BALNEO RESEARCH Balneo and PRM Research Journal English Edition
e ISSN 2734 - 8458 p ISSN 2734 - 844X ROMANIAN ASSOCIATION OF BALNEOLOGY

Research article

Temporal Dynamics of Metabolic and Functional Adaptation Following Thalassotherapy in Dysmetabolic Patients

Mihaela Mihai [1], Liliana Sachelarie [2,*], Clara Ursescu [3,4] and Elena Costescu [5,*]

Citation: Mihai M., Sachelarie L., Ursescu C., Costescu E. - Temporal Dynamics of Metabolic and Functional Adaptation Following Thalassotherapy in Dysmetabolic Patients
Balneo and PRM Research Journal ***2026****, 17(1): 943*

Academic Editor(s):
Constantin Munteanu

Reviewer Officer:
Viorela Bembea

Production Officer:
Camil Filimon

Received: 17.01.2026
Published: 31.03.2026

Reviewers:
Sebastian Giuvara
Corina Sporea

Publisher's Note: Balneo and PRM Research Journal stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2026 by the authors. Submitted for open-access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1 Faculty of Medicine, University of Medicine and Pharmacy "Carol Davila", 050474 Bucharest, Romania; Corpore Sano Sanatorium Techirghiol, Romania.
2 Preclinical Sciences Department, Faculty of Medicine, Apollonia University of Iasi, 700511 Iasi, Romania;
3 "Carol Davila" University of Medicine and Pharmacy Bucharest, Doctoral School, Department of Rehabilitation Medicine, 37 Dionisie Lupu Street, area 2, Bucharest, 4192910;
4 University Emergency Central Military Hospital "Dr. Carol Davila", Department of Rehabilitation Medicine, 010825 Bucharest, Romania;
5 Faculty of Medicine, Apollonia University of Iasi, 700511 Iasi, Romania

* Correspondence: naturaone@gmail.com, lisachero@yahoo.com

Abstract: Dysmetabolic disorders cause ongoing metabolic, inflammatory, and functional problems that need flexible and comprehensive rehabilitation. Thalassotherapy has typically been studied for overall effectiveness, but there is limited information on when its benefits begin, how long they last, and which effects are transient versus lasting. This study aimed to track how metabolic, inflammatory, and functional changes develop over time following thalassotherapy in individuals with dysmetabolic conditions, rather than measuring outcomes at a single point. We conducted a longitudinal observational study of patients with dysmetabolism who participated in a structured thalassotherapy program. We measured metabolic, inflammatory, and functional outcomes at baseline (T0), immediately after the program (T1), and at follow-up (T2), where applicable. We used paired statistical tests to see how these measures changed over time and to distinguish early, delayed, and lasting effects ($p < 0.05$). Functional improvements were observed quickly after the program, whereas inflammatory markers changed in the short term but declined somewhat over time. HOMA-IR decreased by 11.7% at T1, p=0.02; functional mobility score improved by 13.4%, p<0.001. Metabolic changes took longer to develop but tended to last at follow-up. This pattern indicated that some benefits, such as improved function, appeared early but did not persist, whereas other metabolic changes were more stable. Thalassotherapy leads to changes in dysmetabolic patients that depend on timing and the type of effect, with early functional improvements, mixed inflammatory responses, and more lasting metabolic benefits. Examining when these effects occur, how long they persist, and which persist helps position thalassotherapy as a modern, evidence-based approach to metabolic rehabilitation.

Keywords: thalassotherapy, dysmetabolic patients, metabolic rehabilitation, temporal dynamics, functional adaptation, low-grade inflammation

1. Introduction

Dysmetabolic disorders, including insulin resistance, dyslipidemia, obesity, and metabolic syndrome, represent a significant and growing public health challenge worldwide. Early epidemiological and pathophysiological frameworks emphasized the role of energy imbalance and adiposity in metabolic dysfunction [1,2]. These foundational concepts were later expanded by studies demonstrating that dysmetabolism is not a static condition, but a chronic and dynamic process characterized by

low-grade systemic inflammation, neuroendocrine dysregulation, and progressive functional decline [3–5].

Traditional management strategies for patients with dysmetabolism have primarily focused on pharmacological treatment and lifestyle modification, including dietary interventions and structured physical activity [6,7]. Although these approaches can improve selected metabolic parameters, their long-term impact on functional capacity, inflammatory burden, and quality of life remains inconsistent [8,9]. Several authors have highlighted that conventional interventions often fail to address the multifactorial and adaptive nature of dysmetabolic disorders, particularly in patients with long-standing disease [10].

To address these gaps, rehabilitation medicine increasingly employs combined approaches that incorporate physical, environmental, and psychological elements [11]. Early studies on therapies such as balneology and climatotherapy found that natural settings could improve muscle and joint function, cardiovascular health, and overall well-being [12,13]. However, most of these studies examined only pre- and post-treatment changes and primarily focused on symptom relief, paying little attention to metabolic or inflammatory changes [14].

More recent research has revisited marine-based therapies, positioning thalassotherapy as a potentially valuable adjunct in the rehabilitation of chronic metabolic conditions [15,16]. Exposure to seawater, marine climate, and aquatic exercise has been associated with improvements in peripheral circulation, autonomic nervous system balance, and perceived functional status [17]. Emerging evidence also suggests that aquatic exercise and marine environments may favorably influence insulin sensitivity, lipid metabolism, and inflammatory pathways [18–20].

Even with these positive findings, most studies on thalassotherapy examine only whether it works overall, without distinguishing early, delayed, or lasting effects [21]. Importantly, a recurrent methodological limitation in the balneotherapy and thalassotherapy literature is the insufficient differentiation between immediate, short-term, and long-lasting therapeutic effects. Several reviews have highlighted that many studies report post-treatment improvements without adequately characterizing the temporal dynamics of response or providing extended follow-up data. Gutenbrunner et al. noted that variability in outcome timing and reporting remains a major obstacle for evidence synthesis in health resort medicine and balneology [22]. More recently, Antonelli and Donelli pointed out that the current body of thalassotherapy evidence is still limited by methodological inconsistencies, including inadequate longitudinal assessment of outcomes, underscoring the need for studies that clearly distinguish early, delayed, and persistent effects [1]. This is a significant drawback for people with dysmetabolic disorders, since changes in metabolism, inflammation, and function can happen at different times. While tracking outcomes over time is increasingly important in chronic disease rehabilitation research [22,23], it has not been studied sufficiently in thalassotherapy.

It is important to note that improvements in function, inflammation, and metabolism do not always occur simultaneously. Functional gains can appear quickly through changes in nerves and hormones, whereas metabolic changes usually take longer to stabilize, and inflammation may change only briefly or in unpredictable ways [24–26]. Ignoring these timing differences can impede a complete understanding of the effectiveness and durability of thalassotherapy.

Therefore, rather than focusing solely on whether thalassotherapy is effective, there is a critical need to clarify when therapeutic effects appear, how long they persist, and which components of the response are sustained and which are attenuated over time [27]. Addressing this gap allows thalassotherapy to be repositioned from a traditional balneological approach toward an evidence-informed component of modern metabolic rehabilitation.

In this context, the present study aims to characterize the temporal dynamics of clinical, metabolic, inflammatory, and functional responses to a structured thalassotherapy program in adults with dysmetabolic conditions. Rather than evaluating efficacy at a single endpoint, the study adopts a longitudinal perspective to distinguish early, transient, and sustained effects across outcome domains. By clarifying the timing and persistence of adaptations, this work seeks to refine the clinical positioning of thalassotherapy within modern metabolic rehabilitation and to provide evidence that may inform optimized scheduling, monitoring, and maintenance strategies for patients with dysmetabolic profiles. **2. Results**

Results are primarily presented as longitudinal within-group changes across predefined time points (T0–T1–T2) to characterize the temporal dynamics of response to thalassotherapy. Between-group comparisons with the standard rehabilitation cohort were used as supportive analyses to contextualize observed trends.

.2.1. Baseline Characteristics

Baseline demographic, clinical, metabolic, inflammatory, and functional characteristics of the study population are summarized in Table 1. No statistically significant differences were observed between the thalassotherapy and comparison groups at baseline, confirming the effectiveness of the matched-controlled design.

Table 1. Baseline Characteristics of the Study Population (T0)

Characteristic	Total cohort (n = 180)	Reference values
Age (years)	49.7 ± 11.0 (Mean ± SD)	
Sex (Male/Female)	94 (52.2%) / 86 (47.8%) (n, %)	
Body mass index (kg/m²)	31.6 ± 4.8 (Mean ± SD)	18.5 – 24.9 normal; ⩾30 obesity (WHO)
Waist circumference (cm)	102.7 ± 12.0 (Mean ± SD)	<102 men; <88 women (ATP-III)
Fasting glucose (mg/dL)	113.4 ± 19.1 (Mean ± SD)	<100 normal; 100–125 impaired
Fasting insulin (μIU/mL)	14.8 ± 6.2 (Mean ± SD)	~2–15 (laboratory dependent)
HOMA-IR	3.15 (2.45–4.30) (Median, IQR)	<2.5 normal insulin sensitivity
Total cholesterol (mg/dL)	214.6 ± 38.9 (Mean ± SD)	<200 desirable
Triglycerides (mg/dL)	178.2 ± 72.4 (Mean ± SD)	<150 normal
HDL cholesterol (mg/dL)	43.5 ± 9.6 (Mean ± SD)	⩾40 men; ⩾50 women
LDL cholesterol (mg/dL)	132.8 ± 34.1 (Mean ± SD)	<100 optimal
C-reactive protein (mg/L)	3.9 (2.2–6.6) (Median, IQR)	<1 low; 1–3 moderate; >3 elevated
Hypertension	79 (43.9%) (n, %)	⩾130/85 mmHg (ATP-III context)
Type 2 diabetes	60 (33.3%) (n, %)	Fasting glucose ⩾126 mg/dL
Reduced exercise tolerance	121 (67.2%) (n, %)	No universal reference (clinical)
Joint pain	108 (60.0%) (n, %)	No universal reference (clinical)

* Reference ranges based on WHO, NCEP ATP-III, and cardiovascular risk guidelines.

At baseline (T0), the study cohort consisted of 180 adults with dysmetabolic conditions, with a balanced sex distribution (52.2% males and 47.8% females) and a mean age of 49.7 ± 11.0 years (Table 1). Anthropometric measures indicated a predominantly overweight-to-obese population, with a mean body mass index of 31.6 ± 4.8 kg/m² and a mean waist circumference of 102.7 ± 12.0 cm. Metabolic profiling revealed impaired glucose regulation and insulin resistance, reflected by elevated fasting glucose levels (113.4 ± 19.1 mg/dL), increased fasting insulin concentrations (14.8 ± 6.2 μIU/mL), and a median HOMA-IR of 3.15 (IQR: 2.45–4.30). The lipid profile was atherogenic, with elevated total cholesterol (214.6 ± 38.9 mg/dL) and triglycerides (178.2 ± 72.4 mg/dL), and reduced HDL cholesterol (43.5 ± 9.6 mg/dL). Markers of

low-grade systemic inflammation were moderately elevated, with a median C-reactive protein level of 3.9 mg/L (IQR: 2.2–6.6). From a functional perspective, reduced exercise tolerance was present in 67.2% of participants, while joint pain was reported by 60.0%, indicating a clinically relevant degree of functional impairment at study entry.

Although a matched comparison group receiving standard rehabilitation care was included, the primary analytical focus of this study was on within-subject temporal changes following thalassotherapy, rather than on direct between-group superiority testing. The comparison group was used to contextualize observed changes and to control for non-specific rehabilitation effects.

2.2. Clinical Parameters (T0–T1)

Clinical parameters were analyzed to assess early physical adaptations following the intervention. Age and sex were treated as baseline descriptive variables only and were not included in longitudinal analyses.

Follow-up assessments (T2) were conducted 4 weeks after completion of the intervention to evaluate the short-term persistence of therapeutic effects for bouth groups.

Anthropometric measurements and blood pressure were evaluated longitudinally from baseline (T0) to immediately after the intervention (T1). Changes in these parameters are summarized in Table 2.

Between T0 and T1, modest but statistically significant reductions in body mass index and waist circumference were observed, indicating early changes in body composition. In parallel, both systolic and diastolic blood pressure values decreased significantly at T1 compared with baseline. These findings suggest an early clinical response to the rehabilitation program, reflected primarily by improvements in anthropometric indicators and blood pressure regulation.

No adverse clinical changes were observed during the intervention period.

Table 2. Clinical Parameters at T0 and T1

Clinical parameter	T0 (Baseline)	T1 (Post-intervention)	p-value
Body mass index (kg/m²)	31.6 ± 4.8	30.9 ± 4.6	0.01
Waist circumference (cm)	102.7 ± 12.0	99.8 ± 11.4	0.008
Systolic blood pressure (mmHg)	138.5 ± 14.2	131.6 ± 13.8	0.004
Diastolic blood pressure (mmHg)	86.9 ± 9.6	82.3 ± 9.1	0.006

As shown in Table 2, early clinical changes were observed between baseline (T0) and post-intervention (T1). Body mass index decreased significantly from 31.6 ± 4.8 kg/m² to 30.9 ± 4.6 kg/m² ($p = 0.01$), accompanied by a significant reduction in waist circumference (from 102.7 ± 12.0 cm to 99.8 ± 11.4 cm, $p = 0.008$). Blood pressure parameters also improved over the same period, with systolic blood pressure decreasing from 138.5 ± 14.2 mmHg to 131.6 ± 13.8 mmHg ($p = 0.004$) and diastolic blood pressure from 86.9 ± 9.6 mmHg to 82.3 ± 9.1 mmHg ($p = 0.006$). These findings indicate a measurable early clinical response to the intervention, primarily reflected by improvements in anthropometric measures and blood pressure regulation.

2.3. Metabolic Parameters (T0-T1)

Early metabolic changes observed between baseline (T0) and post-intervention (T1) are summarized in Table 3. Metabolic parameters were analyzed to assess short-term responses in glucose homeostasis and lipid metabolism.

Table 3. Metabolic Parameters at T0 and T1.

Metabolic parameter	T0 (Baseline)	T1 (Post-intervention)	p-value
Fasting glucose (mg/dL)	113.4 ± 19.1	108.2 ± 17.6	0.03
Fasting insulin (μIU/mL)	14.8 ± 6.2	13.2 ± 5.8	0.04
HOMA-IR	3.15 (2.45–4.30)	2.78 (2.10–3.85)	0.02
Total cholesterol (mg/dL)	214.6 ± 38.9	208.1 ± 36.7	0.09
Triglycerides (mg/dL)	178.2 ± 72.4	165.3 ± 68.1	0.07

Between T0 and T1, fasting plasma glucose levels showed a modest but statistically significant decrease, declining from 113.4 ± 19.1 mg/dL to 108.2 ± 17.6 mg/dL ($p = 0.03$). A similar pattern was observed for fasting insulin concentrations, which decreased from 14.8 ± 6.2 μIU/mL at baseline to 13.2 ± 5.8 μIU/mL at T1 ($p = 0.04$). Consequently, insulin resistance, assessed using the HOMA-IR index, was reduced at T1, with median values decreasing from 3.15 (IQR: 2.45–4.30) to 2.78 (IQR: 2.10–3.85) ($p = 0.02$).

In contrast, changes in lipid profile parameters were less pronounced over the early post-intervention period. Total cholesterol and triglyceride levels showed numerical reductions at T1; however, these changes did not reach statistical significance. This pattern suggests that early metabolic responses primarily involved glucose regulation and insulin sensitivity, whereas lipid metabolism exhibited slower or more variable short-term adaptation.

2.4. Inflamatory Parameters (T0-T1)

Early inflammatory responses to the intervention were assessed by analyzing changes in C-reactive protein levels between baseline (T0) and post-intervention (T1). Results are presented in Table 4. A statistically significant reduction in median C-reactive protein levels was observed following the intervention, decreasing from 3.9 mg/L (IQR: 2.2–6.6) at baseline to 2.8 mg/L (IQR: 1.6–4.9) at T1 ($p = 0.002$). This finding indicates a short-term attenuation of low-grade systemic inflammation immediately after completion of the rehabilitation program.

Table 4. Inflamatory Parameters at T0 and T1.

Inflamatory parameter	T0 (Baseline)	T1 (Post-intervention)	p-value
C-reactive protein (mg/L)	3.9 (2.2–6.6)	2.8 (1.6–4.9)	0.002

2.5. Functional Parameters (T0-T1)

Functional outcomes were analyzed to evaluate early rehabilitation-related responses following the intervention. Changes between baseline (T0) and immediately post-intervention (T1) are presented in Table 5. Marked improvements in functional status were observed shortly after completion of the intervention. The proportion of participants with reduced exercise tolerance decreased significantly from 67.2% at baseline to 45.6% at T1 ($p < 0.001$). Similarly, the prevalence of moderate-to-severe fatigue declined from 54.4% to 33.9% ($p < 0.001$), and reports of joint pain declined from 60.0% to 38.3% ($p < 0.001$).

Objective functional mobility also improved significantly over the same period, with mean functional mobility scores increasing from 63.4 ± 12.1 at T0 to 71.9 ± 11.3 at T1 ($p < 0.001$). These findings indicate that functional parameters respond early to the rehabilitation program, showing rapid, clinically relevant improvements immediately after the intervention.

Table 5. Functional Parameters at T0 and T1.

Functional parameter	T0 (Baseline)	T1 (Post-intervention)	p-value
Reduced exercise tolerance, n (%)	121 (67.2%)	82 (45.6%)	<0.001
Fatigue (moderate–severe), n (%)	98 (54.4%)	61 (33.9%)	<0.001
Joint pain, n (%)	108 (60.0%)	69 (38.3%)	<0.001
Functional mobility score	63.4 ± 12.1	71.9 ± 11.3	<0.001

2.6. Follow-Up Responses and Sustained Effects (T1–T2)

Follow-up assessments were conducted to evaluate the persistence or attenuation of the effects observed immediately after the intervention. Changes between post-intervention (T1) and follow-up (T2) are summarized in Table 6.

Anthropometric parameters remained relatively stable during follow-up. Body mass index and waist circumference values recorded at T1 were maintained mainly at T2, with no statistically significant changes, indicating partial persistence of early clinical adaptations.

Metabolic parameters also demonstrated sustained effects. Fasting glucose levels and insulin resistance, assessed by HOMA-IR, remained comparable between T1 and T2, suggesting that early improvements in glucose metabolism were preserved mainly over time.

In contrast, inflammatory and functional parameters exhibited distinct temporal patterns. Median C-reactive protein levels increased modestly at follow-up compared with T1 ($p = 0.03$), indicating partial attenuation of the early anti-inflammatory response. Similarly, the proportion of participants with reduced exercise tolerance and moderate-to-severe fatigue increased at T2, reflecting a partial loss of early functional gains. Joint pain showed a less pronounced rebound and did not change significantly between T1 and T2.

Overall, follow-up analyses indicate that metabolic and anthropometric adaptations were more likely to be sustained, whereas functional and inflammatory improvements tended to diminish over time, highlighting distinct temporal response patterns across outcome domains.

Table 6. Functional Parameters at T0 and T1.

Parameter	T0 (Baseline)	T1 (Post-intervention)	p-value
Body mass index (kg/m²)	30.9 ± 4.6	30.7 ± 4.7	0.28
Waist circumference (cm)	99.8 ± 11.4	100.2 ± 11.8	0.41
Fasting glucose (mg/dL)	108.2 ± 17.6	107.4 ± 18.1	0.62
HOMA-IR	2.78 (2.10–3.85)	2.81 (2.15–3.92)	0.74
C-reactive protein (mg/L)	2.8 (1.6–4.9)	3.2 (1.9–5.6)	0.03
Reduced exercise tolerance, n (%)	82 (45.6%)	97 (53.9%)	0.04
Fatigue (moderate–severe), n (%)	61 (33.9%)	74 (41.1%)	0.05
Joint pain, n (%)	69 (38.3%)	76 (42.2%)	0.21

3. Discussion

This study demonstrates that a structured thalassotherapy-based rehabilitation program produces rapid and clinically significant improvements, particularly in functional outcomes. Over a brief intervention period (T0–T1), participants exhibited substantial reductions in body mass index, waist circumference, and both systolic

and diastolic blood pressure, as well as notable improvements in exercise tolerance, fatigue, joint pain, and functional mobility.

These early functional improvements are consistent with previous research documenting rapid neuromuscular and cardiovascular adaptations following marine-based or aquatic rehabilitation programs [2,4,26-29]. Warm seawater immersion, in combination with buoyancy and reduced joint loading, promotes early gains in mobility and reduced perceived exertion, particularly among individuals with musculoskeletal limitations or metabolic comorbidities [29-32]. Furthermore, exposure to the marine environment—including thermal stimuli, mineral content, and coastal climate—has been linked to enhanced autonomic regulation and stress reduction, which may contribute to early decreases in blood pressure [1,7,18].

Age and sex were included solely as baseline descriptors and were not analyzed longitudinally. This approach supports the interpretation that the observed early changes are unlikely to be confounded by demographic variation and instead represent genuine effects of the intervention.

In addition to functional outcomes, the intervention produced early metabolic improvements, particularly in parameters related to glucose homeostasis. Significant reductions in fasting glucose, fasting insulin, and HOMA-IR were observed immediately post-intervention, indicating enhanced insulin sensitivity.

These results are consistent with previous evidence indicating that aquatic and marine-based therapies can influence glucose metabolism by increasing physical activity, enhancing peripheral circulation, and reducing systemic stress [4,26,27]. Although changes in lipid profiles were modest and did not achieve statistical significance during the early phase, this pattern aligns with prior reports that robust modifications in lipid metabolism generally require longer intervention durations [15,29,30].

The observed dissociation between early improvements in insulin resistance and slower lipid responses underscores the need for temporal stratification of outcomes. This methodological consideration is frequently neglected in thalassotherapy research but is explicitly addressed in the current study.

A significant reduction in C-reactive protein levels was observed at T1, indicating early attenuation of low-grade systemic inflammation. This anti-inflammatory effect aligns with previous studies demonstrating reduced inflammatory markers following balneotherapy, mud therapy, and marine-based interventions [17,31,32].

Multiple mechanisms may contribute to this response, including thermal effects, mineral absorption such as magnesium, and neuroendocrine modulation induced by warm seawater exposure [15,33,34]. However, follow-up analysis from T1 to T2 revealed a partial rebound of inflammatory markers, suggesting that anti-inflammatory effects are transient without continued intervention or lifestyle reinforcement.

This distinction between inducible and sustained biological effects of thalassotherapy supports the concept that inflammatory modulation requires repeated exposure or integration into long-term rehabilitation strategies.

A key strength of this study is the inclusion of follow-up assessments, which enables differentiation between effects that are maintained and those that attenuate over time. Anthropometric and metabolic parameters remained relatively stable between T1 and T2, indicating partial persistence of early improvements in body composition and glucose regulation.

In contrast, functional and inflammatory parameters exhibited partial regression at follow-up, as evidenced by increased fatigue, reduced exercise tolerance, and elevated CRP levels. Similar patterns have been reported in studies of climate therapy and rehabilitation, in which functional benefits decline after supervised intervention ceases [9,18,23]. These findings suggest that functional improvements are highly dependent on continued physical engagement and environmental exposure, while metabolic adaptations demonstrate greater resilience in the short- to medium-term.

Collectively, these findings support a domain-specific temporal response model. Functional and inflammatory outcomes respond rapidly but are more susceptible to attenuation. In contrast, metabolic and anthropometric adaptations demonstrate greater persistence. From a clinical perspective, these results indicate that thalassotherapy-based rehabilitation may serve as a catalyst intervention, rapidly improving functional capacity, reducing inflammatory burden, and initiating metabolic improvements in individuals with dysmetabolic conditions. The attenuation of specific effects at follow-up underscores the necessity for structured continuation strategies, such as maintenance exercise programs or repeated marine-based interventions.

Furthermore, the differentiated temporal response observed across outcome domains reinforces the importance of selecting appropriate endpoints and time points when evaluating complex rehabilitation interventions, since immediate post-intervention effects may not adequately reflect long-term efficacy.

Furthermore, the differentiated temporal response observed across outcome domains reinforces the importance of selecting appropriate endpoints and time points when evaluating complex rehabilitation interventions, since immediate post-intervention effects may not adequately reflect long-term efficacy.

Several limitations of the present study should be acknowledged. First, although the prospective matched-controlled design strengthens internal validity, the absence of complete randomization may limit causal inference. Second, follow-up assessments were conducted over a relatively short time frame, which restricts conclusions regarding long-term sustainability of the observed effects. In addition to the previously noted constraints, the results should be interpreted considering the potential influence of regression to the mean, the risk of type I error due to multiple testing across numerous endpoints, and some uncertainty regarding follow-up completeness, which may have affected the stability of longitudinal estimates. Although matching and standardized procedures were used to mitigate bias, residual confounding cannot be fully excluded in this pragmatic design.

The conclusions are consistent with the observed data and support the need for randomized controlled trials with longer follow-up. From a practical standpoint, future protocols should incorporate structured maintenance strategies—such as continued supervised exercise, periodic booster thalassotherapy sessions, or hybrid home-based programs—to help sustain early functional and anti-inflammatory gains and enhance long-term clinical benefit.

Third, functional outcomes were partially based on patient-reported measures, which may be subject to reporting bias, although objective mobility assessments were used to complement them. Additionally, inflammatory status was assessed using C-reactive protein alone, without inclusion of a broader cytokine profile that could provide more detailed mechanistic insight.

In the standard rehabilitation group, improvements were generally smaller and showed a more uniform, gradual pattern without the pronounced early functional surge and partial follow-up attenuation observed in the thalassotherapy group. This supports the interpretation that the domain-specific temporal dynamics identified in the present study are predominantly associated with the marine-based intervention rather than with conventional rehabilitation alone.

Finally, while the study population was well characterized, results may not be fully generalizable to other clinical settings or populations with different baseline metabolic or functional profiles. These limitations highlight the need for larger randomized trials with extended follow-up and more comprehensive biomarker assessment.

The study was not designed as a randomized superiority trial; therefore, findings should be interpreted in terms of temporal adaptation patterns rather than direct treatment superiority over standard rehabilitation care.

The observed domain-specific temporal response has important clinical implications for the management of dysmetabolic patients. The rapid functional gains seen

after thalassotherapy suggest that this intervention may be particularly useful as an early catalytic strategy to improve exercise tolerance, reduce fatigue, and enhance patient engagement in rehabilitation programs. At the same time, the partial attenuation of functional and inflammatory benefits at follow-up highlights the need for structured maintenance strategies, such as continued exercise, periodic marine-based programs, or hybrid rehabilitation models.

From a metabolic perspective, the relative persistence of improvements in insulin resistance and anthropometric parameters indicates that thalassotherapy may contribute to medium-term cardiometabolic risk modulation, even after the supervised program ends. Clinically, this supports integrating thalassotherapy into multimodal metabolic rehabilitation pathways, especially for patients with low baseline physical capacity or poor adherence to conventional exercise.

Overall, these findings suggest that thalassotherapy should be viewed not only as a symptomatic intervention but as a time-sensitive therapeutic component, whose maximal clinical benefit is achieved when followed by continuity-of-care measures designed to sustain early functional and anti-inflammatory gains.

4. Materials and Methods

2.1. Study Design

This prospective, non-randomized, matched-controlled cohort study was conducted over two years at the Corpore Sano Sanatorium, Techirghiol, Romania, to evaluate the clinical, metabolic, and inflammatory impact of thalassotherapy in patients with dysmetabolic conditions. The study was designed to assess not only overall efficacy, but also the temporal dynamics of metabolic and functional adaptation following a structured thalassotherapy-based rehabilitation program. The study received Institutional Ethics Committee approval (Approval No. 75 on 30.03.2024) and adhered to the ethical principles of the 2013 Declaration of Helsinki and the STROBE guidelines for observational research.

The study employed a prospective, non-randomized matched-controlled design due to organizational and ethical constraints inherent to spa-based rehabilitation programs, where patient allocation is often influenced by clinical indication, patient preference, and logistical availability of marine facilities. Random allocation to marine exposure was therefore not fully feasible in the real-world clinical setting.

To minimize potential selection and confounding bias, several methodological safeguards were implemented. Participants in the comparison group were matched a priori to the thalassotherapy group based on age, sex, baseline body mass index, and key metabolic parameters. Baseline comparability between groups was statistically verified. The intervention and control cohorts were treated within the same institution and time frame, under similar medical supervision, and pharmacological treatments were maintained unchanged throughout the study. Outcome assessments were performed using standardized protocols and predefined time points (T0–T1–T2), and multivariable or adjusted analyses were applied when residual imbalances were identified. These measures were intended to enhance internal validity despite the pragmatic non-randomized design.

A total of 180 adult patients aged 25-75 years were consecutively enrolled and prospectively followed. Eligible participants were diagnosed with dysmetabolic disorders, including insulin resistance, dyslipidemia, obesity, or metabolic syndrome, according to established clinical and biochemical criteria. Patients were allocated to study cohorts using a matched controlled approach, ensuring comparability with respect to age, sex, baseline metabolic status, and functional capacity.

The sample size (n = 180) was determined based on feasibility considerations and on expected changes in insulin resistance (HOMA-IR), selected a priori as a key metabolic endpoint. Assuming a moderate within-group effect size (Cohen's d ≈ 0.4–

0.5), an alpha level of 0.05, and a two-tailed paired comparison, a minimum of approximately 130–150 participants would provide 80% statistical power to detect clinically meaningful changes over time.

Potential lifestyle confounders were prospectively monitored during the study period. Participants in both groups received standardized lifestyle counseling at baseline and were instructed to maintain their usual diet and habitual physical activity outside the supervised rehabilitation sessions. No structured dietary intervention was introduced, and pharmacological treatments were kept unchanged throughout the study.

All clinical, metabolic, inflammatory, and functional assessments were performed by trained healthcare personnel (physicians, physiotherapists, and certified laboratory staff) who followed standardized operating procedures. Anthropometric and blood pressure measurements were obtained using calibrated medical equipment, and blood samples were analyzed in the same certified laboratory using validated biochemical assays.

Functional outcomes were evaluated using standardized and previously validated instruments appropriate for rehabilitation settings, and assessors received prior training to ensure uniform administration and scoring. Whenever possible, the same evaluator assessed the same participant across time points (T0–T1–T2) to reduce inter-rater variability. These measures were implemented to enhance measurement reliability and internal validity of the study.

Self-reported adherence to usual diet and daily physical activity was periodically checked during the intervention to identify major deviations. Because no systematic between-group differences were observed in these factors, and the study focused on within-subject temporal dynamics under stable background conditions, lifestyle variables were not included as primary covariates in the main models. Nevertheless, their potential residual influence cannot be fully excluded and should be considered when interpreting the findings.

With the final analyzed cohort of 180 participants, the study was adequately powered (>80%) to detect moderate longitudinal effects in primary metabolic and functional outcomes. Post-hoc power estimation based on the observed HOMA-IR change confirmed sufficient sensitivity of the sample to identify the reported effects.

Nevertheless, the study was not specifically powered for small between-group differences or subgroup analyses, and these results should be interpreted as exploratory in that context.

The intervention group underwent a structured thalassotherapy program integrated into a comprehensive rehabilitation framework, while the comparison group received standard rehabilitation care without marine-based interventions. The thalassotherapy protocol consisted of supervised exposure to seawater-based therapies, aquatic exercise, and controlled marine climate conditions, delivered over a predefined treatment period.

Standardization of marine climate exposure and aerosol inhalation

Exposure to the marine environment was protocolized to ensure consistency across participants. Controlled marine climate conditions were implemented through scheduled outdoor sessions conducted in the designated coastal therapeutic area of the sanatorium. Exposure was standardized by:

- fixed daily time window (morning, 08:00–10:00) to minimize circadian and thermal variability
- predefined duration (20–30 minutes/session)
- monitoring of ambient parameters (air temperature, humidity, wind speed) using the facility's meteorological station
- avoidance of sessions during adverse weather conditions (strong wind, rain, or extreme temperatures)

- similar light physical activity level during exposure (slow walking or breathing exercises)

Marine aerosol inhalation was delivered through supervised seaside breathing sessions performed at a standardized distance from the shoreline (≈50–100 m), where natural marine aerosol concentration is considered therapeutically relevant. The procedure was standardized by:

- guided diaphragmatic breathing protocol (slow nasal inspiration, prolonged oral expiration)
- fixed session duration (10–15 minutes within the climate exposure period)
- upright seated or relaxed standing posture
- supervision by rehabilitation staff to ensure technique compliance

No artificial aerosol generators were used; exposure relied exclusively on natural marine aerosol under controlled environmental conditions. Attendance and protocol adherence were recorded for all sessions.

Participants in the comparison group received a conventional land-based rehabilitation program delivered in the same institution and time frame as the thalassotherapy intervention, but without exposure to marine factors (seawater, marine climate, or aerosol therapy).

The program consisted of:

- Supervised therapeutic exercise (30–40 min/session), including aerobic conditioning, joint mobility, muscle strengthening, and stretching, individualized to functional capacity
- Standard physiotherapy modalities, applied as clinically indicated (e.g., electrotherapy for pain control and muscle relaxation)
- Education and lifestyle counseling, focusing on physical activity, weight management, and metabolic risk reduction
- Relaxation and recovery periods comparable in duration to the intervention group

Sessions were conducted once daily for 10–14 consecutive days, under physiotherapist supervision. Usual pharmacological treatments were maintained unchanged. No aquatic therapy, seawater exposure, or marine climatotherapy elements were included.

This standardized program allowed isolation of the specific contribution of thalassotherapy-related environmental factors.

Follow-up assessments (T2) were conducted 4 weeks after completion of the intervention to evaluate the short-term persistence of therapeutic effects for bouth groups.

Clinical, metabolic, inflammatory, and functional parameters were assessed at baseline (T0), immediately after completion of the intervention (T1), and, where applicable, at follow-up (T2), thereby enabling evaluation of early, delayed, and sustained responses.

Metabolic syndrome was defined according to the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP-III) criteria. Participants were classified as having metabolic syndrome when ≥3 of the following were present:

- Waist circumference ≥102 cm (men) or ≥88 cm (women)
- Triglycerides ≥150 mg/dL or specific treatment
- HDL-cholesterol <40 mg/dL (men) or <50 mg/dL (women)
- Blood pressure ≥130/85 mmHg or antihypertensive treatment
- Fasting plasma glucose ≥100 mg/dL or antidiabetic treatment

Insulin resistance was assessed using the homeostasis model assessment of insulin resistance (HOMA-IR) calculated as:

HOMA-IR = [fasting insulin (μIU/mL)×fasting glucose (mg/dL)] / 405

Insulin resistance was defined using the WHO-referenced threshold of HOMA-IR > 2.5, consistent with commonly accepted cut-offs in adult dysmetabolic populations.

Obesity and overweight were classified according to WHO BMI criteria:

- Normal weight: 18.5–24.9 kg/m²
- Overweight: 25.0–29.9 kg/m²
- Obesity: ≥30 kg/m²

Central adiposity was additionally evaluated using waist circumference thresholds recommended by ATP-III.

Low-grade systemic inflammation was defined as high-sensitivity C-reactive protein (hs-CRP) >3 mg/L, in line with cardiovascular risk stratification guidelines.

All biochemical measurements were performed after an overnight fast using standardized laboratory methods at the same certified laboratory throughout the study.

This longitudinal design enabled differentiation between transient and persistent adaptations across functional, inflammatory, and metabolic domains.

2.2. Participants and Eligibility Criteria

Adult patients were consecutively recruited from individuals referred for rehabilitation at the Corpore Sano Sanatorium, Techirghiol, Romania, during the study period. Eligibility criteria included age between 25 and 75 years and a documented diagnosis of a dysmetabolic disorder, such as insulin resistance, dyslipidemia, obesity, or metabolic syndrome, confirmed by established clinical and biochemical standards.

Inclusion criteria required participants to exhibit at least one dysmetabolic feature necessitating medical or rehabilitative intervention. These features included impaired glucose metabolism or insulin resistance, dyslipidemia managed by lifestyle modification or pharmacological treatment, elevated body mass index or central adiposity, or a clinical indication for structured rehabilitation due to reduced functional capacity.

Exclusion criteria included acute or uncontrolled cardiovascular disease, severe renal or hepatic impairment, active inflammatory or infectious conditions, malignant disease under active treatment, or known contraindications to aquatic therapy or marine exposure. Individuals unable to provide informed consent were also excluded.

Written informed consent was obtained from all participants before enrollment. Baseline clinical, metabolic, and functional characteristics were documented before allocation to study cohorts to ensure comparability between groups at study entry.

2.3. Thalassotherapy Intervention Protocol

The thalassotherapy intervention was implemented as part of a structured rehabilitation program in a marine environment. The protocol included daily supervised sessions that combined seawater-based balneotherapy using natural seawater at controlled temperatures, aquatic exercise therapy in seawater pools tailored to each participant's functional capacity, and structured exposure to the marine climate through controlled outdoor activities to enhance aerosol inhalation.

These therapeutic elements were supplemented by dedicated relaxation and recovery periods to support neuroendocrine regulation and physiological adaptation. Each session lasted approximately 60 to 90 minutes, with the intervention spanning 10 to 14 consecutive days, consistent with established marine-based and balneotherapeutic rehabilitation protocols described in the literature. Exercise intensity and exposure duration were individually adjusted based on functional capacity, clinical tolerance, and safety considerations to optimize adherence and minimize adverse effects. The thalassotherapy program was integrated with standard rehabilitation components, including supervised physical therapy and lifestyle counseling, and pre-existing pharmacological treatments were not modified during the intervention. Protocol compliance was monitored throughout the study.

This standardized intervention enabled the assessment of time-dependent functional, inflammatory, and metabolic responses, thereby facilitating the analysis of early and sustained adaptations following thalassotherapy.

2.4. Outcome Measures

The study evaluated clinical (age, sex, anthropometric measurements, and blood pressure) and metabolic (fasting glucose, insulin, HOMA-IR, and lipid profile), inflammatory (C-reactive protein), and functional (exercise tolerance, fatigue, joint pain, and functional mobility) parameters at predefined time points.

Clinical, metabolic, inflammatory, and functional outcomes were assessed to capture both early and time-dependent adaptations following the thalassotherapy intervention. All parameters were recorded at baseline (T0), immediately after completion of the intervention (T1), and at follow-up (T2), where applicable.

Clinical outcomes included anthropometric measurements and clinical characteristics relevant to dysmetabolic status, including body mass index, waist circumference, blood pressure, and comorbidities. Ongoing pharmacological treatments were documented and maintained unchanged throughout the intervention period.

Metabolic outcomes included fasting plasma glucose, fasting insulin, insulin resistance indices (e.g., homeostasis model assessment of insulin resistance [HOMA-IR]), and lipid profile parameters (e.g., total cholesterol, triglycerides, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol).

Inflammatory outcomes were assessed using markers of low-grade systemic inflammation, with C-reactive protein as the primary inflammatory biomarker. Where available, additional inflammatory mediators were recorded to further characterize inflammatory modulation over time.

Functional outcomes assessed rehabilitation-relevant adaptations and included measures of exercise tolerance, perceived fatigue, joint pain intensity, and overall functional mobility. These parameters were selected to reflect both rapid functional responses and their persistence or attenuation during follow-up.

Together, these outcome measures enabled a comprehensive evaluation of time-dependent, component-specific responses, allowing differentiation between early functional gains, transient inflammatory modulation, and more gradual metabolic adaptations following thalassotherapy.

2.5. Statistical Analysis

Data analysis was performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including means, standard deviations (SD), medians, interquartile ranges (IQR), and frequency distributions, were used to characterize the study population and to summarize baseline clinical, metabolic, inflammatory, and functional parameters.

Normality of continuous variables was assessed using the Shapiro–Wilk test and visual inspection of histograms and Q–Q plots, while homogeneity of variances was evaluated using Levene's test. Baseline comparability between the thalassotherapy and comparison groups was examined using independent-samples t-tests or Mann–Whitney U tests for continuous variables and Chi-square or Fisher's exact tests for categorical variables.

Within-group changes across time points (baseline, T0; post-intervention, T1; and follow-up, T2) were analyzed using repeated-measures ANOVA for normally distributed variables, with Greenhouse–Geisser correction applied when the assumption of sphericity was violated. For non-normally distributed variables, the Friedman test was used, followed by post hoc pairwise comparisons with appropriate multiple-testing adjustment. This approach enabled differentiation among the intervention's early, delayed, and sustained effects.

Between-group differences in temporal response patterns were assessed using mixed-design ANOVA models, with time as the within-subject factor and group (thalassotherapy vs. standard rehabilitation) as the between-subject factor. When baseline differences or potential confounders were identified, analysis of covariance (ANCOVA) models were applied, adjusting for relevant covariates, including age, sex, baseline body mass index, and baseline metabolic parameters.

Correlation analyses were performed to explore associations between time-dependent changes in functional, inflammatory, and metabolic outcomes, using Pearson's or Spearman's correlation coefficients, as appropriate. Missing data were evaluated descriptively, and analyses were conducted using available-case data given the limited and non-systematic nature of missingness. All statistical tests were two-tailed, and a p-value < 0.05 was considered statistically significant.

5. Conclusions

This prospective, matched-controlled study shows that a structured thalassotherapy-based rehabilitation program produces distinct, time-dependent effects in clinical, metabolic, inflammatory, and functional domains among adults with dysmetabolic conditions.

Early post-intervention assessments indicated rapid improvements in functional capacity, fatigue, joint pain, and blood pressure, along with modest but significant reductions in anthropometric measures and markers of insulin resistance. These results show that thalassotherapy can be an effective short-term intervention for enhancing physical performance and initiating beneficial metabolic adaptations.

Follow-up analyses showed that metabolic and anthropometric improvements were more likely to persist, while functional and inflammatory benefits diminished after the intervention ended. This variation highlights the need to differentiate between early and sustained effects when assessing complex rehabilitation strategies.

Clinically, these findings indicate that thalassotherapy-based rehabilitation may be a valuable adjunctive strategy for patients with dysmetabolic profiles, particularly for rapid functional improvement and reduction in inflammatory burden. However, the partial loss of benefits at follow-up suggests that ongoing physical activity or periodic re-exposure may be needed to sustain functional and anti-inflammatory improvements.

Future research should prioritize optimizing intervention duration, frequency, and long-term maintenance strategies, and investigate the mechanistic pathways underlying the observed domain-specific responses. Larger randomized trials with extended follow-up are needed to define further the role of thalassotherapy within integrated rehabilitation and metabolic health programs.

Author Contributions: Conceptualization, M.M. and L.S.; methodology, C.E.; software, L.S.; validation, M.M.; formal analysis, E.C.; investigation, M.M.; resources, M.M.; data curation, L.S.; writing—original draft preparation, L.S.; writing—review and editing, E.C.; visualization, M.M.; supervision, E.C.; project administration, M.M.; funding acquisition, M.M.. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and the STROBE guidelines for observational research and approved by the Ethics Committee of Corpore Sano Sanatorium Techirghiol, Romania (protocol code 75/30.03.2024) for studies involving humans.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Antonelli, M.; Donelli, D. A narrative review of thalassotherapy and the health benefits of seawater and coastal climates. Int. J. Biometeorol. 2024, 69, 517–526. doi:10.1007/s00484-024-02840-0.
2. Chennaoui, M.; Gomez-Merino, D.; Van Beers, P.; Guillard, M.; Drogou, C.; Lagarde, D.; et al. Benefits of thalassotherapy with sleep management on mood states and well-being, and cognitive and physical capacities in healthy workers. J. Sleep Disord. Ther. 2018, 7, 5.

3. Lucchetta, M.C.; Monaco, G.; Valenzi, V.I.; Russo, M.V.; Campanella, J.; Nocchi, S.; et al. The historical-scientific foundations of thalassotherapy: State of the art. Clin. Ter. 2007, 158, 533–541.
4. Morer, C.; Michan-Doña, A.; Alvarez-Badillo, A.; Zuluaga, P.; Maraver, F. Evaluation of the feasibility of a two-week course of aquatic therapy and thalassotherapy in a mild post-stroke population. Int. J. Environ. Res. Public Health 2020, 17, 8163. doi:10.3390/ijerph17218163.
5. Maraver, F.; Michán, A.; Morer, C.; Aguilera, L. Is thalassotherapy simply a type of climatotherapy? Int. J. Biometeorol. 2011, 55, 107–108.
6. Popescu, C.; Onose, G.; Vlădulescu-Trandafir, A.I.; Leanca, M.C.; Neagu, S.G.; Munteanu, C. Exercise-induced hydrogen sulfide biosignaling functional relevance for rehabilitation and balneotherapy – study protocol. Balneo PRM Res. J. 2025, 16(4), 939. doi:10.12680/balneo.2025.939.
7. Jimenez, M.P.; DeVille, N.V.; Elliott, E.G.; Schiff, J.E.; Wilt, G.E.; Hart, J.E.; et al. Associations between nature exposure and health: A review of the evidence. Int. J. Environ. Res. Public Health 2021, 18, 4790. doi:10.3390/ijerph18094790.
8. Cohen, A.D.; Van-Dijk, D.; Naggan, L.; Vardy, D.A. Effectiveness of climatotherapy at the Dead Sea for psoriasis vulgaris. J. Dermatolog. Treat. 2005, 16, 308–313.
9. Wahl, A.K.; Langeland, E.; Larsen, M.H.; Robinson, H.S.; Osborne, R.H.; Krogstad, A.-L. Positive changes in self-management and disease severity following climate therapy in people with psoriasis. Acta Derm. Venereol. 2015, 95, 317–321. doi:10.2340/00015555-1926.
10. Ben-Amitai, D.; David, M. Climatotherapy at the Dead Sea for pediatric-onset psoriasis vulgaris. Pediatr. Dermatol. 2009, 26, 103–104.
11. Nissen, J.B.; Avrach, W.W.; Hansen, E.S.; Stengaard-Pedersen, K.; Kragballe, K. Increased levels of enkephalin following natural sunlight combined with salt water bathing. Br. J. Dermatol. 1998, 139, 1012–1019.
12. Cohen, A.D.; Shapiro, J.; Michael, D.; Hodak, E.; Van-Dijk, D.; Naggan, L.; et al. Outcome of short-term Dead Sea climatotherapy for psoriasis. Acta Derm. Venereol. 2008, 88, 90–91.
13. Harari, M.; Novack, L.; Barth, J.; David, M.; Friger, M.; Moses, S.W. PASI 75 achievement and remission time after Dead Sea climatotherapy. Int. J. Dermatol. 2007, 46, 1087–1091. doi:10.1111/j.1365-4632.2007.03319.x.
14. Proksch, E.; Nissen, H.-P.; Bremgartner, M.; Urquhart, C. Bathing in a magnesium-rich Dead Sea salt solution improves skin barrier function. Int. J. Dermatol. 2005, 44, 151–157. doi:10.1111/j.1365-4632.2004.02214.x.
15. Marsakova, A.; Kudish, A.; Gkalpakiotis, S.; Jahn, I.; Arenberger, P.; Harari, M. Dead Sea climatotherapy versus topical steroid treatment for atopic dermatitis children. J. Dermatolog. Treat. 2020, 31, 711–715. doi:10.1080/09546634.2019.1602360.
16. Czarnowicki, T.; Harari, M.; Ruzicka, T.; Ingber, A. Dead Sea climatotherapy for vitiligo. J. Eur. Acad. Dermatol. Venereol. 2011, 25, 959–963. doi:10.1111/j.1468-3083.2010.03892.x.
17. Staalesen Strumse, Y.A.; Nordvåg, B.-Y.; Stanghelle, J.K.; Røisland, M.; Winther, A.; Pajunen, P.-A.; et al. Rehabilitation in Mediterranean versus Norwegian climate settings. J. Rehabil. Med. 2011, 43, 534–542. doi:10.2340/16501977-0819.
18. Ferrara, E.; Santoro, C.; Giannelli, G.; et al. Emerging evidence on balneotherapy and thermal therapy in post-COVID-19 syndrome. Healthcare 2025, 13, 96. doi:10.3390/healthcare13010096.
19. Mourelle, M.L.; Gómez, C.P.; Legido, J.L. Marine microalgae and cyanobacteria in cosmetics and thalassotherapy. Cosmetics 2017, 4, 46.
20. Pereira, L. Thalassotherapy and marine cosmeceuticals. In Therapeutic and Nutritional Uses of Algae; CRC Press: Boca Raton, FL, USA, 2017; pp. 503–522.
21. Pereira, L. Seaweeds as a source of bioactive substances and skin care therapy. Cosmetics 2018, 5, 68. doi:10.3390/cosmetics5040068.
22. Gutenbrunner, C.; Bender, T.; Cantista, P.; Karagülle, Z. Definition of health resort medicine and balneology. Int. J. Biometeorol. 2010, 54, 495–507. doi:10.1007/s00484-010-0323-5.
23. Gomes, C.S.F.; Fernandes, J.V.; Fernandes, F.V.; Silva, J.B.P. Salt mineral water and thalassotherapy. In Minerals Latu Sensu and Human Health; Springer: Cham, Switzerland, 2021; pp. 631–656.
24. Munteanu, C.; Popescu, C.; Ciobanu, V.; Onose, G. Biosignals and motion-derived outcomes in balneotherapy and physical and rehabilitation medicine (PRM). Balneo PRM Res. J. 2025, 16(3), 885. doi:10.12680/balneo.2025.885.
25. De Andrade, S.C.; de Carvalho, R.F.P.P.; Soares, A.S.; et al. Thalassotherapy for fibromyalgia: A randomized controlled trial. Rheumatol. Int. 2008, 29, 147–152. doi:10.1007/s00296-008-0659-8.
26. Kim, N.-I.; Kim, S.-J.; Jang, J.-H.; et al. Changes in fatigue recovery after deep-sea water thalassotherapy. Appl. Sci. 2020, 10, 8383. doi:10.3390/app10238383.
27. Cegolon, L.; Larese Filon, F.; Mastrangelo, G. Seawater pools versus freshwater pools for inflammatory conditions. Water 2024, 16, 3650. doi:10.3390/w16243650.
28. Bender, T.; Karagülle, Z.; Bálint, G.P.; Gutenbrunner, C.; Bálint, P.V. Hydrotherapy, balneotherapy, and spa treatment in pain management. Rheumatol. Int. 2005, 25, 220–224.
29. Gálvez, I.; Torres-Piles, S.; Ortega, E. Effect of mud-bath therapy on inflammatory responses in osteoarthritis. Int. J. Biometeorol. 2020, 64, 927–935. doi:10.1007/s00484-020-01874-7.

30. Costescu, E.; Ciuhodaru, T.; Călin, G.; Mihai, C.; Grierosu, C.; Damir, D.L. Non-invasive neuromodulatory therapies applied in trigeminal neuralgia. Balneo PRM Res. J. 2024, 15, 2. doi:10.12680/balneo.2024.705.
31. Becker, B.E.; Hildenbrand, K.K.; Whitcomb, R.K.; Sanders, J.P. Biophysiologic effects of warm water immersion. Int. J. Aquat. Res. Educ. 2009, 3, 24–37. doi:10.25035/ijare.03.01.05.
32. Costescu, E.; Călin, G.; Tîrlea, V.; Țabrean, M.C. Non-invasive physiotherapeutic approaches in biliary dyskinesia. Balneo PRM Res. J. 2024, 15, 4. doi:10.12680/balneo.2024.749.
33. Skurvydas, A.; Kamandulis, S.; Stanislovaitis, A.; et al. Warm water immersion and exercise-induced muscle damage. J. Athl. Train. 2008, 43, 592–599. doi:10.4085/1062-6050-43.6.592.
34. Almeida, L.; Rocha, F.; Candeias, C. Pelotherapy, thalassotherapy, and electrotherapy for skin treatment. Int. J. Biometeorol. 2025, in press.