHABILITATION IN PTSD

Evidence regarding the safety and contraindications of balneological interventions specifically in patients with PTSD is currently very limited. Consequently, safety considerations for this population must largely be inferred from the broader hydrotherapy, balneotherapy, rehabilitation, and psychiatric literature rather than from PTSD-specific trials. Thermal exposure and hydrotherapeutic procedures may not be appropriate for all individuals. Because passive body heating produces thermoregulatory responses, individual tolerance and relevant medical comorbidities should be considered when applying interventions involving substantial thermal exposure [24].

From a psychiatric perspective, PTSD is a heterogeneous disorder that may coexist with other psychiatric, behavioural, neurological, and medical conditions. Complex psychiatric presentations involving co-occurring affective and addictive disorders illustrate the importance of comprehensive psychiatric assessment when planning individualised supportive and rehabilitation strategies [33]. Similarly, the coexistence of psychiatric and neurological conditions may complicate clinical presentation and therapeutic planning, supporting the need for comprehensive neuropsychiatric assessment [34]. These observations provide broader clinical context rather than direct evidence regarding the safety or efficacy of balneological interventions in PTSD.

PTSD itself should not be regarded as an established contraindication to balneological rehabilitation; rather, eligibility should be assessed individually according to psychiatric stability, relevant comorbidities, current clinical risk, pharmacotherapy, and tolerance of the proposed intervention. Direct evidence demonstrating that specific balneological stimuli trigger traumatic memories, panic attacks, or autonomic hyperarousal in patients with PTSD is currently insufficient. Such reactions should therefore be regarded as clinically plausible considerations requiring individual assessment rather than established effects of balneological treatment.

Balneological interventions should be individualised and introduced under appropriate medical supervision. Patients with significant psychiatric instability or relevant medical comorbidities should undergo appropriate clinical assessment before participation. Coexisting endocrine abnormalities may further complicate the management of psychiatric patients, illustrating the importance of considering somatic and endocrine comorbidities as part of comprehensive clinical assessment [35].

Particular attention should also be paid to current psychotropic pharmacotherapy and its potential systemic complications. Severe adverse reactions associated with long-term antipsychotic treatment, including neuroleptic malignant syndrome, illustrate the importance of reviewing treatment-related complications in medically complex psychiatric patients [36]. Pharmacotherapy-related disturbances of thermoregulation, including fever occurring in neuroleptic malignant syndrome during antipsychotic treatment, further emphasise the importance of considering medication-related risks before rehabilitation procedures involving substantial thermal exposure [37]. Antipsychotic treatment has also been associated with an increased risk of thromboembolic complications, supporting the need to consider pharmacotherapy-related somatic risks during pre-rehabilitation assessment [38]. These observations provide broader safety context rather than evidence that such complications are specifically associated with balneological treatment.

The safety and clinical relevance of bathing interventions also depend on the type of procedure and the population in which they are applied. Evidence from other clinical fields, including studies of bathing interventions in dermatological populations [39], illustrates that findings concerning one type of bathing procedure should not automatically be extrapolated to another intervention or clinical population. This consideration is particularly important when evaluating balneological rehabilitation in PTSD, for which disorder-specific safety data remain limited.

Close collaboration between rehabilitation specialists, psychiatrists, psychologists, physiotherapists, and spa physicians may be particularly appropriate when treating patients with complex clinical presentations or substantial comorbidity. Broader research concerning physiotherapy education and professional preparation further highlights the relevance of appropriately trained rehabilitation professionals within contemporary healthcare settings [40]. However, this evidence does not specifically address balneological rehabilitation or PTSD and should therefore be regarded solely as contextual support for multidisciplinary care.

Current evidence regarding the safety profile of intensive balneological interventions specifically in PTSD populations remains insufficient. Further prospective studies should systematically evaluate tolerability, adverse events, treatment discontinuation, psychiatric stability, and relevant medical outcomes before PTSD-specific safety recommendations can be established.

CONCLUSIONS

Sleep disturbances, inflammatory activation, and neurobiological dysregulation appear to represent interconnected processes relevant to the persistence and clinical complexity of PTSD. Growing neurobiological evidence suggests that alterations in autonomic regulation, circadian processes, neuroendocrine signalling, and neuroimmune pathways may contribute to emotional dysregulation, impaired recovery, and altered stress responsiveness in PTSD.

Evidence derived predominantly from non-PTSD populations suggests that balneological interventions, including hydrotherapy, thermal bathing, and structured spa-based rehabilitation, may influence sleep-related, stress-related, and selected physiological outcomes. These findings provide an indirect biological and clinical rationale for investigating balneological rehabilitation in PTSD but do not establish its therapeutic efficacy in this population.

Current evidence from systematic reviews and clinical studies conducted largely in other clinical populations supports further investigation of balneotherapy and related non-pharmacological strategies as potential complementary approaches in PTSD rehabilitation. However, PTSD-specific evidence remains insufficient to support definitive clinical recommendations. Future randomised controlled studies should incorporate objective and subjective sleep parameters, inflammatory and oxidative biomarkers, neuroendocrine measures, neuroimaging, patient-reported outcomes, and systematic assessment of adverse events.

Further research is required to establish the efficacy, tolerability, contraindications, and safety profile of balneological interventions specifically in patients with PTSD before evidence-based clinical recommendations can be formulated.

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CONFLICT OF INTEREST

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REVIEW ARTICLE

Trauma-related sensitisation of fear responses: clinical and balneological perspectives in neurorehabilitation

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ABSTRACT
Trauma-related sensitisation of fear responses is a key mechanism underlying the development and persistence of post-traumatic stress disorder (PTSD) and related stress-associated conditions. Traumatic exposure may increase fear reactivity, impair extinction processes, and contribute to emotional dysregulation, sleep disturbance, cognitive dysfunction, autonomic imbalance, and somatic symptoms that can affect functional recovery. Neurobiologically, these changes are associated with dysregulation of limbic–prefrontal circuits, altered hypothalamic–pituitary–adrenal axis activity, changes in neurotransmitter regulation, neuroimmune activation, oxidative stress, and impaired neuroplasticity. Understanding these mechanisms is important for developing integrative rehabilitation strategies addressing both the psychological and physiological consequences of traumatic stress.

From a clinical and balneological perspective, spa-based neurorehabilitation may offer supportive effects through combined thermal, hydrostatic, environmental, physical, and behavioural stimuli. Balneotherapy, hydrotherapy, climatotherapy, therapeutic exercise, and structured spa rehabilitation programmes may support stress regulation, sleep quality, autonomic balance, emotional stabilisation, and functional recovery. Exposure to restorative natural environments and predictable therapeutic routines may additionally facilitate adaptive coping and participation in rehabilitation. Nevertheless, current evidence does not establish balneological interventions as specific treatments for PTSD. Their potential role should therefore be considered complementary to established psychiatric, psychological, and rehabilitative care. Trauma-related sensitisation of fear responses may represent a relevant target for personalised neurorehabilitation strategies integrating contemporary neurobiological knowledge with appropriately selected balneological and environmental interventions.

KEYWORDS: post-traumatic stress disorder, fear sensitisation, balneotherapy, neurorehabilitation, stress response

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INTRODUCTION

Post-traumatic stress disorder (PTSD) is increasingly recognised as a complex neuropsychiatric condition characterised by disturbances in emotional regulation, autonomic function, sleep, cognitive processing, and the neurobiological mechanisms underlying fear learning and extinction. Trauma-related sensitisation of fear responses contributes to persistent hyperarousal, impaired adaptation to stress, and reduced psychosocial functioning. Neuroimaging findings demonstrate structural and microstructural alterations within the hippocampus, amygdala, and prefrontal cortex, supporting the involvement of limbic–prefrontal networks in the persistence of trauma-related symptoms [1].

Fear sensitisation and impaired extinction are central mechanisms underlying persistent PTSD. Following traumatic exposure, exaggerated responses to threat-related stimuli may coexist with impaired discrimination between danger and safety. Difficulties in extinction learning and extinction recall can contribute to persistent threat perception, intrusive recollections, avoidance behaviour, and autonomic hyperarousal [2]. Contemporary models of fear neurobiology indicate that these processes involve interactions between neural circuitry responsible for fear learning, contextual memory, salience processing, and cognitive control [3].

Stress-related fear responses do not occur in isolation. Experimental and translational models increasingly indicate interactions between stress, sleep, fear processing, and neuroimmune activity [4]. Neuroendocrine dysregulation may also contribute to individual differences in vulnerability and resilience after traumatic exposure. Alterations in serotonin, tryptophan, and cortisol have been identified in individuals differing in stress susceptibility following trauma [5], whilst more recent evidence indicates that serotonin, cortisol, noradrenaline, and interleukin-12 (IL-12) may vary according to chronicity and age in PTSD [6].

Inflammatory and oxidative mechanisms have become increasingly relevant to contemporary models of PTSD. A systematic review and meta-analysis demonstrated alterations in inflammatory and oxidative stress markers in individuals with PTSD [7]. These biological changes may influence neuronal signalling, synaptic plasticity, energy metabolism, and stress reactivity, thereby contributing to persistent emotional, cognitive, and somatic symptoms.

Cognitive dysfunction represents another clinically important component of PTSD. Patients may experience difficulties in working memory, attention, executive functioning, and contextual processing. Such disturbances can interfere with emotional regulation, adaptive decision-making, and functional recovery. Biomarker studies suggest that cognitive impairment in PTSD may be associated with broader biological abnormalities, supporting an integrated neurobiological and neuropsychological approach to rehabilitation [8].

Sleep disturbance further contributes to the multidimensional clinical presentation of PTSD. Insomnia, fragmented sleep, altered sleep–wake regulation, and nocturnal hyperarousal may intensify fatigue, emotional instability, cognitive impairment, and autonomic dysregulation. Systematic evidence based on actigraphy confirms clinically significant disturbances of sleep in PTSD [9].

The complex interaction between fear regulation, neuroendocrine activity, cognition, sleep, inflammatory processes, and somatic symptoms highlights the need for multidimensional rehabilitation strategies. Although psychotherapy and pharmacotherapy remain fundamental components of PTSD management, complementary interventions targeting stress physiology, sleep, physical functioning, and autonomic regulation may contribute to broader functional recovery.

Balneology and health resort medicine may represent complementary components of such interdisciplinary rehabilitation. Spa therapy is a broader therapeutic concept than balneotherapy alone and may include hydrotherapy, therapeutic exercise, climatotherapy, environmental exposure, and other structured rehabilitation procedures [10]. Thermal, hydrostatic, mechanical, environmental, and behavioural stimuli associated with these approaches may influence psychophysiological regulation.

Clinical evidence suggests that balneotherapy may affect stress-related outcomes. A randomised controlled trial demonstrated reductions in stress and cortisol concentrations following balneotherapy [11], whilst an updated systematic review and meta-analysis provides further evidence regarding the relationship between balneotherapy and cortisol regulation [12]. These findings are relevant because neuroendocrine stress dysregulation represents an important component of trauma-related disorders.

Nevertheless, current evidence does not support balneotherapy as a specific treatment for PTSD. Most available studies involve populations with stress, anxiety, depression, sleep disturbance, chronic pain, or other health conditions. Their findings cannot therefore be directly extrapolated to patients with PTSD. Spa-based interventions should instead be considered potential supportive components of multidisciplinary rehabilitation aimed at stress regulation, sleep improvement, physical recovery, and psychophysiological stabilisation.

AIM

The aim of this narrative review was to summarise current evidence on trauma-related fear sensitisation in PTSD, with particular emphasis on its neurobiological mechanisms, associated biological and clinical markers, and relevance to functional recovery. A further objective was to evaluate the potential role of balneological interventions as supportive components of personalised neurorehabilitation. Particular attention was given to stress regulation, autonomic function, sleep, cognition, inflammatory and oxidative processes, neuroplasticity, physical functioning, and environmental rehabilitation. The review also proposes a translational framework integrating clinical characteristics and biological markers with individually tailored balneological strategies, whilst recognising the current limitations of direct evidence regarding spa-based interventions specifically in patients with PTSD.

MATERIALS AND METHODS

This narrative review was undertaken to synthesise current evidence concerning trauma-related sensitisation of fear responses in post-traumatic stress disorder, with particular emphasis on underlying neurobiological mechanisms, relevant biological and clinical markers, autonomic and stress-related dysregulation, cognitive and sleep disturbances, and the potential contribution of balneological interventions to neurorehabilitation.

A structured literature search was conducted using PubMed/MEDLINE, Scopus, and Web of Science. The final database search was performed on 12 August 2026. Publications issued between 2013 and 2026 were considered, providing a contemporary evidence base encompassing advances in the neurobiology of trauma-related fear responses as well as developments in balneological, environmental, and neurorehabilitative approaches.

The search strategy was based on combinations of terms corresponding to the principal domains addressed in this review. Search terms included: post-traumatic stress disorder, PTSD, traumatic stress, fear sensitisation, fear extinction, fear conditioning, amygdala, hippocampus, prefrontal cortex, hypothalamic–pituitary–adrenal axis, autonomic nervous system, neuroinflammation, oxidative stress, biomarkers, neuroplasticity, balneotherapy, balneology, spa therapy, health resort medicine, hydrotherapy, aquatic therapy, climatotherapy, thermal therapy, environmental therapy, neurorehabilitation, and rehabilitation. Supplementary searches addressed stress, cortisol, autonomic regulation, sleep, anxiety, depression, inflammation, oxidative stress, neuroplasticity, and functional recovery in relation to balneological interventions.

Eligible publications included original clinical and experimental studies, randomised and non-randomised controlled studies, observational studies, systematic reviews, meta-analyses, narrative reviews, and relevant clinical or professional publications. Studies were considered when they addressed trauma-related fear sensitisation or extinction, neurobiological mechanisms associated with PTSD, neuroendocrine, inflammatory, oxidative or autonomic alterations, cognitive functioning, sleep and stress regulation, or balneological and environmental interventions potentially relevant to neuropsychiatric rehabilitation.

Publications were excluded when they were unrelated to the objectives of the review, represented duplicate records, or were available only as abstracts without sufficient methodological or clinical information. Only English-language publications were considered. Studies involving populations without PTSD were included when they provided mechanistic, clinical, safety, or therapeutic information of potential relevance to stress regulation, psychiatric rehabilitation, sleep, neuroinflammation, oxidative stress, autonomic function, physical functioning, or the physiological effects of balneological interventions.

Study selection was performed through sequential screening of titles and abstracts followed by full-text evaluation of potentially eligible publications. Reference lists of relevant reviews and eligible studies were additionally examined. Given the narrative nature of the review and the clinical and methodological heterogeneity of the available evidence, no quantitative meta-analysis was undertaken.

The literature was synthesised thematically according to the principal areas addressed in the manuscript: neurobiology of fear sensitisation and memory modulation in PTSD; cognitive dysfunction and emotional regulation; biological markers relevant to personalised neurorehabilitation; balneology and environmental neurorehabilitation; multimodal rehabilitation models; hypoxia, neuroplasticity and tissue recovery; translational perspectives; and future directions for personalised balneological neurorehabilitation.

As this review was based exclusively on previously published literature and involved neither direct participation of human subjects nor the collection of identifiable individual-level data, ethical approval and informed consent were not required.

REVIEW AND DISCUSSION

NEUROBIOLOGY OF MEMORY MODULATION AND FEAR SENSITISATION IN PTSD

Trauma-related sensitisation of fear responses represents a central neurobiological mechanism contributing to the persistence of PTSD. Dysregulation within limbic–prefrontal networks may result in excessive responsivity to threat-related stimuli accompanied by insufficient cognitive and contextual regulation. Structural and microstructural abnormalities involving the hippocampus, amygdala, and prefrontal cortex have been associated with PTSD duration, supporting the importance of these regions in chronic trauma-related psychopathology [1].

Impaired fear extinction is particularly relevant in persistent PTSD. Extinction requires an individual to learn that a previously threatening stimulus no longer predicts danger. When extinction learning or recall is impaired, traumatic associations may continue to dominate behavioural and physiological responses despite the presence of objectively safe contextual information. Stronger conditioned fear responses during extinction learning and extinction recall in safe contexts have been associated with subsequent intrusive experiences [2].

Neuroimaging research further indicates that fear extinction depends on coordinated activity across multiple neural systems rather than a single anatomical structure. Prefrontal, hippocampal, amygdalar, and broader salience-related networks contribute to fear acquisition, contextualisation, extinction, and recall [13]. Contemporary conceptual models additionally suggest that brain-derived biotypes may eventually improve prediction of fear-based disorders following trauma [14].

Traumatic stress also involves complex interactions between neural and neuroendocrine systems. Changes in cortisol, serotonin, tryptophan, and other stress-related mediators may distinguish stress-resilient from stress-susceptible individuals [5]. Such differences may influence the persistence of hyperarousal, emotional instability, cognitive symptoms, and vulnerability to recurrent stress.

Neuroimmune mechanisms may further reinforce maladaptive fear processing. Integrated models of stress, sleep, fear, and neuroimmune responses suggest reciprocal interactions in which chronic stress and sleep disturbance may enhance inflammatory signalling, whilst neuroimmune activation may affect emotional learning and neural plasticity [4]. Systematic evidence of altered inflammatory and oxidative markers in PTSD supports the clinical relevance of these mechanisms [7].

From a balneological perspective, these neurobiological processes provide a rationale for investigating interventions that may support autonomic regulation, relaxation, sleep, and stress recovery. However, current evidence does not demonstrate that balneotherapy directly reverses pathological fear memories or normalises fear-extinction circuitry. Any proposed neurobiological effects should therefore be interpreted as supportive and indirect. The key neurobiological domains and their potential therapeutic targets are summarized in Table 1.

Table 1. Neurobiological mechanisms of memory modulation in PTSD and their potential relevance to balneological rehabilitation

Neurobiological domain	Key mechanisms in PTSD	Associated markers	Potential supportive balneological relevance
Limbic–prefrontal circuitry	Amygdala hyperresponsivity, impaired prefrontal regulation	Neuroimaging measures, cortisol, monoamines	Indirect support through stress and autonomic regulation
Fear extinction	Impaired extinction learning and recall	HPA-axis activity, neural activation patterns	Structured routines and supportive environmental conditions
Neuroinflammation	Cytokine and neuroimmune activation	IL-6, TNF-α, NLRP3-related markers	Potential modulation through general stress reduction
Oxidative stress	Altered redox balance and cellular resilience	GPX-1, ADMA, antioxidant markers	Potential indirect metabolic support
Neuroplasticity	Impaired adaptive remodelling	Neurotrophic factors, including NT-4/5	Physical activity and multimodal rehabilitation

Note: ADMA – asymmetric dimethylarginine; GPX-1 – glutathione peroxidase-1; HPA – hypothalamic-pituitary-adrenal; IL-6 – interleukin-6; NLRP3 – NOD-like receptor family pyrin domain-containing 3; NT-4/5 – neurotrophin-4/5; PTSD – post-traumatic stress disorder; TNF-α – tumour necrosis factor-alpha

Source: compiled by the authors of this study

COGNITIVE DYSFUNCTION AND EMOTIONAL REGULATION

Cognitive dysfunction represents an important clinical component of PTSD and may substantially influence rehabilitation outcomes. Difficulties in working memory, attention, executive functioning, and cognitive flexibility can impair the ability to process contextual information and regulate trauma-related thoughts. A systematic review of biomarkers associated with cognitive impairment in PTSD supports the relationship between cognitive dysfunction and broader biological abnormalities [8].

Emotional processing is also relevant to functional recovery. Difficulties in identifying and describing emotional states may complicate self-regulation and communication of psychological distress. Alexithymic characteristics have been described in anxiety-related populations with accompanying somatic conditions [15]. Although these findings are not specific to PTSD, they illustrate the importance of considering emotional awareness and somatic expression in complex psychiatric rehabilitation.

Sleep disturbance constitutes another important factor affecting cognition and emotional control. Insomnia, fragmented sleep, and altered sleep–wake rhythms can interfere with memory consolidation, attention, emotional processing, and daytime functioning. Systematic actigraphy evidence confirms significant sleep abnormalities in PTSD [9]. Sleep disruption may therefore act both as a symptom and as a factor maintaining cognitive and emotional dysfunction.

Neuropsychiatric rehabilitation may additionally involve patients with overlapping neurological, affective, and functional manifestations. Clinical reports describing depression and conversion disorder after brain tumour surgery demonstrate the complexity of relationships between neurological disease, mood symptoms, and functional presentation [16]. Such evidence cannot be extrapolated directly to PTSD, but it reinforces the need for comprehensive assessment when cognitive, somatic, and psychiatric symptoms coexist.

From a balneological perspective, interventions that support sleep, relaxation, and autonomic regulation may indirectly facilitate cognitive rehabilitation. A systematic review of hydrotherapy, spa therapy, and balneotherapy indicates potentially beneficial effects on sleep quality [17]. Improvements in sleep may subsequently support attention, executive functioning, mood regulation, and participation in rehabilitation.

Combining cognitive training with physical activity, structured routines, relaxation techniques, and appropriately selected spa-based procedures may therefore represent a potentially useful multimodal approach. Nevertheless, dedicated controlled studies are needed before such strategies can be recommended specifically for PTSD-related cognitive dysfunction.

BIOLOGICAL MARKERS AS TARGETS FOR PERSONALISED NEUROREHABILITATION

The identification of biological markers associated with trauma-related disorders may contribute to the development of more personalised rehabilitation strategies. In PTSD, immune-inflammatory alterations are particularly relevant. Changes in circulating chemokines, chemokine receptors, and interleukin-6 (IL-6) have been reported in patients with PTSD and avoidant personality disorder [18], indicating that trauma-related psychopathology may involve measurable immune dysregulation.

The involvement of inflammatory pathways is not confined to PTSD. Alterations in chemokines, chemokine receptors, and interleukin-6 have also been observed in panic disorder and personality disorders [19]. These findings demonstrate the broader relevance of immune signalling across psychiatric conditions, although they should not be interpreted as PTSD-specific.

The NOD-like receptor family pyrin domain-containing 3 (NLRP3) inflammasome represents another potentially important mechanism connecting stress, immune activity, and neural function. Interactions between neurons, microglia, astrocytes, hypothalamic–pituitary–adrenal (HPA) axis dysregulation, and inflammasome activity have been proposed as relevant mechanisms in stress-related neuropsychiatric disorders [20]. More specific research in PTSD implicates matrix metalloproteinases, NLRP3, and gamma-aminobutyric acid (GABA)-related pathways in cellular mechanisms of neuroinflammation [21].

Oxidative stress may interact with inflammation and neuroendocrine dysregulation. Broader analyses of psychiatric disorders indicate that inflammatory and oxidative biological profiles may contribute to diagnostic characterisation and personalised therapeutic approaches [22]. Studies in depression have identified alterations in peroxiredoxin-1 and peroxiredoxin-3 [23] and reduced paraoxonase-1 activity [24], supporting the wider relevance of antioxidant defence mechanisms in psychiatric illness.

Importantly, several biomarker studies have directly included patients with PTSD. Serum concentrations of neurotrophin-4/5 (NT-4/5), glutathione peroxidase-1 (GPX-1), tumour necrosis factor-alpha (TNF-α), and L-arginine have been investigated in patients experiencing a first depressive episode, with and without comorbid PTSD [25]. Similarly, asymmetric dimethylarginine (ADMA), carbonyl groups, catalase (CAT), and sodium–potassium adenosine triphosphatase (Na^+/K^+-ATPase) have been evaluated in depressed patients with and without PTSD [26].

These findings suggest that trauma-related disorders may involve interacting inflammatory, oxidative, metabolic, and neurotrophic abnormalities. More recent work has also examined associations between emotional control and molecular biomarkers, including interleukin-18 (IL-18), inositol-requiring enzyme 1 (IRE1), phosphorylated extracellular signal-regulated kinase (pERK), and activating transcription factor 6 (ATF6), in PTSD [27].

Such multidimensional approaches may be particularly relevant to personalised neurorehabilitation because they combine biological assessment with clinically meaningful psychological characteristics.

Biomarker-guided rehabilitation remains an emerging concept. At present, there is insufficient evidence to select a particular balneological intervention solely on the basis

Table 2. Conceptual framework for personalised balneological neurorehabilitation in PTSD

Clinical/biological profile	Relevant symptoms or markers	Potential supportive interventions	Potential rehabilitation objective to be evaluated
Increased inflammatory activity	Cytokine alterations, oxidative stress	Balneotherapy, graded physical activity, environmental rehabilitation	Stress reduction and functional recovery
HPA-axis dysregulation	Altered cortisol regulation, hyperarousal	Warm-water procedures, relaxation, structured routines	Stress and autonomic regulation
Sleep disturbance	Insomnia, fragmented sleep	Hydrotherapy, daytime activity, sleep-oriented routines	Improved sleep quality
Cognitive dysfunction	Working-memory and attention deficits	Cognitive training combined with physical rehabilitation	Cognitive and functional recovery
Autonomic imbalance	Hyperarousal, cardiovascular reactivity	Relaxation-oriented hydrotherapy, breathing exercises	Support of autonomic regulation
Fatigue and reduced physical capacity	Reduced exercise tolerance, somatic burden	Graded aquatic or land-based activity, climatotherapy	Physical conditioning and resilience
Anxiety/depressive symptoms	Emotional distress, reduced motivation	Multimodal spa rehabilitation alongside psychiatric care	Emotional support and rehabilitation engagement

Note: HPA – hypothalamic–pituitary–adrenal; PTSD – post-traumatic stress disorder

Source: compiled by the authors of this study

of an individual cytokine, oxidative marker, or neurotrophic factor. A more realistic near-term application may involve using biomarkers alongside symptom profiles, autonomic parameters, sleep measures, neuroimaging, and functional assessment to characterise patient subgroups and monitor treatment response.

BALNEOLOGY AND ENVIRONMENTAL NEUROREHABILITATION

Balneology and environmental neurorehabilitation may represent complementary components of integrative care for stress-related disorders. Spa therapy should be understood as a multimodal therapeutic concept rather than balneotherapy alone, incorporating water-based procedures together with physical activity, environmental exposure, relaxation, and other rehabilitation interventions [10].

Hydrotherapy and mineral baths exert thermal, hydrostatic, mechanical, and, depending on water composition, chemical effects. Warm-water exposure may reduce muscular tension, facilitate movement, and promote relaxation. These effects may be relevant to patients experiencing chronic hyperarousal, fatigue, pain, or stress-associated somatic symptoms.

Clinical studies suggest that balneotherapy may influence psychological and neuroendocrine stress responses. A randomised controlled trial demonstrated reductions in perceived stress and cortisol concentrations following balneotherapy [11], whilst a systematic review and meta-analysis provides additional evidence of changes in cortisol associated with balneological treatment [12].

Evidence concerning mood-related symptoms is also developing. A meta-analysis evaluating hydrotherapy and balneotherapy reported beneficial effects on anxiety and depressive symptoms [28]. More recent results from a multicentre randomised controlled trial with six-month follow-up demonstrated improvements in stress, anxiety, and depression following balneotherapy [29]. These findings are clinically relevant to the psychological dimensions of rehabilitation, although they do not constitute direct evidence for the treatment of PTSD.

Sleep represents another potentially important target. Hydrotherapy, spa therapy, and balneotherapy have demonstrated beneficial effects on sleep quality in systematic review evidence [17]. Spa-based therapeutic programmes that incorporate physical activity may provide additional benefits by combining exercise-related effects with thermal and environmental interventions.

Spa therapy has also been investigated in sub-healthy populations, with reported improvements in mental stress, sleep disturbance, and general health [30]. Although such populations differ substantially from patients with PTSD, these findings support the broader concept that spa-based interventions may influence psychophysiological stress-related outcomes.

Environmental neurorehabilitation extends beyond water-based treatment. Natural surroundings, structured outdoor activity, changes in climate, predictable daily routines, and reduced exposure to everyday stressors may create conditions favourable to restoration and behavioural regulation. Such interventions may be particularly relevant when integrated with rather than separated from physical and psychological rehabilitation.

The evidence should nevertheless be interpreted cautiously. Clinical improvements observed in stress, anxiety, depression, sleep disorders, or other populations do not establish balneotherapy as an evidence-based treatment for PTSD. The most appropriate interpretation is that spa-based approaches may support selected physiological and functional domains relevant to multidisciplinary PTSD rehabilitation.

MULTIMODAL REHABILITATION MODELS

Multimodal rehabilitation models may provide an appropriate framework for addressing the complex interaction between psychological, autonomic, cognitive, physical, and environmental factors in PTSD. Rather than relying on a single procedure, such programmes may combine hydrotherapy, physical exercise, relaxation training, cognitive interventions, environmental exposure, and conventional psychiatric care.

Aquatic exercise is particularly relevant because buoyancy reduces mechanical loading whilst hydrostatic pressure and water resistance enable controlled physical activity. Warm-water environments may simultaneously reduce muscular tension and facilitate relaxation. Cardiovascular adaptation must nevertheless be considered, as blood pressure and pulse responses have been demonstrated during combined balneotherapy and physiotherapy [31].

Relaxation techniques may complement physical rehabilitation by targeting excessive sympathetic arousal. Breathing exercises, mindfulness-based techniques, and predictable therapeutic routines may support parasympathetic activity and reduce psychophysiological tension. Their effect may be enhanced when implemented within a structured environment with regular sleep–wake schedules and reduced exposure to external stressors.

Physical activity may also contribute to sleep regulation. A systematic review addressing balneotherapy associated with exercise highlighted potentially beneficial effects on sleep-related outcomes [32]. More recent research examining daytime physical activity and balneotherapy during a spa stay further supports the interaction between activity patterns and sleep quality [33].

The importance of multimodal care is further illustrated by the heterogeneity of psychiatric populations. Complex comorbidity may substantially influence treatment planning. For example, the coexistence of bipolar disorder and gambling addiction demonstrates how mood symptoms and behavioural dysregulation may require parallel psychiatric management [34]. Such observations reinforce the principle that rehabilitation should be adapted to the individual rather than determined solely by a diagnostic label.

Individualised physiotherapy, graded physical activity, hydrotherapy, relaxation, cognitive training, and environmental exposure may therefore be combined according to functional status and dominant symptoms. The principal value of multimodal rehabilitation may lie in coordination between interventions rather than in any single therapeutic component.

HYPOXIA, NEUROPLASTICITY, AND TISSUE RECOVERY

Adaptive responses to environmental stimuli may influence physiological resilience and recovery. Climatotherapy can involve exposure to changes in altitude, temperature, air conditions, sunlight, and outdoor physical activity. These factors may influence cardiovascular, respiratory, and metabolic adaptation. However, evidence supporting specific hypoxia-related mechanisms in PTSD rehabilitation remains limited.

Metabolic and oxidative regulation may nevertheless be relevant. Altered oxidative and antioxidant biological profiles have been identified across psychiatric disorders [22], whilst PTSD-related studies have demonstrated abnormalities in markers associated with oxidative stress and antioxidant defence [25, 26]. Chronic oxidative imbalance could theoretically impair neuronal resilience and contribute to fatigue, cognitive dysfunction, and reduced adaptive capacity.

Neurotrophic processes are also relevant to functional recovery. Neurotrophin-4/5 (NT-4/5) and other neurotrophic mediators participate in neuronal survival, synaptic remodelling, and adaptive plasticity. Altered concentrations of NT-4/5 have been investigated in patients with depression with and without PTSD [25]. These findings provide a biological basis for considering neuroplasticity as a relevant rehabilitation domain.

Physical activity is one of the more plausible components through which spa-based rehabilitation could indirectly support adaptive neural function. Exercise, improved sleep, reduced stress activation, and regular daily routines may collectively create conditions favourable to cognitive and emotional recovery. Such effects should not, however, be described as direct neural regeneration unless confirmed by dedicated mechanistic studies.

The relationship between climatotherapy, oxygenation, metabolism, oxidative balance, and neuroplasticity therefore remains a promising research area. Future investigations should include objective physiological and neurobiological outcomes rather than relying exclusively on subjective measures of well-being.

TRANSLATIONAL MODEL: TOWARDS PERSONALISED BALNEOLOGICAL NEUROREHABILITATION

Advances in translational medicine enable the integration of biological, clinical, cognitive, and environmental data when developing personalised rehabilitation strategies. In PTSD, individual profiles may differ substantially in the degree of neuroinflammation, oxidative stress, neuroendocrine dysregulation, sleep disturbance, cognitive impairment, autonomic imbalance, and somatic burden.

Neurochemical differences may be particularly relevant. Research investigating serotonin, cortisol, noradrenaline, and IL-12 across chronicity and age in PTSD supports the concept that neurobiological profiles may vary according to patient characteristics and disease course [6]. Similarly, biomarker correlations involving IL-18, IRE1, pERK, ATF6, and emotional control suggest that biological and psychological dimensions may be meaningfully integrated [27].

Neuroimaging provides an additional layer of information. Positron emission tomography studies have identified a range of neuromarkers associated with PTSD [35], whilst neuroimaging research on fear extinction demonstrates distributed networks involved in contextual learning and fear regulation [13]. Brain-derived biotypes have consequently been proposed as a potential future approach to predicting fear-based disorders after trauma [14].

Within this translational framework, personalised balneological rehabilitation would not imply assigning a particular mineral bath to a specific biomarker. Instead, biological and clinical data could be used to identify dominant rehabilitation needs. A patient with severe sleep disturbance and hyperarousal may require a different programme from a patient whose principal difficulties are fatigue, pain, cognitive impairment, or reduced exercise tolerance.

An interdisciplinary approach is therefore essential. Psychiatrists, psychologists, balneologists, physiotherapists, rehabilitation specialists, and other clinicians should collaborate to integrate established PTSD treatment with supportive physical and environmental interventions. A proposed translational framework linking clinical profiles, biomarkers, and tailored balneological interventions is presented in Table 2.

CLINICAL IMPLICATIONS AND FUTURE DIRECTIONS

The integration of balneological interventions into psychiatric rehabilitation highlights the potential role of spa medicine as a complementary approach to stress-related disorders. In chronic PTSD, persistent autonomic dysregulation, sleep disturbances, fatigue, pain, somatic symptoms, and reduced physical functioning may remain clinically important even when patients receive conventional treatment.

Evidence from balneological studies suggests that stress, anxiety, and depressive symptoms may respond to spa-based interventions [28, 29]. Such findings may be relevant to PTSD rehabilitation because anxiety and depressive symptoms frequently contribute to reduced functioning, although the studies concerned do not establish efficacy specifically for PTSD.

Research in fibromyalgia also indicates that balneotherapy may reduce pain, disability, and depression [36]. Fibromyalgia differs substantially from PTSD, but this evidence is relevant to the rehabilitation of patients with a high somatic burden because it illustrates possible interactions between physical symptoms, disability, and emotional well-being.

The clinical use of balneological interventions nevertheless requires appropriate medical assessment. Psychiatric patients may have complex comorbidities and may receive medications associated with significant adverse effects. Reports concerning electroconvulsive therapy in the context of thyroid hormone imbalance illustrate the importance of considering endocrine and systemic factors during psychiatric treatment [37].

Rare but serious complications of antipsychotic therapy must also be recognised. Neuroleptic malignant syndrome has been reported after prolonged olanzapine exposure [38], and fever development during treatment with olanzapine and clozapine illustrates the need for appropriate differential diagnosis and urgent medical management [39]. Antipsychotic use has additionally been investigated as a risk factor for thromboembolism [40]. These publications do not relate directly to balneotherapy or PTSD, but they emphasise that psychiatric rehabilitation programmes must account for medication-related risks and physical comorbidity.

The same principle applies to psychiatric heterogeneity more broadly. Clinical presentations may include disturbances in emotional awareness [15], anxiety-related immune changes [19], behavioural addictions and mood instability [34], or neurological and functional symptoms [16]. A personalised rehabilitation model should therefore include comprehensive psychiatric, somatic, cognitive, and functional assessment rather than focusing exclusively on PTSD severity.

Future studies of spa-based rehabilitation in PTSD should employ well-designed randomised controlled methodologies. Treatment protocols should specify mineral composition where relevant, water temperature, duration and frequency of bathing, exercise intensity, climatotherapeutic exposure, environmental components, and total programme duration.

Outcome assessment should also be multidimensional. Clinical PTSD severity should be combined with measures of sleep, anxiety, depression, cognition, autonomic function, physical capacity, cortisol regulation, inflammatory markers, oxidative parameters, and, when feasible, neuroimaging outcomes.

Long-term follow-up is particularly important. The six-month follow-up included in recent multicentre balneotherapy research demonstrates the value of evaluating whether improvements persist beyond the immediate treatment period [29]. Similar longitudinal designs would be valuable in PTSD rehabilitation.

Future research should also investigate which patient subgroups are most likely to benefit. Neuromarker and brain-biotype approaches may ultimately contribute to stratification [14, 35], whilst inflammatory, oxidative, neuroendocrine, and neurotrophic markers may provide complementary biological information [6, 22, 25, 27].

The concept of precision balneology should therefore be considered a research framework rather than an established clinical standard. Its value lies in integrating individual biological and functional characteristics with carefully selected supportive interventions rather than assuming that spa therapy exerts uniform effects across all patients.

CONCLUSIONS

Trauma-related sensitisation of fear responses represents an important neurobiological mechanism contributing to the development and persistence of PTSD. Disturbances in limbic–prefrontal circuitry, impaired fear extinction, neuroendocrine dysregulation, neuroimmune activation, oxidative stress, sleep abnormalities, cognitive dysfunction, and altered neuroplasticity may interact to maintain emotional, physiological, and functional symptoms.

The available evidence indicates that biological markers may contribute to more comprehensive characterisation of individual neurobiological profiles. Immune-inflammatory, oxidative, neuroendocrine, and neurotrophic measures may eventually support patient stratification and monitoring, although their routine use for selecting specific rehabilitation interventions requires further validation.

Balneological interventions, including balneotherapy, hydrotherapy, climatotherapy, therapeutic exercise, and structured spa rehabilitation programmes, may complement conventional treatment by supporting stress regulation, sleep quality, physical functioning, autonomic balance, and general psychophysiological recovery. Evidence indicates effects on stress and cortisol [11, 12], anxiety and depressive symptoms [28, 29], sleep-related outcomes [17, 32, 33], and selected functional and somatic outcomes [30, 36].

Nevertheless, current evidence does not establish balneotherapy or spa-based rehabilitation as specific treatments for PTSD. Most available studies involve other clinical or stress-related populations. Their findings should therefore be interpreted as indirect evidence supporting further investigation rather than as proof of efficacy in PTSD.

The proposed translational framework integrates neurobiological mechanisms, clinical characteristics, biomarkers, functional assessment, and individual rehabilitation needs within a personalised balneological model. Such an approach may facilitate comprehensive rehabilitation addressing both psychological and physiological consequences of traumatic stress.

Future research should include well-designed randomised controlled trials specifically involving patients with PTSD, standardised balneological protocols, appropriate medical supervision, and objective assessment of clinical, autonomic, neuroendocrine, inflammatory, oxidative, cognitive, sleep-related, functional, and neuroimaging outcomes. Such studies are required to determine clinical effectiveness, identify appropriate patient subgroups, assess long-term safety and sustainability, and establish evidence-based recommendations for personalised balneological neurorehabilitation.

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CONFLICT OF INTEREST

The Author declares no conflict of interest

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REVIEW ARTICLE

Laser therapy in the rehabilitation of patients with hemophilia: a review of methods, recommendations, and clinical outcomes

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ABSTRACT
This literature review highlights the importance of comprehensive rehabilitation management in patients with hemophilia who experience joint and intramuscular hemorrhages. It also discusses the usefulness of physiotherapeutic interventions, particularly the potential application of laser therapy in patients with hemophilia. The review was based on an analysis of PubMed and Scopus databases concerning the planning and organization of comprehensive rehabilitation for patients with hemophilia, with particular consideration of multicenter studies with high methodological reliability. Properly conducted rehabilitation contributes to reducing the negative effects of hemophilic arthropathy. Laser therapy may be an effective rehabilitation method following both traumatic and spontaneous hemorrhages. This paper presents physiotherapeutic options for patients with hemophilia, taking into account rehabilitation procedures for both spontaneous and traumatic bleeding. Particular attention is paid to rehabilitation management in cases of joint and intramuscular hemorrhages. The presented approaches may support their broader implementation in clinical practice. Early targeted rehabilitation may help improve quality of life and shorten recovery time.

KEYWORDS: hemophilia, rehabilitation, physical therapy modalities, laser therapy, hemophilic arthropathy

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INTRODUCTION

Hemophilia is a congenital blood clotting disorder resulting from a deficiency of factor VIII (hemophilia A) or factor IX (hemophilia B), leading to recurrent bleeding, primarily into the joints and muscles [1]. Hemophilia is a hereditary disease that most commonly occurs in families with a history of the condition; however, it can also arise as a de novo mutation within a family. The most common type is hemophilia A [2], characterized by reduced or absent factor VIII activity. Although it is the most common form, it remains a rare bleeding disorder, with an estimated incidence of 1 in 10,000 live-born males. It is caused by various mutations in the factor VIII gene, located on the long arm of the X chromosome. The second type is hemophilia B – also known as Christmas disease – resulting from a deficiency or lack of activity of plasma factor IX. Clinical forms of hemophilia include: the mild form (factor VIII activity >5%), where patients typically experience bleeding only after major trauma or surgery, and joint bleeding occurs sporadically; the moderate form, characterized by factor activity levels between 1% and 5%, with infrequent bleeding episodes; and the severe form, defined by clotting factor levels below 1%, characterized by bleeding following even minor trauma as well as spontaneous bleeding.

SYMPTOMS AND CLINICAL PRESENTATION OF HEMOPHILIA

The most common symptom is bleeding, particularly into the joints and muscles. Bleeding most frequently occurs in large joints [3] – the knee, elbow, and ankle – although hemorrhagic episodes can also affect muscles and structures of the foot. It should be noted that bleeding in a person with hemophilia may become symptomatic even several days after an injury. Recurrent bleeding into tissues leads to the development of so-called hemophilic arthropathy, characterized by chronic pain, limited range of motion, muscle atrophy, and joint deformities; this significantly impairs patients' quality of life and poses a challenge for therapeutic teams. A hematoma can also affect muscle strength and lead to muscle shortening due to fibrosis [4]. The greatest risk to the patient is the occurrence of recurrent intra-articular bleeding, a hallmark symptom of severe hemophilia. Spontaneous or trauma-induced bleeding episodes in "target joints" result in joint damage known as hemophilic arthropathy [5, 6]. A lack of sufficiently rapid and targeted treatment, as well as rehabilitation, can contribute to articular cartilage damage and, consequently, even to bone demineralization. The primary treatment involves administering the missing clotting factor to the patient and implementing targeted, specialized rehabilitation [7].

PHYSIOTHERAPY

Physiotherapy plays a vital role in the comprehensive management of patients with hemophilia, complementing pharmacological therapy, prophylaxis, and the treatment of joint complications [8]. Appropriately selected kinesiotherapy and the use of modern physical therapy methods help reduce pain and improve joint range of motion and muscle function [9]. The primary goals of physiotherapy are to maintain musculoskeletal function, help prevent the consequences of joint bleeding and hemophilic arthropathy, and improve patients' quality of life [1, 3]. Quality of life in patients with hemophilia can be assessed using the EQ-5D-5L scale, which evaluates aspects such as mobility, self-care, usual activities, pain/discomfort, and anxiety/depression.

When rehabilitating patients with hemophilia, it is essential to tailor the physiotherapy program strictly to the stage of the disease, the patient's age, and their current hemostatic status. Current clinical guidelines recommend initiating physiotherapy as early as possible – following the very first bleeding episodes. Key principles include injury prevention, individualized loading, and close cooperation with a hematologist. It is crucial for the physiotherapist to possess the knowledge necessary to adjust the rehabilitation regimen according to current clotting factor levels [1, 8, 10].

PHYSIOTHERAPY DURING THE ACUTE PHASE FOLLOWING AN INTRA-ARTICULAR BLEED

Conservative interventions – rest, cooling, limb elevation, and joint immobilization – predominate during the acute phase of bleeding in patients with hemophilia. Once hemostatic stability is achieved, gradual mobilization is introduced, progressing from passive exercises to active-assisted and then active exercises [4, 8, 10]. Patients should be informed about rehabilitation options and encouraged – as soon as pain and swelling begin to subside – to shift the joint from a position of comfort to a functional position, gradually reducing flexion and aiming for full extension [11]. Whenever possible, patients should be taught to achieve this through active muscle contractions. Initially, gentle passive assistance may be used, with caution exercised if muscle inhibition or restriction is present [11]. Patients should be encouraged to engage in early active muscle control to minimize muscle atrophy and prevent chronic loss of joint mobility. Guidelines indicate that active exercises and proprioceptive training should continue until the pre-bleed range of motion and joint function are restored and symptoms of acute synovitis have resolved [11].

Kinesiotherapy aims to maintain or regain range of motion and to improve muscle strength and joint stability. Lobet et al. emphasize the importance of proprioception and neuromuscular control exercises, particularly for the ankle and knee joints, which are most frequently affected by hemophilic arthropathy. A personalized physiotherapy exercise program may contribute to pain reduction and improved stability and postural control in patients with hemophilia [8, 9].

Among physical therapy modalities, increasing importance is being attached to the use of laser therapy – both low-level and high-level – as an adjunct to the rehabilitation process [10]. Clinical studies confirm its biostimulatory, anti-inflammatory, and analgesic effects [5, 6]. Scipio del Campo et al. demonstrated the beneficial impact of low-level laser therapy on knee joint function in children with hemophilia, noting improvements in range of motion and a reduction in swelling [7]. Meanwhile, Elnaggar demonstrated the efficacy of a pulsed Nd:YAG laser in reducing pain and improving postural stability in children with hemophilic ankle arthropathy [12].

Kinesiotaping is another method that may support the treatment of patients with hemophilia. This method involves applying elastic, self-adhesive tape to the skin to support musculoskeletal function, reduce pain, and improve microcirculation and lymphatic drainage [13, 14, 15]. The mechanism of action relies on the gentle lifting of the epidermis, which reduces pressure on blood and lymphatic vessels, thereby facilitating the outflow of interstitial fluid and reducing edema [13]. Additionally, by stimulating sensory receptors, the method improves proprioception, motor coordination, and postural control [14]. Studies conducted by Kazanci et al. and Azab et al. indicate that kinesiotaping can be an effective adjunct to physiotherapy for children and adolescents with various medical conditions, particularly those involving pain, edema, or limited range of motion [13, 14]. In hemophilia, where frequent intra-articular bleeding leads to swelling, pain, and secondary arthropathy, kinesiotaping serves as a valuable tool in the rehabilitation process. Significant improvements in joint function and muscle strength, as well as pain reduction, have been observed in patients treated with kinesiotaping alongside standard physiotherapy. A positive impact of taping on proprioception and dynamic stability has also been noted [13]. Kinesiotaping also yields beneficial effects in the treatment of acute intramuscular hematomas in individuals with hemophilia; the method accelerates hematoma resorption and reduces tissue tension [15, 16].

Other physiotherapeutic approaches, including manual therapy, muscle-strengthening exercises, post-isometric relaxation, balance and proprioceptive training, as well as selected physical modalities, have also been used in patients with hemophilic arthropathy [17].

REHABILITATION FOLLOWING INTRAMUSCULAR BLEEDING

Intramuscular bleeding is one of the most common complications in patients with hemophilia, requiring both replacement therapy and appropriate physiotherapeutic management. According to guidelines by Srivastava et al. (2020), the rehabilitation process should proceed in stages, in close cooperation with a hematologist and while ensuring adequate clotting factor levels. During the acute phase (the first 24–48 hours), the goal is to stop the bleeding and prevent further damage. Rest and offloading of the affected muscle, limb elevation, and cautious application of cold therapy are recommended [11]. No manual

Table 1. Potential applications of laser therapy and selected rehabilitation methods for patients with hemophilia

Author	Publication	Physical modalities (laser therapy / others)	Kinesiotherapeutic methods	Duration / number of sessions	Clinical effects
K.Scipio del Campo, P.Łaguna, M. Brzewski, M. Matysiak [7]	Nowa Pediatria 3/2013, 91–96	– LLLT 830 nm, 140 mW, 1000 Hz, 2 J/point (analgesic) – LLLT 635 nm, 10 mW, 2 J/point (stage I: anti-edema) – LLLT 830 nm, 140 mW, continuous wave, 2 J/point (stage II: anti-edema)	Not used	10 treatments	Reduction of synovial membrane congestion, reduction of knee joint swelling
Ragab K. Elnaggar [12]	Lasers in Medical Science, 2020	High-energy Nd:YAG laser (pulsed), total dose 1500 J	Not used	3 times a week for 4 consecutive weeks	Pain reduction, improved postural control, and improved weight-bearing pattern
Scaturro D, Benedetti MG, et al. [18]	Medicine (Baltimore) 100(50), 2021	Low-level laser therapy	Low-load isotonic exercises; isometric exercises; concentric and eccentric exercises	20 sessions, 60 min	Pain reduction and improvement in joint health and functional independence
Zawilski J. et al. [17]	Acta Haematologica Polonica, 2017	Deep electromagnetic stimulation (Salus Talent); AlterG anti-gravity treadmill	Mobilization and manipulation techniques; post-isometric relaxation (PIR) exercises; proprioceptive and balance exercises; muscle-strengthening exercises	3 months	Reduced joint swelling, improved mobility, and reduced pain in target joints

Source: compiled by the authors of this study

interventions or exercises should be undertaken during this period until full hemostasis is achieved. In the early recovery phase, once pain has subsided and swelling has decreased, gentle isometric exercises for unaffected muscles and movements of adjacent joints may be introduced to prevent stiffness and contractures. Exercise intensity should be increased very cautiously, always during the period of clotting factor activity. During the muscle function restoration phase, active exercises in an offloaded position are implemented, followed by low-resistance exercises to rebuild strength, flexibility, and coordination. Subsequently, balance and proprioceptive exercises may be introduced to prepare the patient for a return to normal activity. In cases of extensive hematomas, drainage techniques may be cautiously introduced only after the acute symptoms have completely resolved. The guidelines emphasize that every physiotherapeutic intervention should be closely coordinated with clotting factor therapy, and the pace of rehabilitation progress should depend on the patient's clinical response. Premature or overly intense exercise can lead to recurrent bleeding, fibrosis, and loss of muscle function. Thus, the goal of physiotherapy following an intramuscular bleed is to safely restore muscle function and prevent atrophy, contractures, and secondary complications. Properly conducted, staged rehabilitation contributes to faster recovery and improved motor function and quality of life for patients with hemophilia [11].

REHABILITATION AS A PREVENTIVE MEASURE

An objective assessment of the joints is a crucial element of the rehabilitation process. For patients with hemophilia, the HJHS (Hemophilia Joint Health Score) – a global joint assessment tool – is a valuable instrument. The WFH Guidelines for the Management of Hemophilia (3rd edition, 2020) [11] identify the HJHS as the most thoroughly studied tool for physical assessment in both children and adults. It is recommended that the hemophilia care team include a physiotherapist responsible for assessing the patient's body structure and function, conducting a clinical joint evaluation, and designing an individualized rehabilitation program. Tailoring training and physical activity to the patient's clotting factor level is essential, as is knowledge regarding the prevention of hemophilic arthropathy. The physiotherapist should be knowledgeable about safe rehabilitation practices and conduct a detailed patient interview covering prior rehabilitation programs (if any), general physical fitness, bleeding frequency, and the severity of hemophilic arthropathy [11].'

AIM

The aim of this study was to assess the potential efficacy of laser therapy as an adjunct to rehabilitation in patients with hemophilia and to evaluate its role in the management of intra-articular and intramuscular bleeding.

MATERIALS AND METHODS

The study was based on an analysis of bibliographic databases, including PubMed and Scopus, concerning rehabilitation management, particularly the planning and implementation of rehabilitation protocols for patients with hemophilia A and B. Recommendations regarding rehabilitation management and treatment in patients with hemophilia A and B were also analyzed. Methods of systems analysis and bibliosemantic analysis were employed.

REVIEW AND DISCUSSION

This study highlights the value of rehabilitation – specifically laser therapy – in treating both spontaneous and traumatic bleeding. Incorporating physical therapy alongside clotting factor administration significantly aids in reducing hematomas and shortening recovery times. The use of low-level laser therapy (LLLT) in hemophilia management, particularly for spontaneous and traumatic bleeds, offers a promising alternative or adjunct to standard therapeutic methods. Study results demonstrate the therapy's high efficacy in alleviating clinical symptoms such as pain, swelling, and hematomas, as well as in improving joint function and accelerating recovery. Furthermore, available research indicates that LLLT can support pharmacological treatment, offering patients benefits such as a faster return to physical activity and reduced reliance on medication.

A study by Scipio del Campo et al. [7] provides solid evidence that a series of laser therapy sessions (10 sessions) reduces synovial congestion and swelling, leading to significant improvements in pain control. A reduction in inflammatory symptoms was also noted, which is particularly important in patients with hemophilia, where inflammatory processes and recurrent joint bleeding can lead to serious complications such as hemophilic arthropathy. Interestingly, the authors suggest that, for optimal therapeutic effects, the treatments should be performed in a series of 10–15 sessions, repeated every 2–3 weeks. This approach may increase the effectiveness of the therapy by minimizing the risk of symptom recurrence, a finding confirmed by studies conducted by other authors [7].

In the study by Ragab K. Elnaggar [12], which included children aged 8–16 years with hemophilia A and hemophilic ankle arthropathy, pulsed Nd:YAG laser therapy combined with a physical exercise program was associated with greater improvements in pain, selected measures of postural control, and weight-bearing pattern than placebo laser combined with the same exercise program. The active treatment was administered three times per week for four consecutive weeks, with a total energy of 1500 J.

Additionally, the studies by Mohamed A. Eid and Sobhy M. Aly indicate that laser therapy may be an important tool in the treatment of recurrent joint bleeding in children with hemophilia [19]. Compared to magnetic field therapy (PEMF), LLLT proved more effective, especially in the first weeks of treatment. After 6 weeks of therapy, patients treated with laser noticed significantly greater improvement in pain reduction, swelling, and increased range of joint mobility. It is worth noting that after 12 weeks of treatment, both methods (LLLT and PEMF) yielded benefits; however, the superiority of LLLT in short-term treatment supports its wider application in hemophilia therapy.

Nevertheless, despite promising results, further research is needed to more precisely define optimal treatment protocols (e.g., number of sessions, treatment frequency) and to fully understand the mechanisms by which laser therapy influences inflammatory and regenerative processes in patients with hemophilia. Studies involving larger cohorts are also required to confirm the reproducibility of the results and to evaluate the method's long-term efficacy. In summary, the findings indicate that low-level laser therapy (LLLT) can serve as an effective adjunct to traditional pharmacological treatment for hemophilia. Thanks to benefits such as pain reduction, decreased swelling, improved range of motion, and support for healing processes, LLLT can significantly contribute to enhancing patients' quality of life. This therapy shows particular potential for treating children with hemophilia, for whom recurrent joint bleeding is a primary source of complications. Future research aimed at optimizing this treatment could facilitate even broader clinical application of LLLT. It is also worth noting that reducing recovery times and potential hospital stays through targeted rehabilitation has positive implications for healthcare economics.

CONCLUSIONS

Prophylactic treatment in patients with hemophilia helps reduce the frequency of bleeding episodes, significantly improving their quality of life. Available rehabilitation methods, including laser therapy, may support functional recovery and reduce periods of immobilization. An appropriately selected laser therapy dosage may improve patient function and help reduce the adverse consequences of intramuscular and/or intra-articular bleeding. Laser therapy can serve as a complementary treatment method alongside clotting factor therapy.

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CONFLICT OF INTEREST
The Author declares no conflict of interest

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REVIEW ARTICLE

Non-pharmacological management of vestibular migraine: a systematic review of prospective studies on vestibular rehabilitation therapy

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ABSTRACT

Aim: Vestibular rehabilitation therapy (VRT) is recommended for vestibular migraine (VM); however, existing reviews include heterogeneous study designs, limiting the reliability of their conclusions. This systematic review evaluated the efficacy of VRT in adults with VM by restricting the analysis to prospective studies published between 2016 and 2026, with an exploratory consideration of its potential relevance to spa and health resort settings.

Materials and Methods: A systematic search of PubMed and the Cochrane Library was conducted for studies published from January 2016 to May 2026. Inclusion criteria comprised adults (≥18 years) with a diagnosis of VM according to the Bárány Society/International Headache Society criteria, prospective study design, VRT as the primary or adjunctive intervention, and reporting of at least one standardized outcome measure. Retrospective studies, case reports, and narrative reviews were excluded. Risk of bias was assessed using the Newcastle-Ottawa Scale.

Results: Two prospective studies meeting all inclusion criteria were identified, comprising 311 participants overall, including 58 patients with VM. Both studies demonstrated statistically significant improvements in Dizziness Handicap Inventory (DHI) scores following VRT ($p<0.001$). Significant improvements were also observed in balance confidence, gait stability, activities of daily living, headache impact, and psychological well-being. Clinical improvements were reported following VRT used both as monotherapy and in combination with pharmacological treatment.

Conclusions: Although based on a limited number of prospective studies, the available evidence suggests that VRT may reduce dizziness-related disability and improve quality of life in adults with VM. Future well-designed randomized controlled trials with standardized protocols, larger VM-specific cohorts, and long-term follow-up are urgently needed.

KEYWORDS: vestibular migraine, vestibular rehabilitation therapy, balance disorders, non-pharmacological treatment, systematic review

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INTRODUCTION

Vestibular migraine (VM) is currently recognized as the most common cause of recurrent spontaneous vertigo in adults and the second most frequent vestibular disorder encountered in specialized balance clinics, following benign paroxysmal positional vertigo (BPPV) [1, 2]. Its estimated prevalence in the general population reaches approximately 1–2.7%, with a marked female predominance (female-to-male ratio of approximately 5:1) [3, 4]. Despite its high prevalence, VM remains substantially underdiagnosed, largely due to the absence of pathognomonic signs or biomarkers and the considerable overlap of symptoms with other vestibular and headache disorders [5].

The diagnosis of VM is established according to the consensus criteria jointly developed by the Bárány Society and the International Headache Society (IHS), published in 2012 and revised in 2022, which require a minimum of five episodes of vestibular symptoms of moderate or severe intensity lasting between 5 minutes and 72 hours, in conjunction with a current or previous history of migraine and the presence of at least one migrainous feature during at least 50% of vestibular episodes [6, 7]. The clinical manifestations of VM are heterogeneous and may include spontaneous or positional vertigo, dizziness, imbalance, visual vertigo, phonophobia, photophobia, and aura, with or without concurrent headache [8]. Balance disorders, defined as the loss of control over maintaining the center of gravity above the support base, contribute significantly to functional disability and reduced quality of life, and may be effectively addressed through targeted physiotherapy interventions [9]. The episodic and unpredictable nature of attacks, combined with persistent interictal vestibular dysfunction in a subset of patients, contributes to significant impairment of daily functioning, reduced quality of life, and considerable psychological burden including anxiety and depression [5, 8].

The pharmacological management of VM remains largely extrapolated from migraine treatment guidelines, given the absence of VM-specific randomized controlled trials for most agents [10]. Abortive therapy with triptans and prophylactic regimens including beta-blockers, antidepressants, anticonvulsants, and more recently anti-CGRP monoclonal antibodies have been employed with variable efficacy [10]. Importantly, pharmacological treatment alone does not address the persistent vestibular dysfunction, motion sensitivity, and deconditioning that commonly develop in VM patients, particularly in those with frequent or prolonged episodes [2]. Vestibular rehabilitation therapy (VRT) is an exercise-based intervention grounded in the neuroplasticity mechanisms of the central vestibular system, encompassing habituation, adaptation, and sensory substitution [1, 3]. VRT has been established as an effective treatment for a broad spectrum of peripheral and central vestibular disorders, including vestibular neuritis, bilateral vestibular hypofunction, and post-surgical vestibular deficits [8]. In VM, VRT is hypothesized to reduce central sensitization to vestibular stimuli, improve gaze stability through vestibulo-ocular reflex adaptation, and enhance postural control through balance retraining [3]. Individualized home-based exercise programs, supervised by qualified physiotherapists and adjusted according to symptom progression, represent the current standard of delivery [8]. Despite growing interest in VRT as a non-pharmacological management option for VM, the evidence base remains limited and methodologically heterogeneous. Previous systematic reviews, including those by Alghadir and Anwer (2018) [8], El Ahdab et al. (2026) [11], and Sfakianaki et al. (2026) [12], have incorporated studies of varying design quality, including retrospective case series and uncontrolled observational studies, which carry a substantial risk of selection and measurement bias. The pooling of data from such heterogeneous sources limits the validity of conclusions regarding the true therapeutic effect of VRT in VM. The present systematic review addresses this methodological gap by restricting the analysis exclusively to prospective studies, thereby providing a more reliable assessment of the current evidence and more clearly delineating the research priorities required to establish definitive evidence-based recommendations for VRT in the management of VM.

AIM

The aim of this systematic review was to evaluate the efficacy of non-pharmacological vestibular rehabilitation therapy (VRT) in adults with vestibular migraine (VM), restricting the analysis exclusively to prospective studies published between 2016 and 2026, with exploratory consideration of its potential relevance to spa and health resort treatment settings, while acknowledging the current absence of direct evidence from such contexts.

MATERIALS AND METHODS

SEARCH STRATEGY

A systematic literature search was performed in two electronic databases: PubMed (MEDLINE) and the Cochrane Library (CENTRAL), covering the period from January 2016 to May 2026. The date restriction was applied to reflect evidence published following the widespread adoption of the Bárány Society/IHS diagnostic criteria for VM (originally published in 2012, updated in 2022), thereby ensuring diagnostic consistency across included studies [6, 7].

The following search string was applied: („vestibular migraine" OR „migraine-associated vertigo" OR „migrainous vertigo" OR „migraine-associated dizziness") AND („vestibular rehabilitation" OR „vestibular exercises" OR „balance rehabilitation" OR „habituation exercises" OR „vestibular physical therapy").

Additional records were identified through manual screening of reference lists of relevant systematic reviews and narrative reviews retrieved during the search.

INCLUSION CRITERIA

Studies were included if they met all of the following criteria:

1. Population: adult patients (≥18 years of age) with a diagnosis of VM established according to the Bárány Society/IHS criteria [6, 7] or the earlier Neuhauser criteria [13];
2. Intervention: VRT as the primary or adjunctive intervention, encompassing any combination of habituation exercises, adaptation exercises, gaze stability training, balance and gait retraining, or sensory substitution exercises;
3. Study design: prospective studies only, including prospective cohort studies, prospective comparative studies, and randomized controlled trials (RCTs);
4. Outcome measures: reporting of at least one standardized, validated outcome measure of vestibular function, dizziness-related disability, balance, or quality of life.

EXCLUSION CRITERIA

Studies were excluded if they were:

1. Retrospective in design (including retrospective chart reviews and retrospective case series);
2. Case reports or case series with fewer than 10 participants;
3. Narrative reviews, systematic reviews, or meta-analyses (used as background references only);
4. Non-English language publications;
5. Studies in which VM patients could not be distinguished from other diagnostic groups in the reported outcomes.

STUDY SELECTION

Title and abstract screening, followed by full-text assessment, was performed independently by both authors (K.K. and K.N.). Disagreements were resolved by discussion and consensus.

DATA EXTRACTION

Data were extracted independently by both authors using a standardized extraction form. The following variables were recorded for each included study: first author and year of publication; study design; country; sample size and demographic characteristics (age, sex); diagnostic criteria used for VM; duration of vestibular symptoms prior to enrolment; VRT protocol (type of exercises, duration, frequency, setting); comparator group (if applicable); outcome measures used; follow-up duration; and main results.

OUTCOME MEASURES

The primary outcome measure was the change in the Dizziness Handicap Inventory (DHI) score from baseline

Table 1. Characteristics of included studies

Characteristic	Sugaya et al. 2017	Koc & Cevizci Akkılıç 2022
Journal	Front Neurol	Braz J Otorhinolaryngol
Country	Japan	Turkey
Study design	Prospective comparative	Prospective comparative
Total N	251	60
VM group N	28	30
Mean age (years)	47.7 (SD 18.2)	VM: 46.1 (SD 13)
Sex (F/M)	195F/56M (total)	VM: 28F/2M
Diagnostic criteria	Bárány Society/IHS 2012	Bárány Society/IHS 2012
Duration of symptoms	NR	VM: mean 9.3 months
VRT protocol	5-day inpatient; VSR + VOR training; group 8–10 patients; 30 min/day	18 sessions; 3×/week; 1.5 months; individual + CDP-based; ~90 min/session
Setting	Inpatient	Outpatient
Comparator group	Dizziness without headache (n=144); tension-type headache (n=79)	Non-migraine vestibular dysfunction (n=30)
Primary outcomes	DHI, HIT-6, HADS	DHI, VADL
Secondary outcomes	CDP (centre of gravity)	CDP (SOT), dizziness frequency, headache frequency
Follow-up	Baseline, 1 month, 4 months	Baseline, post-treatment (1.5 months)
NOS score	7/9 (low risk of bias)	7/9 (low risk of bias)

Note: DHI - Dizziness Handicap Inventory; VADL - Vestibular Disorders Activities of Daily Living Scale; HIT-6 - Headache Impact Test; HADS - Hospital Anxiety and Depression Scale; CDP - Computerized Dynamic Posturography; SOT - Sensory Organization Test; VSR - vestibulo-spinal reflex; VOR - vestibulo-ocular reflex; NR - not reported.

Source: compiled by the authors of this study

to post-intervention. The DHI is a validated 25-item self--report questionnaire assessing the functional, emotional, and physical impact of dizziness, with a total score ranging from 0 to 100; higher scores indicate greater disability [14].

Secondary outcome measures included: the Activities--specific Balance Confidence Scale (ABC); the Dynamic Gait Index (DGI); the Vestibular Disorders Activities of Daily Living Scale (VADL); Computerized Dynamic Posturography (CDP); and measures of anxiety and depression using the Hospital Anxiety and Depression Scale (HADS).

RISK OF BIAS ASSESSMENT

The methodological quality of included studies was assessed using the Newcastle-Ottawa Scale (NOS), which evaluates selection, comparability, and outcome assessment domains (maximum score: 9 stars) [15].

DATA SYNTHESIS

Due to the limited number of eligible studies (n=2) and substantial heterogeneity in VRT protocols, comparator groups, and outcome reporting, a formal meta-analytic pooling of effect estimates was not performed. Results are presented as a narrative synthesis, with tabular summary of study characteristics and outcomes.

REVIEW

Search results and study selection

The systematic database search of PubMed and the Cochrane Library yielded 76 records in total (PubMed: n=41; Cochrane Library: n=35). Following removal of 15 duplicates, 61 titles and abstracts were screened. After full-text assessment of 26 potentially eligible studies, two prospective studies met all predefined inclusion criteria and were included in the final qualitative synthesis [1, 2]. The primary reasons for exclusion of full-text records were retrospective study design, inability to isolate VM patient outcomes from mixed vestibular disorder populations, and absence of standardized outcome measures.

Characteristics of included studies

The two included studies comprised a total of 311 participants, including 58 patients with VM. Table 1 presents the detailed characteristics of both studies.

Risk of bias assessment

Both included studies were prospective in design; however, neither was a randomized controlled trial. Koc and Cevizci Akkılıç (2022) is a prospective comparative study in which consecutive patients were enrolled and outcomes measured at pre-defined time points, fully meeting the inclusion criterion of prospective design. The primary methodological limitation is the absence of randomization and outcome assessor blinding, rather than any retrospective element. Neither study reported blinding of outcome assessors in relation to group allocation, and neither provided a formal sample size justification. The absence of an untreated control group in both studies represents the most significant methodological limitation, as it precludes definitive attribution of observed improvements to VRT rather than to spontaneous symptom resolution or regression to the mean. Detailed NOS scoring is presented

Table 2. Newcastle-Ottawa Scale (NOS) quality assessment of included studies

NOS Domain / Criterion	Sugaya et al. 2017	Koc & Cevizci Akkılıç 2022
SELECTION (max. 4 stars)		
1. Representativeness of exposed cohort	Yes	Yes
2. Selection of non-exposed cohort	Yes	Yes
3. Ascertainment of exposure (VRT protocol described)	Yes	Yes
4. Outcome not present at start*	Yes (baseline DHI scores documented for all groups prior to intervention)	Yes
COMPARABILITY (max. 2 stars)		
5. Comparability on key confounders (VM diagnosis criteria)	Yes	Yes
6. Comparability on additional factors (age, sex, symptom duration)	No (no randomization)	No (no randomization)
OUTCOME (max. 3 stars)		
7. Independent blind assessment of outcomes	No (no blinding)	No (no blinding)
8. Adequate follow-up length	Yes (4 months)	No (1.5 months only)
9. Adequacy of follow-up (dropout described)	Yes	Yes
TOTAL SCORE	**7/9**	**6/9**
Risk of bias classification	**Low**	**Moderate**

Note: Yes = criterion met (1 point); No = criterion not met (0 points).
NOS scoring: 7–9 stars = low risk; 4–6 = moderate risk; 0–3 = high risk of bias.
*Criterion 4 is interpreted as the availability of a documented baseline measurement of the primary outcome prior to intervention.

Source: compiled by the authors of this study

in Table 2. Sugaya et al. (2017) achieved a score of 7/9 (low risk of bias) and Koc and Cevizci Akkılıç (2022) a score of 6/9 (moderate risk of bias).

PRIMARY OUTCOME: DIZZINESS HANDICAP INVENTORY (DHI)

Both included studies reported statistically significant reductions in DHI scores following VRT in VM patients ($p<0.001$ in both cases). Koc and Cevizci Akkılıç (2022) reported a mean pre-treatment DHI score of 68.7 (SD 8.5) in the VM group, which decreased to 24.0 (SD 8.8) post-treatment, representing a mean reduction of 44.7 points. In the non-migraine vestibular dysfunction comparator group, DHI decreased from 67.7 (SD 19.5) to 30.3 (SD 23.0), a mean reduction of 37.4 points. The between-group difference in DHI improvement did not reach statistical significance ($p=0.881$), indicating comparable benefit from VRT regardless of migraine status [1]. Sugaya et al. (2017) reported a mean DHI improvement of 20 points in the VM group following 5-day inpatient VRT, equivalent to the improvement observed in the tension-type headache group and comparable to the non-headache dizziness group. Improvements were sustained at both the 1-month and 4-month follow-up assessments [2].

SECONDARY OUTCOMES

Vestibular Disorders Activities of Daily Living Scale (VADL)

Koc and Cevizci Akkılıç (2022) reported a statistically significant reduction in VADL scores in the VM group, from a mean of 99.5 (SD 10.7) at baseline to 37.5 (SD 8.6) post-treatment ($p<0.001$), indicating marked improvement in independence in daily living activities [1].

Computerized Dynamic Posturography (CDP) – Sensory Organization Test (SOT)

Koc and Cevizci Akkılıç (2022) demonstrated statistically significant post-treatment improvements across all six SOT conditions in the VM group, in both anteroposterior and mediolateral planes ($p<0.001$ for most conditions), with the exception of mediolateral vestibular and preferential scores. Post-treatment SOT results were higher than pre-treatment results in both patient groups [1].

Headache Impact Test (HIT-6) and psychological outcomes (HADS)

Sugaya et al. (2017) reported a mean improvement of 7 points on the HIT-6 in the VM group following VRT. Scores on the Hospital Anxiety and Depression Scale (HADS) improved by a mean of 3.02 points in the VM group, indicating a reduction in anxiety and depressive symptoms. These improvements were statistically significant [2].

Dizziness and headache frequency

Koc and Cevizci Akkılıç (2022) reported that the mean frequency of dizziness in the VM group decreased from 3 to 1 episode per month following VRT, and mean headache frequency decreased from 4 to 1 episode per month (both $p<0.05$) [1].

DISCUSSION

This systematic review evaluated the efficacy of vestibular rehabilitation therapy (VRT) in adults with vestibular migraine (VM), restricting the analysis exclusively to prospective studies published between 2016 and 2026. Two studies meeting all predefined inclusion criteria were identified, comprising 311 participants overall, including 58 patients with VM. Despite the limited number of eligible studies and the small VM-specific subgroups (n=28 in Sugaya et al. and n=30 in Koc et al.), the findings were consistent: VRT produced statistically significant improvements in dizziness-related disability, balance, daily living activities, headache impact, and psychological well-being in patients with VM. These results should, however, be interpreted with caution given the non-randomized design and limited sample sizes.

COMPARISON WITH EXISTING REVIEWS

The findings of the present review are broadly consistent with those of previous systematic reviews, while extending their conclusions through a more rigorous methodological framework. Alghadir and Anwer (2018) reviewed five studies investigating VRT in VM, including three retrospective case series, and concluded that the evidence for VRT efficacy was promising but inconclusive due to the absence of control groups and the predominance of retrospective designs [8]. The present review directly responds to this methodological concern by restricting inclusion to prospective evidence and confirms that even within this higher-quality subset, significant improvements were reported across the assessed outcome measures.

More recently, El Ahdab et al. (2026) conducted a systematic review and meta-analysis of available evidence on VRT in VM, searching MEDLINE, Embase, Cochrane Library, and Scopus up to March 2025, and reported significant improvements in patient-reported dizziness outcomes [11]. Similarly, Sfakianaki et al. (2026) analyzed eleven studies with 977 participants, encompassing six prospective, three retrospective, and two RCTs, and concluded that VRT is effective for managing dizziness, balance, and psychological outcomes in VM [12]. The present review complements these findings by demonstrating that the positive signal persists even when the analysis is restricted to prospective designs alone, thereby reducing the influence of retrospective bias on the overall conclusion.

MAGNITUDE OF CLINICAL BENEFIT

The magnitude of DHI improvement observed in both included studies warrants particular attention. Koc and Cevizci Akkılıç (2022) reported a mean DHI reduction of 44.7 points in the VM group following 18 sessions of VRT over 1.5 months [1]. Sugaya et al. (2017) reported a mean DHI improvement of 20 points following a 5-day inpatient VRT programme, sustained at 4-month follow-up [2]. Both reductions substantially exceeded values typically reported in mixed-design reviews, reflecting the real-world clinical relevance of structured, supervised VRT programmes in this population.

EFFECT OF MIGRAINE ON VRT OUTCOMES

A clinically important finding emerging from both included studies is that the presence of VM does not significantly impair the response to VRT compared with non-migraine vestibular dysfunction. Koc and Cevizci Akkılıç (2022) found no statistically significant difference in post-treatment DHI scores between the VM group and the non-migraine vestibular dysfunction group (p=0.881), despite patients with VM demonstrating a heightened subjective perception of disability at baseline [1]. This observation has direct clinical implications: the migraine diagnosis itself should not be considered a contraindication to VRT referral, nor should it lead clinicians to anticipate an inferior rehabilitation outcome. Rather, patients with VM may benefit from extended treatment duration and closer physiotherapeutic supervision, with particular attention to exercise adherence and psychological support, given the higher levels of anxiety and motion intolerance frequently reported in this population [3, 4].

VRT COMPONENTS AND DELIVERY MODELS

The two included studies employed markedly different VRT protocols, reflecting the broader lack of standardization in the field. Sugaya et al. (2017) utilized a brief, intensive, group-based inpatient programme focusing on vestibulo-spinal reflex (VSR) and vestibulo-ocular reflex (VOR) training over 5 consecutive days [2]. Koc and Cevizci Akkılıç (2022) applied an individualised outpatient programme combining computerized dynamic posturography (CDP)-based biofeedback with conventional VRT exercises delivered over 18 sessions across 1.5 months [1]. Despite these substantial differences in protocol design, setting, and duration, both studies reported clinical improvements following VRT. This heterogeneity, however, precludes direct comparison of outcomes and prevents identification of the optimal VRT protocol.

IMPACT ON HEADACHE AND PSYCHOLOGICAL OUTCOMES

An important and frequently underreported dimension of VRT in VM is its effect on headache frequency and psychological comorbidities. Sugaya et al. (2017) demonstrated that VRT not only reduced vestibular symptoms but also significantly attenuated headache impact (HIT-6 improvement of 7 points) and anxiety and depression scores (HADS improvement of 3.02 points) in patients with VM [2]. Koc and Cevizci Akkılıç (2022) reported a reduction in mean monthly headache frequency from 4 to 1 episode following VRT [1]. These findings support the role of VRT as a component of comprehensive, multimodal VM management rather than a purely vestibular intervention.

VRT IN THE CONTEXT OF MULTIMODAL VM MANAGEMENT

The present findings support the integration of VRT into multimodal VM management protocols alongside pharmacological prophylaxis. Almohammed et al. (2025) reviewed prophylactic pharmacological options for VM and highlighted the absence of VM-specific randomized controlled trial data for most agents [10]. Given this pharmacological evidence gap, VRT represents a particularly valuable non-pharmacological adjunct, especially in patients who do not respond adequately to or cannot tolerate prophylactic medications [1]. This position is further supported by the Cochrane review by Webster et al. (2023) on non-pharmacological interventions for VM prophylaxis, which identified VRT as a promising but insufficiently studied modality [16].

The potential role of VRT in the context of spa and balneological medicine warrants exploratory consideration, though it must be emphasized that no prospective study to date has evaluated VRT delivery in a spa or health resort setting. Vestibular migraine, with its characteristic episodic vertigo and persistent interictal imbalance, is among the neurological conditions that may be encountered in health resort settings, where patients seek comprehensive non-pharmacological management. Standardised assessment tools are also used to evaluate treatment outcomes in health resort rehabilitation, including subjective and objective measures such as VAS and algometry [17]. The structured and multidisciplinary environment of a spa centre could theoretically provide favourable conditions for VRT delivery; however, this hypothesis requires dedicated prospective investigation before any clinical recommendations can be made.

LIMITATIONS

The present systematic review has several important limitations. First, only two prospective studies met all inclusion criteria, limiting the breadth of the evidence base and precluding formal meta-analytic synthesis. Second, neither included study was a randomized controlled trial, and neither employed blinding of outcome assessors, introducing a risk of performance and detection bias. Third, the absence of untreated control groups in both studies means that observed improvements cannot be unequivocally attributed to VRT alone. Fourth, the heterogeneity of VRT protocols, outcome measures, and follow-up durations between the two studies prevents direct comparison of effect sizes. Fifth, the search was restricted to two databases and to English-language publications, which may have resulted in the omission of relevant studies indexed in other databases or published in other languages. Sixth, and importantly in the context of the present journal, neither of the two included studies was conducted in a spa or health resort setting: Sugaya et al. (2017) delivered VRT in a hospital-based inpatient programme in Japan, while Koc and Cevizci Akkılıç (2022) used an outpatient clinic model in Turkey. Direct prospective evidence for the efficacy of VRT delivered within balneological or spa settings is therefore still lacking and represents an important direction for future research.

CONCLUSIONS

This systematic review evaluated the efficacy of vestibular rehabilitation therapy (VRT) in adults with vestibular migraine (VM), applying a methodologically rigorous inclusion criterion by restricting the analysis exclusively to prospective studies. Despite the limited number of prospective studies and small VM-specific subgroups, the available evidence suggests a potential clinical benefit of VRT in this patient population, though definitive conclusions cannot be drawn.

Both included prospective studies demonstrated statistically significant improvements in dizziness-related disability, postural stability, daily living activities, headache frequency, and psychological well-being following structured VRT programmes. The magnitude of benefit in patients with VM was comparable to that observed in patients with non-migraine vestibular dysfunction, indicating that the presence of migraine does not preclude a favourable rehabilitation outcome. These findings suggest that VRT may be considered as a component of multimodal management protocols for VM, both as an adjunct to pharmacological prophylaxis and as an option for patients with insufficient response to medication, pending confirmation from adequately powered randomized controlled trials.

The present review identifies a critical gap in the evidence base: to date, no adequately powered, blinded randomized controlled trial specifically designed for patients with VM has been published. This represents the most important priority for future research in this field. Standardisation of VRT protocols, mandatory reporting of the Dizziness Handicap Inventory as a primary outcome measure, inclusion of active or sham control groups, and long-term follow-up of at least 6–12 months are essential requirements for future trials to generate definitive, guideline-level evidence.

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CONFLICT OF INTEREST
The Authors declare no conflict of interest

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REVIEW ARTICLE

The problem of organising the rehabilitation for patients with lower limb amputations due to mine-explosive trauma

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ABSTRACT

Aim: To analyse and summarise modern scientific research related to the problems of organising the rehabilitation of patients with lower limb amputations due to mine-explosive trauma.

Materials and Methods: To achieve this aim, we used the PubMed and Google Scholar databases to identify studies published between 2010 and 2025 related to the organisation of rehabilitation of patients with lower limb amputations due to mine-explosive trauma. A total of 68 sources were reviewed, and 30 were selected as containing relevant information directly related to this topic.

Conclusions: Currently, in Ukraine, clinical pathways for patients with amputations and criteria for the stages of medical and rehabilitation care have been developed, reflecting the current amendments to the Law of Ukraine "On Rehabilitation in the Healthcare Sector". The development and implementation of rehabilitation pathways for patients with lower limb amputations due to mine-explosive trauma are important for the effective organisation of the rehabilitation process. The use of these pathways will ensure consistency and continuity of rehabilitation and facilitate patients' return to an active life.

KEYWORDS: mine-explosive trauma, lower limb amputations, organisation of rehabilitation after amputations, route of a patient with an amputation, stages of rehabilitation in amputations

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INTRODUCTION

Modern approaches to the rehabilitation of patients with lower limb amputations involve the participation of a multidisciplinary team, which includes physical therapists, occupational therapists, physical and rehabilitation medicine physicians, prosthetists, psychologists, and social workers. Each specialist plays a crucial role in restoring the patient's functional capacity, thereby increasing their independence and overall quality of life. However, in the context of the full-scale war in Ukraine, the rehabilitation process has become much more complicated due to a shortage of qualified specialists, limited material, technical, and logistical resources, as well as a lack of adequate long-term rehabilitation and social integration programmes. This significantly affects patients' ability to return to an active life and participate fully in society.

The article examines the main problems and challenges faced by the rehabilitation system in Ukraine when providing care to patients with lower limb amputations resulting from mine-explosive trauma sustained on the battlefield. The main rehabilitation pathways for patients with amputations are also described, and promising areas for improving rehabilitation care and ways of integrating international experience into domestic practice are outlined.

AIM

The aim of this study was to analyse and summarise, based on scientific literature, modern research related to the problems of organising the rehabilitation of patients with lower limb amputations due to mine-explosive trauma (MET).

MATERIALS AND METHODS

The search for domestic and international scientific publications was conducted using the PubMed and Google Scholar databases for the period from 2010 to 2025. The methods of generalisation, comparative analysis, a system-structural approach, and analysis of logical relationships between the stages of rehabilitation were used. A total of 68 publications containing the following keywords were considered: "stages of rehabilitation of patients with MET", "rehabilitation pathways", "organisation of rehabilitation of patients with MET", and "problems of prosthetics after MET".

Of these, 30 publications were selected based on the following inclusion criteria: 1) publications containing an analysis of the organisation of rehabilitation care and clinical pathways for patients with lower limb amputations resulting from hostilities and MET; 2) regulatory legal acts of Ukraine governing the stages and conditions for the provision of rehabilitation services; and 3) studies on gait biomechanics, balance training, and prevention of comorbidities (e.g. hypermetabolic syndrome or obesity) in combatants. Publications addressing lower limb amputations due to diabetes mellitus and other non-military somatic vascular diseases were excluded from the analysis.

REVIEW AND DISCUSSION

EPIDEMIOLOGICAL CHARACTERISTICS AND SPECIFIC FEATURES OF COMBAT TRAUMA

Modern medical practice is faced with highly complex and specific types of injuries. One of the most common is mine-explosive trauma, which causes significant tissue damage and requires a multicomponent approach to treatment, often including reconstructive surgery or, in severe cases, limb amputation [1].

The problem of amputations remains a persistent issue worldwide. According to information published by C. L. MacDonald et al. in 2021, based on the Global Burden of Disease (GBD) programme, as of 2017, 57.7 million people worldwide were living with limb amputation due to traumatic causes, including falls (36.2%), road traffic accidents (15.7%), other transport injuries (11.2%), and mechanical forces (10.4%). The highest number of amputations occurred in East and South Asia [2].

Yudenko O. et al., in their study, highlight statistical data from various ministries and report that as of December 2023, more than 55,000 servicemen had received treatment and prosthetic care in Ukraine during the full-scale invasion of the Russian Federation. Almost the same number of service members were receiving rehabilitation assistance. Doctors state that today, 8 out of 10 cases are associated with severe and moderate injuries. These injuries have irreversible consequences for the health and quality of life of servicemen, including amputations due to mine-explosive and gunshot wounds and multiple traumatic shrapnel injuries affecting the soft tissues of the musculoskeletal system, nerves, lymphatic vessels, and blood vessels [3].

As of 2023, according to Olha Rudneva, head of the Superhumans rehabilitation centre for Ukrainian military amputees, 20,000 Ukrainians had suffered at least one amputation since the beginning of the war, most of them soldiers [4].

In a study on the causes of amputations in participants of the anti-terrorist operation/Joint Forces Operation (ATO/JFO), conducted by A. A. Bespalenko et al. (2020), the leading cause of amputation was also MET (78.4% of cases), which in 47% of cases was combined with acubarotrauma, in 41.2% with closed craniocerebral trauma, and in 84.3% with adaptation and depressive disorders. The absence of one limb due to amputation was observed in 84.3% of patients, double amputation in 13.7%, and triple amputation in 2.0% [5].

It is known that combat trauma can be accompanied not only by systemic inflammation but also by secondary toxic damage due to the absorption of tissue breakdown products, a neuroendocrine response, and a metabolic reaction, the so-called hypermetabolic syndrome. This is characterised by an increased metabolic rate accompanied by disturbances in carbohydrate metabolism (activation of glycogenolysis and gluconeogenesis, development of glucose intolerance, relative insulin insufficiency, and increased glucose levels), protein metabolism (decreased protein synthesis and increased protein breakdown), and lipid metabolism (increased lipolysis and inhibition of lipogenesis). Correlation analysis showed interrelationships between indicators of protein, lipid, and carbohydrate metabolism and the influence of metabolic disorders on the risk of developing secondary cardiovascular pathology in service members with combat trauma. These findings supported the hypothesis that hypermetabolic syndrome may act as a pathogenetic mechanism for the development of secondary internal organ pathology in this population and enabled the development of models for calculating the risk of secondary cardiovascular pathology. Based on this work, approaches to the primary and secondary prevention of cardiovascular diseases in combatants with combat trauma and a high risk of developing secondary pathology, depending on the time elapsed since the injury, were developed [6].

A study by Tavares K. et al. (2021) assessed obesity among combat-related amputees from 2003 to 2014 (a total of 1,233 medical records were analysed). According to this study, the prevalence of obesity among amputees is much higher than in the general population, which makes it possible to classify them as a risk group [7].

REGULATORY AND LEGAL REGULATION AND CLINICAL PATIENT PATHWAYS IN UKRAINE

The recovery process for a person with an amputation is complex and long-term. It involves a large number of specialists, including doctors, rehabilitation specialists, prosthetists, and social workers. The pathway for patients with amputations is as follows:

1. Amputation. Initially, all patients require surgical intervention. Provided that there are no additional complications, the recovery stage begins. Rehabilitation care is provided simultaneously with medical care. This period is called the acute period. Its main goal is to prevent complications.
2. Healing. After limb amputation, there is pronounced swelling of the stump and adjacent tissues. This is a normal reaction of the body to surgery. During this period, prevention of contractures (restriction of joint mobility) begins, and anti-oedema therapy is initiated, yielding results after a few weeks.
3. Pre-prosthetic rehabilitation. Once the scar has healed, pre-prosthetic rehabilitation begins with the involvement of a multidisciplinary rehabilitation team. This process involves key components: physical exercises to maintain joint range of motion, compression therapy (using an elastic bandage or a compression stocking), scar massage, stump hygiene, and management of phantom pain. During pre-prosthetic rehabilitation, a physical and rehabilitation medicine doctor or social worker should also provide the patient with comprehensive information about all manufacturers of rehabilitation aids and the necessary documents for obtaining a prosthesis. The choice of company is up to the patient. The list of prosthetic companies can be found on the website of the Ministry of Social Policy or on the relevant dashboard.
4. Prosthetics. A crucial stage in obtaining a prosthesis is the issuance of an appropriate conclusion. This can

be provided by a medical commission, a multidisciplinary rehabilitation team (MRT), or specialists from a medical and social expert commission. Such a document must take into account all the characteristics and needs of the patient and indicate the characteristics of the rehabilitation device. To submit documents for the provision of a prosthesis, patients can contact a social worker at the hospital, the Centre for Administrative Services, or the territorial department of the Fund for Social Protection of Persons with Disabilities.

5. Prosthetic rehabilitation. Once the prosthesis has been made, the stage of prosthetic rehabilitation and adaptation begins. The MRT, which includes a prosthetist, teaches the patient how to use the device, helps restore motor activity, and enables the patient to become accustomed to the prosthesis [8].

In Ukraine, a state programme provides free prostheses to civilians and combatants. To receive a prosthesis, documents can be submitted through the personal account of the Ministry of Social Policy, Family and Unity of Ukraine.

Each patient, depending on the severity of the injury, can receive between 2 and 8 rehabilitation cycles per year. Inpatient rehabilitation services should last at least 14 days, with procedures lasting three hours per day. Outpatient rehabilitation involves more than 14 days of intensive sessions, which should last more than one hour per day [9].

Today, in Ukraine, particular attention is paid to the rehabilitation of combatants. This is because the health of society is of national importance. Proper planning and operation of the rehabilitation system are crucial for addressing issues related to the comprehensive rehabilitation of military personnel. Therefore, a modern comprehensive approach to the rehabilitation of military personnel should be based on both a scientifically sound concept and state support [10].

In Ukraine, clinical pathways are formed in accordance with Order No. 197 of the Ministry of Health of Ukraine (MHU) dated February 15, 2021, and include the following rehabilitation periods:

1. The acute rehabilitation period is a rehabilitation period that begins from the moment of occurrence and/or detection of limitations in daily functioning due to the development of an acute health condition. During this period, the person receives medical care, and rehabilitation care begins.
2. The post-acute rehabilitation period begins when, according to the clinical protocol, a person no longer requires 24-hour care by a specialist for medical reasons or upon the initial diagnosis of a chronic health condition after the full range of diagnostic measures has been carried out in accordance with the clinical protocol and a disease (health condition) that causes or may lead to limitations in daily functioning has been diagnosed.
3. The long-term rehabilitation period begins when a limitation in daily functioning or a persistent limitation of vital activities is detected, or in the case of a progressive chronic disease requiring rehabilitation to achieve and maintain optimal functioning. High-volume rehabilitation care should be provided periodically to maintain optimal functioning [11].

The development of rehabilitation pathways for health conditions most commonly encountered during war (spinal cord and brain injuries, limb amputations, and complex skeletal injuries) is a key aspect of effective rehabilitation. These pathways take into account the criteria for patients' transition between acute, post-acute, and long-term rehabilitation periods, as well as the use of functional assessment tools [12].

Paragraph 12 of Section III, as amended by Order of the Ministry of Health No. 2194 of 02.12.2022, describes the following rehabilitation pathway for amputations:

- The acute rehabilitation period continues in specialised surgical departments of civilian healthcare institutions and healthcare institutions of the security and defence forces that provide rehabilitation care in inpatient settings and have the necessary conditions for delivering rehabilitation care during this period. Medical care is provided in accordance with industry standards. Nutritional support is provided. Rehabilitation and prevention of complications are initiated, including stump formation in the case of lower limb amputations.
- The post-acute rehabilitation period continues in inpatient departments of post-acute and long-term rehabilitation facilities within civilian healthcare institutions and healthcare institutions of the security and defence forces that provide rehabilitation care in inpatient settings during the post-acute rehabilitation period. Medical care is provided in accordance with the recommendations contained, for example, in the extract from the inpatient medical record (form 027/o) issued by the healthcare institution in which medical care was provided during the acute rehabilitation period.
- The long-term rehabilitation period continues in inpatient (rehabilitation) departments at the primary and complex levels of medical care within civilian healthcare institutions and healthcare institutions of the security and defence forces that provide rehabilitation care during the long-term rehabilitation period. Medical care is provided in accordance with existing chronic health conditions or other concomitant functional disorders. Rehabilitation is provided in accordance with the recommendations contained in the extract from the inpatient medical record (form No. 027/o) issued by the healthcare institution in which medical care was provided during the acute rehabilitation period [13].

The quality of rehabilitation of military personnel with lower limb amputations should be assessed comprehensively using criteria such as the availability of an inclusive rehabilitation environment in a healthcare facility, trained and qualified personnel, the necessary modern rehabilitation equipment, close cooperation with prosthetic providers with the future prospect of establishing such a unit within the facility, timely provision of prosthetic devices and other aids, maintenance of the required intensity of the rehabilitation process, timely development of an individual rehabilitation plan using the International Classification of Functioning, Disability and Health, and organisation of work within a multidisciplinary team [14].

Combatants constitute a special group of patients who require an individualised system of medical and rehabilitation measures. Therefore, the rehabilitation of military personnel is of national importance and is a crucial component of an effective healthcare system [10].

The presence of institutions involved in the rehabilitation of military personnel within the Armed Forces of Ukraine requires the establishment of systematic relationships between the responsible central government body and these institutions in order to create a functioning system. These systematic relationships should be established not only at the legislative level but also through social agreements on cooperation and collaboration. Information exchange is a key feature of goal-oriented systems. This would enable the Rehabilitation System to function as an integrated system that utilises the capabilities and advantages of each institution for the effective rehabilitation of military personnel [15].

At the same time, it should be noted that current legislation does not provide specific standards for organising rehabilitation activities for this category of military personnel, and rehabilitation methods for military personnel remain undeveloped and unapproved at the level of instructional documents (standards). Currently, this gap is addressed by methodological approaches developed by specialists in medicine and psychology, primarily within grant projects and implemented as experimental models of rehabilitation for military personnel in individual rehabilitation centres, often established with the support of public organisations and donors [16].

Today, the rehabilitation of combatants is a highly relevant topic because the health of this population directly affects society and its development. Combatants who require medical and psychological care constitute a special group of patients requiring an individualised approach to rehabilitation. Successful restoration of the health of military personnel is crucial for maintaining the combat readiness of the armed forces, reducing social tensions associated with the integration of veterans into society, and improving the overall health of the nation, which forms the foundation for economic and social development [17].

The Decree of the President of Ukraine provides for physical education and sports competitions and other rehabilitation activities for war veterans, their family members, and the families of deceased war veterans, with the involvement of local government bodies, public associations whose statutory activities are related to the rehabilitation of war veterans, institutions, organisations, and specialists providing rehabilitation and readaptation services [18].

FEATURES OF THE PRE-PROSTHETIC AND PROSTHETIC STAGES OF REHABILITATION

The rehabilitation process after traumatic lower limb amputation is divided into three main stages, each with its own tasks and characteristics:

1. Early postoperative period (1–7 days). At this stage, postoperative care is provided, with the primary goal of ensuring wound healing. Medical personnel monitor the patient's vital signs, administer medications that promote healing, and prevent infectious complications.
2. Late postoperative period (7–21 days). This stage involves further monitoring of the healing process and restoration of blood circulation and nerve conduction in the amputation area. Additionally, physiotherapy procedures are prescribed to help reduce swelling, strengthen muscles, and prevent muscle atrophy.
3. Recovery period (from 17–21 days to 10–12 weeks after surgery). The primary focus during this period is on restoring function and adapting to the use of the prosthesis. The patient performs exercises to improve mobility, balance, coordination, and muscle strength. Specialists select appropriate prosthetic equipment and teach the patient how to use it [12].

At the same time, Hutchenko K. and Hutchenko O. (2024) argue that, based on their analysis of the requirements for the national rehabilitation system for military personnel of the Armed Forces of Ukraine, these requirements do not meet the rehabilitation needs arising from the Russian-Ukrainian war [15].

Prosthetic rehabilitation presents particular challenges, necessitating collaboration among specialists from diverse fields within the MRT. Stable vertical balance is a crucial condition for the mobility of prosthesis users, and learning to maintain standing balance helps inform clinical decisions [19].

Examination and assessment of the patient's condition are essential components of the rehabilitation process, as they form the basis for setting goals and developing the patient's treatment plan. The main elements of examination after lower limb amputation are: interview and medical history; physical examination, including palpation, measurement of stump circumference and length, and assessment of sensitivity; application of scales and tests, including manual muscle testing, goniometry, the Berg Balance Scale, Tinel's test for the presence of neuroma, and the AMPnoPRO mobility assessment test; and additional examinations, including radiography, ultrasonography, and Doppler ultrasonography [20].

A multidisciplinary approach is the foundation of adequate rehabilitation and encompasses a combination of medical, physical, and psychological rehabilitation measures. The interdisciplinary rehabilitation team includes specialists who provide rehabilitation services. Its establishment in a rehabilitation institution is mandatory and is regulated by Article 18 of the Law of Ukraine "On Rehabilitation in the Healthcare Sector" [21].

A multidisciplinary approach is essential for both assessing the patient's condition and setting goals and objectives throughout the rehabilitation process. The members of the MRT in this case are a physical and rehabilitation medicine physician, a physical therapist, an occupational therapist, assistants, a prosthetist, and a psychologist. At this stage, the components of the prosthesis are selected, specifically the suspension system of the prosthetic socket, the level of foot functionality, and the knee joint in the case of transfemoral amputation; basic measurements of the stump are also taken. It is essential to consider the patient's physical capabilities, needs, expectations, and preferences and to assess the situation realistically when setting and pursuing rehabilitation goals [20].

A common complication after amputation is phantom pain in the area of the missing limb. Up to 80% of patients experience chronic phantom pain after amputation, which limits daily activities and reduces quality of life [22].

One of the latest systematic reviews, conducted by S. Ghai et al. (2024), also points to shortcomings in studies involving amputees. The authors primarily focused on analysing physical functioning in amputees (55.5% of articles). They noted insufficient assessment of the psychological and social aspects of patients (only 4.5% of articles). These authors emphasise the need to develop unified approaches to assessing such patients, which are currently lacking [23].

Bespalenko A. A. et al. (2020) investigated complications after lower limb amputation due to MET that hindered timely prosthetic fitting. Analysis of the main complications that occurred during the rehabilitation treatment of patients with amputations revealed that phantom pain was the most frequent, occurring in 57% of cases, followed by stump pain (41.2%), osteophytes (25.5%), joint contractures (11.8%), and heterotopic ossification (4%). Among concomitant conditions, the most common were acubarotrauma (47%), closed craniocerebral trauma (42.2%), internal organ injuries (13.7%), and traumatic eye injuries (15.6%) [5].

Balance control deficits are among the most common and severe mobility problems faced by people with lower limb loss. However, dynamic postural balance control among people with lower limb loss remains poorly understood [24].

Stelmakh et al. (2024), in their study on balance training during prosthetic rehabilitation, found that a significant improvement in the Barthel Index in the experimental group indicated that the additional use of exercises on a stability platform helped improve functional ability and made patients more independent in performing various activities of daily living, including dressing and hygiene activities. In contrast, patients in the control group performed such tasks less effectively [25].

In the early stages of the rehabilitation process, the patient lacks trust and confidence in the prosthesis; there is a false impression that it should not be loaded to the same extent as the unaffected limb. In addition, it is psychologically challenging for a person to load the postoperative area because it is associated with pain, the wound, and danger. However, temporary step asymmetry may also be related to other factors, such as the characteristics of the prosthetic components and the person's physical abilities [26].

Gait asymmetry is also a significant problem in patients with unilateral lower limb amputation. Calculating the symmetry of body weight distribution in patients with amputations is a valuable tool for assessing the functional aspects of lower limb prostheses and their impact on overall gait mechanics. The amputated lower limb should achieve a standing and walking pattern that approximates that of the unaffected limb to attain optimal function. Success depends on the effective and painless transfer of body weight through the stump to the prosthetic socket, as well as on optimal alignment of the prosthesis [27].

Similarly, in the absence of an evidence-based rehabilitation programme to correct or minimise pre-existing gait asymmetry, instrumental gait analysis assessing the biomechanical function of prosthetic devices may be more likely to quantify physical gait abnormalities that have developed due to habit or lack of training rather than device-specific features [28].

Sydorova N. M. et al. (2023) believe that current rehabilitation programmes for patients with amputations focus on prosthetic fitting and restoration of physical activity in daily life without taking into account the metabolic characteristics of these patients or the need to modify calculations of various indicators that account for the patient's body mass/area, etc. [29].

The war became a catalyst for the rapid development of medicine in Ukraine. Particular progress was achieved in reconstructive surgery, prosthetics, rehabilitation, plastic surgery, and ensuring access to medications. Today, Ukrainian doctors share their experience with foreign colleagues, as the knowledge and skills acquired while saving lives are of great importance and are unique [1].

Lytovchenko M. (2024) demonstrates in his study that adaptive sports have a positive impact on restoring patients' functional capabilities after serious injuries. The engagement of soldiers in adaptive sports is important for several reasons. First, it helps them physically recover and adapt to new limitations or disabilities that may arise due to injuries or other forms of impairment. Participation in sports helps strengthen muscles, improve movement coordination, and restore motor functions [30].

CONCLUSIONS

The organisation of rehabilitation for patients with lower limb amputations due to mine-explosive trauma remains a critical challenge for the Ukrainian healthcare system. In Ukraine, clinical pathways for the rehabilitation of patients who have undergone lower limb amputations due to mine-explosive trauma are in place and are being continuously improved. These pathways cover the main stages of care, from primary surgical care, surgery, postoperative care, and prosthetic fitting to the restoration of functional capabilities and return to an active life. Their implementation involves close cooperation among MRT specialists, including a physical and rehabilitation medicine physician, a physical therapist, an occupational therapist, a prosthetist, a psychologist, and a social worker. A standardised, patient-centred approach ensures consistency and continuity of the rehabilitation process. Additionally, it complies with the provisions of the Law of Ukraine "On Rehabilitation in the Healthcare Sector" (2020) and the Order of the Ministry of Health No. 197 of 15 February 2021 on the formation of clinical pathways for patients, as well as the amendments of 12 February 2022, No. 2194.

Existing state prosthetic programmes and regulatory rehabilitation periods provide the basis for a systematic approach; however, the key tasks of the rehabilitation system remain ensuring timely transitions between stages, high-quality interaction between specialists, and the availability of rehabilitation services. Further improvement of the system is possible through the development of unified protocols, the integration of modern evidence-based methods, and increased coordination between medical institutions.

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CONFLICT OF INTEREST
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