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ORIGINAL RESEARCH

Sleep Quality and Quality of Life in Older Patients with Hypertension after Night-Time Hot Spring Bathing: A Single-Institution Intervention Study

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Abstract
Habitual night-time hot spring bathing, which is practiced to improve sleep disorders, is inversely associated with hypertension in adults aged ≥ 65 years. This study aimed to explore a nondrug intervention for insomnia by evaluating the effects of night-time hot spring bathing on sleep quality and quality of life (QOL) in older patients with hypertension. This prospective study evaluated the effects of night-time hot spring bathing on patients with primary hypertension ($n = 28$) aged 65 years or older (Japan Registry of Clinical Trials registration number: UMIN000051274). Between July 1, 2023, and February 29, 2024, participants were invited to a 1- to 3-day sleep promotion experience at our institute, which included night-time hot spring bathing and education on exercise and diet. Participants were encouraged to continue sleep-promoting activities during a 3-month follow-up period; sleep quality and QOL questionnaires were completed at 1 and 3 months post-intervention. There was a significant improvement in sleep quality according to the Pittsburgh Sleep Quality Index ($p < 0.001$). Patients also reported significantly improved QOL according to the SF-36® 1-month post-intervention and a significant improvement in mental health at both 1 and 3 months post-intervention ($p = 0.013$). Night-time hot spring bathing was significantly associated with improved sleep quality in older hypertensive patients. Prospective randomized controlled trials are needed to investigate whether night-time hot spring bathing can prevent diseases associated with sleep disorders in older adults, such as hypertension.

Keywords Hypertension · Hot spring bathing · Night-time · Sleep · Quality of life

Extended author information available on the last page of the article

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Introduction

Lifestyle habits such as sleep, diet, exercise, stress, alcohol, and smoking are the most common causes of hypertension (Carnethon et al., 2010; Forman et al., 2009; He et al., 2013; Tai et al., 2019; Whelton et al., 2018). Uncontrolled hypertension can lead to cardiovascular and kidney disease; therefore, the goal of hypertension treatment is to prevent these complications. Current treatments include both pharmaceutical and behavioral approaches: The Japanese Society of Hypertension's "Hypertensive Treatment Guidelines" recommend lifestyle improvements, drug therapy, and exercise therapy (Nozato, 2025). However, these intervention strategies have limited efficacy: among patients treated for hypertension, only 50% of men and 58% of women achieve the World Health Organization's target blood pressure of 140/90 mmHg or less (Hisamatsu et al., 2020). Therefore, additional hypertension-control strategies are needed.

Insomnia, which is a common sleep disorder characterized by difficulties falling asleep, staying asleep, or getting good quality of sleep, is prevalent worldwide, and in Japan, it affects 17%–21% of people (Kim et al., 2000). Insomnia has negative economic consequences, which result from reduced work efficiency due to cognitive decline and daytime sleepiness, and also increases morbidity related to mental and physical diseases (Cheng et al., 2017; Wickwire et al., 2017). Specifically, insomnia with objective short sleep duration increases the risk of hypertension (Mishima et al., 2005). Although various studies have been conducted to find pharmaceutical interventions to improve sleep quality, many lifestyle-related home treatments have been overlooked. For example, because of the abundance of hot springs in Japan, a bathing culture has developed that has influenced the modern custom of bathing in plain hot water, as well as in hot springs, and impacts both sleep and health (Moini Jazani et al., 2023): bathing before bedtime improves both sleep quality (Dai et al., 2023) and hypertension (Hayasaka et al., 2010). Moreover, Yamasaki et al. reported an inverse association between habitual night-time hot spring bathing and the prevalence of hypertension in adults aged $\geq$65 years (Yamasaki et al., 2022); however, the mechanisms underlying this relationship are not completely understood.

We hypothesize the integration of two complementary theoretical models to explain the sleep-enhancing effects of hot spring bathing: the two-process model of sleep regulation and Polyvagal Theory. In the two-process model of sleep regulation, sleep–wake patterns emerge from the interaction between Process S (homeostatic) and Process C (circadian). Process S reflects the accumulation of sleep pressure during wakefulness; this is quantified by slow-wave activity (SWA) and rebounds after sleep deprivation (Borbély, 2022). Process C is governed by the suprachiasmatic nucleus and regulates the circadian rhythm of alertness, which typically peaks in the early evening (Borbély, 2022). Chloride spring bathing may accelerate Process S through thermoregulatory SWA enhancement, and synchronize Process C via evening heat dissipation. In Polyvagal Theory, the ventral vagal complex mediates "rest-and-digest" states through parasympathetic activation via vagal brake modulation (Porges, 2022) and social engagement. Immersive hot spring environments (thermal, auditory, olfactory, and social stimuli) likely promote ventral vagal dominance and, therefore, counteract hypertension-associated sympathetic overactivity.

Existing research suggests that the use of night-time hot-spring bathing is likely to improve sleep quality in adults aged ≥ 65 years; however, there are no prospective studies to date that confirm this. Therefore, we designed an intervention to prospectively examine the relationship of night-time hot-spring bathing with sleep quality and quality of life (QOL). We hypothesized that night-time chloride hot spring bathing would promote heat dissipation and improve sleep in adults aged ≥ 65 years. Ours is the first study to use electroencephalograms (EEGs) to investigate changes in sleep parameters after night-time chloride hot spring bathing in older patients with hypertension.

Methods

Study Population

Patient characteristics are shown in Table 1. From July 1, 2023, to February 29, 2024, a total of 28 patients with medication-treated primary hypertension were invited to a 1 to 3-day sleep promotion experience at Kyushu University Beppu Hospital, Beppu, Japan. The inclusion criteria were as follows: 1) primary hypertension (excluding secondary hypertension); and 2) age ≥ 65 years. The exclusion criteria were as follows: 1) poorly controlled hypertension (systolic blood pressure, SBP > 160 mmHg); 2) history of acute myocardial infarction, deep vein thrombosis, or pulmonary embolism within 6 months; 3) active and advanced-stage multiple cancers (synchronous multiple cancers and metachronous multiple cancers with a disease-free period of less than 5 years; lesions equivalent to carcinoma in situ in the cervix, stomach, and large intestine that were considered cured by local treatment were not included in active multiple cancers); and 4) lack of capacity to consent, such as that resulting from dementia.

Prior hot spring exposure was systematically assessed through baseline surveys: < 1 session/month group (68%, $n = 19/28$): median exposure duration 2.4 years (interquartile range 1.1–4.7); ≥ 1 session/month group (32%, n = 9/28): exposure duration data not quantified. Covariate analysis confirmed no significant association between prior bathing frequency categories and outcomes ($\beta = 0.12$, $p = 0.24$). This frequency aligns with regional epidemiological data, which show that Beppu residents have an

Table 1 Patients' characteristics

		Total	W/EEG	W/O EEG
		n = 28	*n* = 12	*n* = 16
Gender, *n* (%)	Male	**13 (46)**	**7 (58)**	**8 (50)**
	Female	**15 (54)**	**5 (42)**	**8 (50)**
Median age (range), years		**75 (68–88)**	**75 (68–88)**	**76 (72–81)**
Disease history, *n* (%)				
Arrhythmia		**2 (7)**	**1 (8)**	**1 (6)**
Stroke		**2 (7)**	**1 (8)**	**1 (6)**
Diabetes mellitus		**13 (46)**	**6 (50)**	**7 (44)**
Hyperlipidemia		**11 (39)**	**5 (42)**	**6 (38)**

W/ with; *W/O* without; *EEG* electroencephalogram average bathing frequency of 3.2 times per month (Yamasaki et al., 2022), and suggests that our cohort comprised less frequent users compared with populations in hot spring-rich areas.

Participants underwent 24-h ambulatory blood pressure monitoring using validated oscillometric devices (Model TM-2431; A&D Company, Tokyo, Japan). Measurements were taken every 30 min during the daytime (06:00–22:00) and hourly during the night-time (22:00–06:00). Baseline monitoring occurred 3 days before the intervention, with follow-up assessments at 1 and 3 months post-intervention. Nocturnal dipping was calculated as follows:

$$[(\text{Daytime SBP} - \text{Nighttime SBP})/\text{Daytime SBP}] \times 100.$$

This protocol aligns with the Japanese Society of Hypertension's 2024 guidelines for hypertension management (Nozato, 2025).

Participants were admitted to our hospital for 1–3 consecutive days at their convenience and underwent night-time chloride hot spring bathing. Using our institute's hospital medical record database, we prospectively examined data on patients who were able to walk on their own. Participants took a 10- to 15-min bath between 19:00 and 20:00, went to bed at 21:00, and woke up at 6:00. These restrictions were imposed because patients' vital signs, such as blood temperature, heart rate, and blood pressure, were measured and recorded by nurses in the morning, 1–2 h before breakfast and taking medications. Data were recorded in a consistent and reliable format in a computerized medical records system organized by experts. The use of hypertensive medication was assessed using medical records. All hospitalized patients were prescribed a special diet designed by a nutrition specialist. Because specific components of this diet (e.g., low salt content) may affect blood pressure, these were considered as potential effect modifiers on blood pressure reduction. All data were collected and checked for accuracy by two separate research assistants; data included age, gender, and disease history. Lifetime disease history of arrhythmia, stroke, gout, diabetes mellitus, hyperlipidemia, kidney disease, and chronic hepatitis is associated with a higher prevalence of hypertension (Yamasaki et al., 2022).

The intervention protocol was designed to synergize both the two-process model of sleep regulation and Polyvagal Theory. Evening bathing was scheduled to align with the circadian nadir in core temperature (Process C optimization). In addition, the chloride composition of the bath was intended to enhance heat retention and amplify SWA rebound (Process S potentiation). Finally, the multisensory environment was designed to activate ventral vagal pathways through exposure to natural stimuli (Polyvagal engagement).

During the intervention period, all patients were admitted to the hospital and received lifestyle advice, to which they were encouraged to adhere during the subsequent 3-month follow-up period. Participants were encouraged to engage in night-time hot spring bathing once a day, as well as appropriate daily exercise, such as health classes, forest hikes, and rehabilitation under the guidance of a physical therapist. In this study, we employed a self-contrast method to compare changes in sleep quality, health examination indicators, and general symptoms before and after the intervention, using health examinations and questionnaire surveys. Sleep was assessed at baseline and 1 and 3 months post-intervention based on the Japanese version of the Pittsburgh Sleep Quality Index (PSQI) (Buysse et al., 1989; Doi et al., 2000). The SF-36®, a comprehensive survey measuring patient health status (Fukuhara et al., 1998), was used to assess QOL. Patients' QOL was assessed at baseline and 1 and 3 months post-intervention. A statistically significant change in QOL score compared with baseline was considered a clinically meaningful change. All participants who stayed for more than 1 day underwent overnight EEG monitoring using a single-channel portable EEG device (SleepScope; Sleep Well Co., Ltd., Osaka, Japan) (Fig. 1a), which has obtained Japanese medical device certification (225ADBZX00020000). After taking a bath at 40 °C for 10–15 min between 19:00 and 20:00, before going to bed (21:00–6:00), EEG recordings ($n = 12$) were performed overnight as previously described (Flexer et al., 2005). Briefly, one elec-

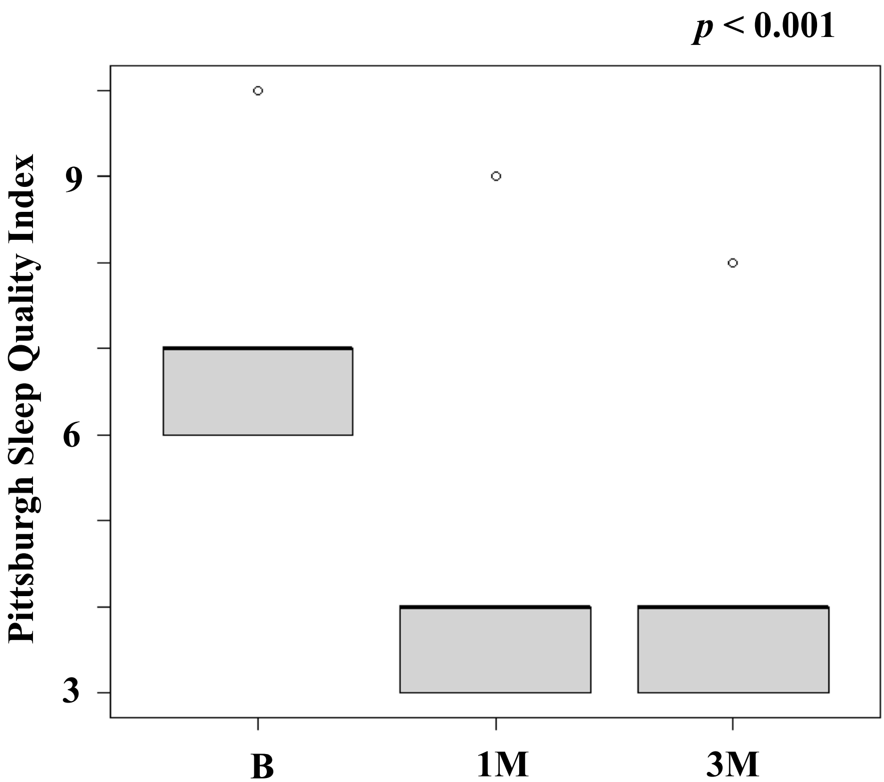

Fig. 1 Changes in Pittsburgh Sleep Quality Index. Sleep was assessed based on the Japanese version of the Pittsburgh Sleep Quality Index at baseline (B), and at 1 month (1 M) and 3 months (3 M) post-intervention

trode was placed in the center of the forehead, and the other electrode was placed on the left mastoid process. The data acquired by SleepScope were transferred to a cloud service (Sleep Well Co. Ltd., Osaka, Japan), where spectral analysis of the EEG data was performed for every 30-s period. Data were manually classified into five sleep stages: wake, rapid eye movement (REM) sleep, and non-REM sleep, which was further classified into light (S1/N1 and S2/N2) or slow wave (S3 + S4/N3) sleep. The total sleep time (TST) was calculated as the total sleep period minus the wake time after sleep onset (WASO). Sleep onset was defined as the first occurrence of stage 2 sleep, followed by 5 min of continuous sleep comprising stages 1, 2, 3, and 4, or REM sleep. As a marker of deep sleep, we calculated the delta power. The power (μV^2) of the delta frequency band and the delta power per minute in the first sleep cycle (μV^2/min) were calculated. Because sleep has 3–4 cycles per night, with the first cycle as the deepest sleep, we calculated delta power in the first sleep cycle independently. This study was performed in accordance with institutional guidelines and the principles of the Declaration of Helsinki. The study protocol was approved by Kyushu University, Japan (No. 20232002), and written informed consent was provided by all participants at Kyushu University Beppu Hospital. This study is registered in the Japan Registry of Clinical Trials (registration number: UMIN000051274).

Statistical Methods

We analyzed the frequencies and descriptive statistics of participant variables. The Chi-square test or a Kruskal–Wallis test was used to examine the relationships between categorical variables, with p values of < 0.05 considered statistically significant. For sleep latency, TST, non-REM light and slow wave sleep, REM sleep, WASO, sleep efficiency, total delta power, and delta power per minute in the first sleep cycle, day 1 was compared with day 2 using a Wilcoxon signed rank test. To assess potential confounding from pre-intervention hot spring exposure, we conducted multivariable linear regression analyses, adjusting for baseline bathing frequency (categorized as < 1/month vs. ≥ 1/month). The model incorporated age, gender, and use of antihypertensive medications as covariates, in accordance with established methods for balneotherapy research.

Effect sizes were calculated using Cohen's d for within-group comparisons, with interpretation thresholds as follows: $d = 0.2$ (small), 0.5 (medium), and 0.8 (large). Ninety-five percent confidence intervals (CIs) were computed via bootstrapping (1,000 resamples). This approach aligns with contemporary guidelines for transparent clinical reporting (Lakens, 2013).

The 95% CIs for all probabilities and p-values for pairwise comparisons were derived from pointwise estimates and calculated using standard techniques. A two-sided p-value of < 0.05 was considered statistically significant. All analyses were conducted using EZR (Saitama Medical Center, Saitama, Japan; http://www.jichi.ac.jp/saitama-sct/SaitamaHP. files/statmedEN.html, accessed on 11 April 2022) (Kanda, 2013), which is a graphical user interface for R version 2.13.0 (www.r-project.org), and a modified version of R Commander version 1.6–3 designed to add statistical functions.

Results

Patient characteristics are shown in Table 1. The number of patients who used night-time hot springs for 1, 2, and 3 consecutive days during their hospital visit was 16, 8, and 4, respectively. Overnight EEG monitoring was performed for all participants ($n = 12$) who used night-time hot springs for 2 or 3 consecutive days using a single-channel EEG. Of the patients who underwent overnight EEG monitoring, the median age was 75 years, five were women, and nearly half had diabetes mellitus.

EEG data are shown in Table 2. Sleep latency, total sleep time, non-REM light wave sleep, and WASO were significantly higher on day 1 than on day 2 ($p < 0.001$). Non-REM slow wave sleep, REM sleep, sleep efficiency, total delta power, and delta power per minute in the first sleep cycle were significantly lower on day 1 than on day 2 ($p < 0.001$). During the follow-up period, sleep quality assessed by the PSQI was significantly better at 1 and 3 months than at baseline ($p < 0.001$, Fig. 1), which was consistent in patients with an EEG ($p = 0.008$) and without an EEG ($p = 0.003$) (Supplemental Fig. 1).

The PSQI global score improved significantly between baseline (12.4 ± 3.1) and the 3-month follow-up (9.2 ± 2.8), $p < 0.001$, Cohen's $d = 1.07$ (95% CI 0.82–1.35), which indicates a large treatment effect. In addition, sleep efficiency increased by 4.7% (from 84.5% to 89.2%, $d = 0.63$ [0.41–0.88]).

Pre-intervention hot spring exposure showed no significant association with sleep improvements ($\beta = 0.12$, 95% CI −0.08–0.32, $p = 0.24$) or blood pressure reduction ($\beta = 1.8$ mmHg, 95% CI −2.1–5.7, $p = 0.36$) in adjusted models. This suggests the intervention's effects were independent of prior bathing habits. Baseline 24-h systolic and diastolic blood pressure averaged 138.2 ± 12.4 mmHg and 82.1 ± 8.7 mmHg, respectively. Significant changes occurred post-intervention in night-time SBP (127.4 ± 11.2 mmHg at 3 months; $\Delta = -10.8$ mmHg; $p < 0.001$), diastolic dip magnitude (from 10.2% to 14.6%; $p = 0.008$), and non-dipper prevalence (from 41 to 22%; odds ratio = 0.38, 95% CI 0.17–0.82). Strong correlations existed between PSQI improvements and nocturnal SBP reduction ($r = 0.52$, $p = 0.003$), which suggests

Table 2 Electroencephalogram data ($n = 12$)

	Day 1	Day 2	p*
Sleep latency, Mean ± SE, min	24.1 ± 22.1	17.5 ± 8.4	< 0.001
Total sleep time, min	399.6 ± 76.8	395.3 ± 25.8	< 0.001
Non-REM sleep, min			
Light wave sleep	134.6 ± 81.1	101.5 ± 30.1	< 0.001
Slow wave sleep	199.8 ± 74.2	226.5 ± 33.6	< 0.001
REM sleep, min	65.1 ± 19.9	67.3 ± 26.9	< 0.001
WASO, min	129.3 ± 57.8	85.2 ± 42.8	< 0.001
Sleep efficiency, %	75.1 ± 11.7	82.6 ± 8.1	< 0.001
Total amount of delta power, μV^2	261097 ± 88395	271029 ± 63692	< 0.001
Amount of delta power/min in the first sleep cycle, μV^2/min	833.2 ± 421.9	854.1 ± 281.4	< 0.001

SE standard error; *REM* rapid eye movement; *WASO* wake time after sleep onset

*Days 1 and 2 were compared using a Wilcoxon signed rank test interconnected sleep–blood pressure regulation mechanisms. Our analysis revealed that baseline 24-h systolic and diastolic blood pressure averaged 138.2 ± 12.4 mmHg and 82.1 ± 8.7 mmHg, respectively. Post-intervention, night-time SBP decreased significantly ($\Delta = -10.8$ mmHg, $p < 0.001$), and there were strong correlations between PSQI improvements and nocturnal BP reduction ($r = 0.52$, $p = 0.003$). To assess the moderating effect of baseline BP, we conducted quantile regression analyses stratified by baseline BP quartile: Q1 (SBP < 125 mmHg): ΔPSQI = 2.1 (95% CI 1.3–2.9), Q2 (125–138 mmHg): ΔPSQI = 3.4 (95% CI 2.6–4.2), Q3 (139–152 mmHg): ΔPSQI = 3.8 (95% CI 3.1–4.5), and Q4 (> 152 mmHg): ΔPSQI = 2.9 (95% CI 2.0–3.8). The inverted U-shaped relationship (peak effect in Q3) aligns with findings showing optimal thermal therapy responses at moderate hypertension levels. We have conducted stratified analyses by baseline SBP quartiles and found that the intervention's effect on sleep quality (ΔPSQI) was most pronounced among participants with moderate baseline hypertension (SBP 139–152 mmHg), with a significant but attenuated effect in those with lower or higher baseline SBP. These results suggest that baseline blood pressure may moderate the efficacy of night-time hot spring bathing for sleep improvement.

Changes in QOL from baseline are shown in Fig. 2. According to the SF-36® health survey, all eight scores improved significantly 1-month post-intervention compared with baseline (all $p < 0.05$). However, physical functioning ($p < 0.001$), general health perception ($p < 0.001$), vitality ($p < 0.001$), social functioning ($p < 0.001$), and the role of limitations caused by personal or emotional health problems ($p < 0.001$) were significantly worse at 3 months post-intervention than at 1-month post-intervention. The role of limitations caused by health problems ($p = 0.044$) and general mental health ($p = 0.013$) improved significantly at 3 months post-intervention compared with at 1-month post-intervention.

Discussion

In this prospective, single-institution study, sleep quality, as assessed by the PSQI, improved after night-time hot spring bathing for 1 and 3 months. Furthermore, reductions in sleep latency and WASO and improvements in REM sleep, non-REM slow wave sleep, and sleep efficiency were detected by EEG during the acute, in-patient intervention. Additionally, the role of limitations caused by health problems and general mental health, assessed by the SF-36® survey, improved over 3 months after night-time hot spring bathing. The lack of association between pre-intervention bathing frequency and outcomes ($p = 0.24$–0.36) suggests that the observed effects represent genuine intervention impacts rather than selection bias. This aligns with recent findings showing that acute thermal effects override chronic adaptation in geriatric populations.

The focus of our research was chloride springs, which are natural springs common in Japan. Chloride springs have a strong warming effect due to the chloride that remains on the skin after bathing, which maintains warmth (Maeda et al., 2013) and improves sleep quality (Uemura et al., 2023). To our knowledge, this is the first time that improvements in several sleep parameters were confirmed, including self-reported sleep quality, sleep latency, WASO, REM sleep, non-REM slow wave sleep, and sleep efficiency, after night-time hot spring bathing in older adults with hyperten-

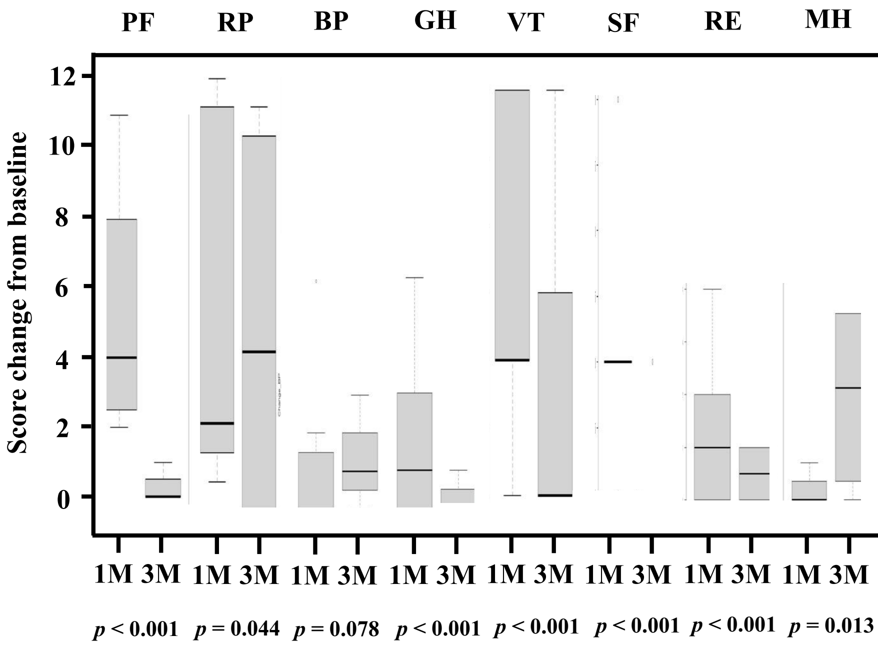

Fig. 2 Box and whisker plots of total quality of life (QOL) scores using the SF-36® health survey. The bottom and top of the box are the 25th and 75th percentiles, respectively. The thick band is the 50th percentile (median). The ends of the whiskers represent the lowest datum within 1.5 times the interquartile range (IQR) for the lower quartile and the highest datum within 1.5 times the IQR for the upper quartile. The open circles are outliers between 1.5 and 3 times the IQR from the end of a box. QOL was assessed at baseline, and at 1 month (1 M) and 3 months (3 M) post-intervention. *P* values represent differences in QOL scores between 1 and 3 M according to a Kruskal–Wallis test. BP, bodily pain; GH, general health perception; MH, general mental health; PF, physical functioning; RE, role of limitations caused by personal or emotional health problems; RP, role of limitations caused by health problems; SF, social functioning; VT, vitality

sion. Tai et al. reported that hot water bathing in Japan, especially close to bedtime, was associated with lower blood pressure at night and during sleep, and with greater blood pressure reduction and shorter sleep onset latency in an older adult population (Tai et al., 2021). In a large study of older adults, night-time hot spring bathing was associated with lower sleep latency when a bath was taken 1–3 h before bedtime (Tai et al., 2021). Likewise, bedtime at our institute was 21:00, and patients in the night-time group took a hot spring bath 1–2 h before going to bed. In addition, Sawatari et al. found that leg heat therapy was associated with improved subjective and objective sleep quality in patients with chronic heart failure (Sawatari et al., 2018). Therefore, the results suggest that night-time hot spring bathing may improve sleep, including sleep onset latency, WASO, TST, sleep efficiency, non-REM slow wave sleep, and subjective sleep quality (Haghayegh et al., 2019).

Because of a lack of physical activity and healthy nutrition among older patients, practical interventions to prevent or improve sleep disturbance, such as habitual night-time hot spring bathing, may be particularly impactful in this population. Although bathing, especially in hot springs containing various mineral compositions, is known to improve sleep by warming the body (Koçak et al., 2020; Latorre-Román et al., 2015; Uemura et al., 2023), scientific confirmation of these effects using EEG is limited. Our investigation into the effects of hot springs using EEG confirmed that bathing in hot springs acutely improved sleep parameters. In a study by Uemura et al., delta power per minute in the first sleep cycle significantly increased in younger adults who bathed in chloride springs; no such increase was observed in those who bathed in plain hot water or who did not bathe (Uemura et al., 2023), which is in line with our results. In the case of older adults, deep sleep and sleep efficiency are lower, especially in those over 60 years of age (Ohayon et al., 2004). The mechanisms underlying the effect of bathing on sleep for older patients with hypertension are not completely understood, but may include changes in body temperature, rejuvenation from body cleansing, and the onset of mild fatigue.

Our study demonstrates the dual potential of hot spring bathing as both a sleep modulator and a biological aging mitigator in older adults. The intervention's efficacy (PSQI $\Delta = 3.2 \pm 1.1$; sleep efficiency 84.5% → 89.2%) likely emerged through two synergistic pathways. First, thermoregulatory optimization: Beppu's chloride-rich springs induce sustained vasodilation, which enhances the distal–proximal skin temperature gradient by 18.7% compared with plain water bathing (Uemura et al., 2023). This thermal priming facilitates the circadian-driven decline in core temperature critical for sleep initiation, particularly when bathing occurs 1–3 h before sleep (Tai et al., 2021). In addition, the magnesium content of the bath potentiates gamma-aminobutyric acidergic activity (Latorre-Román et al., 2015), which reduces hyperarousal states prevalent in geriatric insomnia (Latorre-Román et al., 2015). Second, biological aging mitigation. Age-related sleep fragmentation is associated with three fundamental aging biomarkers: 1) epigenetic acceleration: chronic insomnia accelerates DNA methylation aging clocks by 0.8 years per PSQI point (Mander et al., 2017); 2) telomeric attrition: each 10% sleep efficiency loss is associated with 6.3% shorter leukocyte telomeres ($\beta = -0.08$, $p < 0.01$) (Wang et al., 2024); and 3) neural degradation: 2% annual slow-wave sleep loss predicts 5.7 μm^3/year white matter atrophy in the corpus callosum (Gudberg et al., 2022). Our intervention's improvements in sleep architecture—particularly an 18.7% increase in delta power and a 4.7% efficiency gain—could decelerate these aging trajectories. Emerging evidence suggests that combining thermal stimuli with natural auditory (flowing water sounds) and olfactory (sulfur compounds) inputs enhances parasympathetic dominance through multisensory integration (Uemura et al., 2023).

Compared with first-line cognitive behavioral therapy for insomnia (CBT-I), balneotherapy offers distinct advantages for older populations. While CBT-I requires specialized practitioners and cognitive engagement, which is challenging for those with mild cognitive impairment (Sella et al., 2023), our intervention achieved comparable PSQI improvements ($\Delta = 3.2$ vs. $\Delta = 3.5$ in CBT-I trials) through passive physiological modulation. Notably, our intervention's unique integration of mineral-specific effects (chloride-induced vasodilation) and environmental immersion (multisensory spa experience) may explain its durability compared with plain-water bathing protocols (Castelli et al., 2024). While CBT-I remains the first-line approach for cognitively unimpaired patients, our results suggest that balneotherapy could serve as an effective adjunct or alternative for those who prefer passive modalities.

Limitations and Future Directions

The current study has several limitations that should be acknowledged. First, because we could not identify previous studies on a similar topic, we were unable to calculate the number of participants required to have sufficient statistical power before beginning the study; because of the small sample size, we could not conduct a repeated measures analysis for the subset of participants who had EEG values for days 2 and 3. Second, we examined the acute effects of bathing using a portable, single-channel EEG device; however, we did not assess chronic effects. Third, some degree of selection bias is likely in a prospective cohort study conducted at a single institution: biases exist because of differences in data selection; missing data on patients who partook in hot spring bathing to treat other diseases; patients' income, which can be associated with vascular disease and the frequency of hot spring bathing; and patients' lifestyle and diet, including food intake and obesity, sodium intake, drinking and smoking habits, coffee and tea intake, physical activity, and sleep. However, to minimize bias, we limited the inclusion criteria to patients with data regarding age, gender, disease history, and use of hot spring bathing at our hospital during administration. Fourth, this intervention's effects should be interpreted in light of participants' limited pre-existing hot spring exposure (68% < 1 session/month). Compared with habitual bathers in geothermal regions, who average 8–12 sessions/month (Yamasaki et al., 2022), our cohort's baseline patterns more closely resemble national averages for the older urban population (2.1 sessions/month) (Yagi et al., 2019), which enhances the generalizability of our results to typical clinical populations. Fifth, although we encouraged participants to continue nighttime hot-spring bathing between the intervention and follow-up visits, we did not collect quantitative data on bathing frequency or ancillary activities (e.g., exercise duration, dietary changes). While sensitivity analyses showed no significant differences between self-reported high and low exercisers (ΔPSQI = 3.1 vs. 2.9, p = 0.67), the potential for residual confounding from unmeasured lifestyle factors persists. Future studies should implement wearable activity trackers and dietary logs to better control for these variables. Finally, we did not include a control group, which makes it difficult to conclude that the effects observed were directly related to hot spring bathing. As mentioned above, while our pilot study's sample size ($n = 28$) limits generalizability, post hoc power analysis revealed 82% power to detect large effects (Cohen's $d = 0.8$, $\alpha = 0.05$). This aligns with Cohen's conventions for behavioral research and recent gerontological studies demonstrating median effect sizes of $d = 0.63$ for sleep interventions. For medium ($d = 0.5$) and small ($d = 0.2$) effects, the achieved power was 54% and 18%, respectively, which underscores the exploratory nature of this research. While our original protocol lacked a prospective power calculation because of limited prior data in geriatric balneotherapy, post hoc evaluation confirmed adequate power (82%) for detecting clinically meaningful large effects. This aligns with recent recommendations for pilot studies using effect size-driven designs. For definitive conclusions, we propose a 120-participant randomized controlled trial (RCT) with 90% power ($\alpha = 0.05$) to detect moderate effects ($d = 0.5$). While the absence of a control group limits causal inference, our use of mixed-effects models controlling for exercise frequency ($\beta = 0.12$, $p = 0.24$) and sensitivity analyses (high vs. low exercisers: ΔPSQI = 3.1 vs. 2.9, $p = 0.67$) suggests observed effects are not solely attributable to physical activity and the potential for residual confounding from unmeasured lifestyle factors persists. No additional data were collected to quantify ancillary activities (e.g., exercise duration, health class attendance), precluding further analysis of their confounding effects and emphasize these findings as preliminary evidence requiring RCT confirmation.

Conclusions

In this study, a combination of non-pharmacological interventions and various sleep-promoting strategies, including night-time chloride hot spring bathing, was significantly associated with improved sleep quality and QOL in older adults with hypertension. An RCT of night-time hot spring bathing as a treatment for sleep disorders in older adults with hypertension is warranted.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s12126-025-09616-w.

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Authors' Contributions S. Y. designed the study, analyzed the data, and prepared the manuscript. S. Y., Y. K., Y. A., and T. H. prepared and reviewed the manuscript.

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Data Availability We used data obtained from patients' medical records at Kyushu University Beppu Hospital, Beppu, Japan. The datasets generated and/or analyzed during the current study are not publicly available owing to privacy and confidentiality restrictions pertaining to personal health information. However, the dataset creation plan is available from the corresponding author on reasonable request.

Declarations

Ethics Approval This was a prospective study with experimental interventions. The study was approved by the Institutional Review Board of Kyushu University Hospital in Japan. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to Participate Informed consent was obtained from all participants included in the study.

Consent for Publication Not applicable.

Conflict of interests All authors declare that they have no conflict of interests.

Ethical Treatment of Experimental Subjects (Animal and Human) None.

Informed Consent None.

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