International Journal of Biometeorology (2019) 63:1707–1718
https://doi.org/10.1007/s00484-019-01780-4

REVIEW PAPER

Head-out immersion in natural thermal mineral water for the management of hypertension: a review of randomized controlled trials

Dan Yuan[1] · Zhao-xia Yu[1] · Wen Wang[2] · Yu Chen[1]

Received: 5 April 2019 / Revised: 14 July 2019 / Accepted: 31 July 2019 / Published online: 11 August 2019

Abstract

Hypertension is a major public health problem in the world, and the management of hypertension has always been a research of interest. Balneotherapy, with its recreational aspect, is more acceptable than medication intake and lifestyle change for the management of hypertension. The aim of this review was to summarize the current available data on the clinical effects of head-out immersion in natural thermal mineral water (HINTMW) as the most common method of balneotherapy used in the management of hypertension. We screened the PubMed, EMBASE, Cochrane Library, China Science and Technology Journal, China National Knowledge Infrastructure, WANFANG, and China Biology Medicine disc databases and selected 12 randomized controlled trials involving a total of 1122 participants. Among 12 trials, HINTMW was taken as the only intervention in only one study, HINTMW was taken in addition to basic antihypertensive drugs in three studies, and HINTMW was taken in combination with advice to follow nonpharmacological methods in one study involving participants who partly used antihypertensive drugs, while HINTMW combined with other interventions, such as natural convalescent factor therapy, psychotherapy, exercises, nutrition therapy, and integrated care, was taken in addition to basic antihypertensive drugs in the other 7 studies. Our results showed that natural thermal mineral water immersion alone or natural thermal mineral water immersion as an adjuvant therapy to medication or natural thermal mineral water immersion combined with other interventions had no adverse effects on hypertensive patients, and most even had positive effects. However, more high-quality evidences on therapeutic effectiveness of natural thermal mineral water immersion on hypertension are needed from additional randomized controlled trials with high methodological quality.

Keywords Balneotherapy · Hypertension · Balneology · Natural water · Immersion · Randomized controlled trials

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00484-019-01780-4) contains supplementary material, which is available to authorized users.

✉ Yu Chen
chenyu@cqmu.edu.cn

Dan Yuan
1225872243@qq.com

Zhao-xia Yu
928695265@qq.com

Wen Wang
1125431932@qq.com

[1] School of Public Health and Management, Chongqing Medical University, Research Center for Medicine and Social Development, Innovation Center for Social Risk Governance in Health, Chongqing 400016, China

[2] People's Hospital of Nanan District, Chongqing, China

Introduction

Hypertension is a major public health issue and has been considered the leading preventable cause of premature mortality and disability worldwide (Miller 2015; Manzur et al. 2018). Observational studies have demonstrated various extents of associations between high systolic blood pressure (SBP) and diastolic blood pressure (DBP) and an increased risk of cardiovascular diseases (CVDs) (Lewington et al. 2002; Rapsomaniki et al. 2014). According to the data from the World Health Organization, CVDs are the leading cause of death globally, with an estimated death of 17.9 million people in 2016, accounting for 31% of all global deaths.

The World Health Organization estimated that elevated blood pressure (BP) (defined as systolic and/or diastolic blood pressure higher than or equal to 140/90 mmHg) in adults aged 18 years and over was present in approximately 24.1% of men

and 20.1% of women in 2015. The number of adults with elevated BP increased from 594 million in 1975 to 1.13 billion in 2015. The situation of hypertension in the world is grim.

Pharmacological treatment and nonpharmacological interventions are used to manage BP. The primary agents used in the treatment of hypertension include thiazide diuretics, angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers (ARBs), calcium channel blockers (CCBs), and beta blockers. Lifestyle change is the most important nonpharmacological intervention; lifestyle-modifying approaches include weight loss (Neter et al. 2003), the DASH (Dietary Approaches to Stop Hypertension) diet (Blumenthal et al. 2010), sodium reduction (He et al. 2013), potassium supplementation (Aburto et al. 2013), increased physical activity (Cornelissen and Smart 2013; Carlson et al. 2014; Inder et al. 2016), and reduction in alcohol consumption (Roerecke et al. 2017).

The 2017 American College of Cardiology/American Heart Association Clinical Practice Guideline for High Blood Pressure defines hypertension as BP ≥ 130/80 mmHg and recommends that hypertensive patients maintain their BP < 130/80 mmHg (Whelton et al. 2017). Compared with previous guidelines, this change emphasizes early prevention and intervention in the management of hypertension. Consequently, the use of nonpharmacological interventions has become more important.

Both pharmacological medication and lifestyle change are associated with poor compliance in hypertensive patients. However, balneotherapy, with its recreational aspect (Ablin et al. 2013), is a treatment that patients are willing to accept. Balneotherapy refers to the use of thermal and mineral waters, muds and other peloids, and natural gases (carbon dioxide, hydrogen sulfide, radon, etc.) for preventive, therapeutic, and rehabilitative purposes (Antonelli and Donelli 2018), with head-out immersion in natural thermal mineral water (HINTMW) being the most common method.

Previous studies have shown that when the human body is immersed in thermal water, due to the warming effect, the blood vessels dilate, the peripheral blood vessel resistance decreases, the release of vasopressin into the blood decreases, the skin pores dilate, and the exchange of metabolic wastes with external thermal water ions accelerates. All of these effects are conducive to reducing BP (Stadeager et al. 1992; Christensen et al. 2000). When immersed in water, the individual is in a semi-floating state, which leads to the relaxation of muscles and emotions, the decrease in myocardial oxygen consumption and adrenocortical hormone levels, the decrease in the activity of the renin angiotensin system, and the dropping of BP (Nishimura and Onodera 2000; Hu et al. 2000). Because of the hydrostatic pressure, the central blood volume increases, stroke volume increases, heart rate decreases, blood viscosity reduces, and sympathetic nerve activity decreases (Smith 1998; Sik Park et al. 1999; Christie et al. 1990; Gabrielsen et al. 2000). The movement of liquid particles in mineral water exerts frictional effects on the human body and has a mild soothing effect on the body's peripheral nerve terminals, which stimulates the vagus nerve, leading to dilation of peripheral blood vessels and a decrease in BP (Hao et al. 2013). Previous studies have shown that the antihypertensive effect of the water containing radon (Yamaoka et al. 2004), hydrogen sulfide (Ercegrukavina and Stefanovski 2014), or carbon dioxide (Resch and Just 1994; Kuliński 2015; Rühle et al. 2018) is good.

Existing studies on the effect of HINTMW on hypertension have been carried out with differences in research designs, interventions (such as water temperature, intervention frequency, and total intervention time), and ways of measuring and recording BP, and the findings of these studies are also inconsistent. The aim of this review was to summarize the currently available information on the clinical effects of natural thermal mineral water immersion in the management of hypertension.

Methods

Criteria for selecting studies for this review

Types of studies

Studies were eligible if they were randomized controlled trials (RCTs).

Types of participants

All the participants were diagnosed with hypertension. Their diagnostic criteria, age, sex, race, nationality, and medication intake were not restricted.

Types of interventions

HINTMW was the intervention under study and was compared with another intervention or with no intervention.

Types of outcome measures

Outcome measures included the BP, SBP, and DBP values of the participants.

Search methods

Two authors (Dan Yuan, Zhao-xia Yu) independently screened the PubMed, EMBASE, Cochrane Library, China Science and Technology Journal (VIP), China National Knowledge Infrastructure (CNKI), WANFANG, and China Biology Medicine disc (CBMdisc) databases in December 2018. The following search terms were used: hypertension,

hypertensive, "high blood pressure," "elevated blood pressure," balneology, hydrotherapy, ammotherapy, climatotherapy, balneotherapy, crenotherapy, thalassotherapy, bath, water, mud, peliod, spa, climate, "randomized controlled trial," "controlled clinical trial," "clinical trials," "controlled study," and "blood pressure." The published languages were limited in English and Chinese. We applied no date restrictions. The search strategies performed in PubMed, EMBASE, and Cochrane Library are presented in Appendix 1 in the supplementary material.

Selection of studies and data collection

Two review authors (Dan Yuan, Zhao-xia Yu) independently performed the first screening by inspecting titles and abstracts to determine whether studies met the inclusion criteria regarding design, participants, interventions, and outcome measures. Then, we obtained the full text of the studies remaining after the first screening and conducted the secondary screening according to the inclusion criteria. Two review authors (Dan Yuan, Zhao-xia Yu) independently extracted data on the participants, interventions, outcome measures, and results.

Assessment of risk of bias

The risk of bias for each study was assessed by two reviewers (Yu Chen, Dan Yuan), following the revised Cochrane risk-of-bias tool for randomized trials (RoB 2), which covers bias arising from the randomization process, bias due to deviations from intended interventions (assessments for this domain depend on whether the intervention effect of interest to the review authors is "the effect of assignment to intervention" or "the effect of adhering to intervention"), bias due to missing outcome data, bias in measurement of the outcome, and bias in selection of the reported result. We judged the risk of bias for each study as "low risk," "some concerns," or "high risk" by answering (the response options for the signaling questions are "yes," "probably yes," "probably no," "no," "no information") the signaling questions. We answered the signaling questions of "the effect of adhering to intervention" to assess the "bias due to deviations from intended interventions."

Results

Results of the search

We identified 986 articles in the initial search, of which 62 were selected on the basis of the title and abstract according to the inclusion criteria. We obtained the full text of the 62 articles, of which 4 articles were excluded because of language, 3 articles were excluded because their publication type was conference abstracts, 18 articles were excluded because they appeared not to be RCTs, 21 articles were excluded because their interventions were not HINTMW, 1 article was excluded because of the selected outcome measures, and 1 article was excluded because of the incomplete results. As a result, 14 articles (Naumann et al. 2015, 2016; Peng 1994; Li and Jin 2014; He 2009; Fang et al. 2014; Hu et al. 2013; Liu et al. 2017; Liu and Hu 2009; Li et al. 2013; Zhang 2016; Luo 2017; Yang 1997; Su 2015) were included in this review, but 2 trials were reported in 2 articles (Naumann et al. 2015, 2016; Fang et al. 2014 and Hu et al. 2013). Therefore, twelve trials and fourteen articles were finally included, of which 2 were written in English (Naumann et al. 2015, 2016), while 12 were in Chinese. See the study flow chart in Fig. 1.

Included studies and participants

Twelve trials and fourteen articles involving a total of 1122 participants, with the age range from 28 to 84 years, were included in the review. The participants comprised 594 patients undergoing intervention and 528 patients as controls, with the number of participants in each trial ranging from 59 to 140 and that in the intervention group ranging from 36 to 74. The total number of females/males was 468/654, with the percentage of males in each trial varying between 36 and 97% and that of females varying between 3 and 64%. All the participants were hypertensive, and patients in one study also had comorbid diabetes (Su 2015) (Tables 1 and 2).

The exclusion criteria of participants were described in some studies. The exclusion criteria in one study were severe diseases (heart failure grading 3 or 4, peripheral arterial disease grading 3 or 4, unstable angina, renal failure, and creatinine > 1.5 mg/dl) that may restrict the patient from participating in the study or require other treatments as necessary; secondary hypertension; acute infection; fever; contraindications

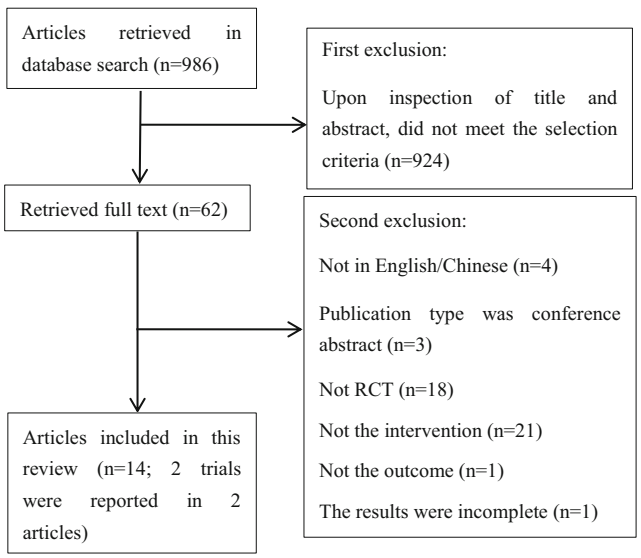

Fig. 1 Study flow diagram

Table 1 The characteristic of the included studies in the review

Trial	Group	Sex (female/male)	Age (years)	Intervention	Frequency	Outcome measures	Measurement
Naumann et al. (2015, 2016)	Randomization codes, blinding A:19 B:21 C:19	29/30	57.6 ± 9.6	A + B: original drug + HINTMW (34–36 °C) + advised nonpharmacological therapy C: original drug + practice relaxation + advised nonpharmacological therapy	45–60 min/treatment A: 4 times/week for 4 weeks +1 time/week for 20 weeks B: 4 times/week for 24 weeks C: 4 times/week for 24 weeks	BP: baseline and at 4 and 24 weeks. BMI, waist circumference, blood lipids, fasting blood glucose, and CRP.	Morning home BP, morning office BP, 24-h ambulatory BP, > 48 h after the treatment
Peng (1994)	No details on randomization A: 43 B: 42	42/43	43–75	A: drug + HINTMW (38–40 °C) B: drug	15 min/treatment once a day for > 30 days	BP: before and after the whole treatment	Morning home BP; patient seated; right arm; averaged measurements taken on 3 days
Li and Jin (2014)	No details on randomization A: 68 B: 68	58/78	51–78	A: drug + HINTMW (38–39 °C) + natural convalescent factor B: drug	HINTMW: 30–40 min/treatment once a day for 1 month	BP: before and after the whole treatment	Taken after 10 min of rest with a mercury sphygmomanometer; patient seated; averaged measurements taken on 3 days
He (2009)	No details on randomization A: 36 B: 36	23/49	38–84	A: drug + HINTMW (38–40 °C) B: Drug	20–30 min/treatment, once a day for 15 days	BP: before and after each HINTMW	Measured the brachial artery by a mercury sphygmomanometer; average BP was calculated after treatment
Fang et al. (2014) and Hu et al. (2013)	Random number table A: 36 B: 36	25/47	33–62	A: drug + HINTMW (38–40 °C) B: drug	20–30 min/treatment, once a day (90 min after lunch) for 20 days Xingcheng hot spring, radon, sodium chloride	RBC, Hct, Hb, RDW; BP	BP: taken at 8:00 a.m. and 4:00 p.m. with a calibrated mercury sphygmomanometer; patient seated; recorded average of 3 measurements on the right upper arm
Liu et al. (2017)	Random number table A: 70 B: 70	69/71	40–60	A: basic recuperation + drug + HINTMW (38 °C) + psychotherapy B: basic recuperation + drug	30 min/treatment, 5 times/week for 4 weeks	BP: before and after the whole treatment, treatment satisfaction	Not indicated
Liu and Hu (2009)	No details on randomization A: 36 B: 36	25/47	33–62	A: drug + low intensity aerobic exercise + HINTMW (38–40 °C) B: drug	Aerobic exercise: 30–45 min/day, 3–5 times/week for 8 weeks HINTMW: 15 min/treatment, 3–5 times/week for 8 weeks	BP: before and after each HINTMW; blood lipid parameters: TC, LDL-C, HDL-C, TG	Taken after 5 min of rest with a calibrated mercury sphygmomanometer; patient in recumbent position; average values of 2 consecutive measurements on the right upper arm

Table 1 (continued)

Trial	Group	Sex (female/male)	Age (years)	Intervention	Frequency	Outcome measures	Measurement
Li et al. (2013)	No details on randomization A: 74 B: 30	67/37	A: 65.0 ± 4.2 B: 64.8 ± 4.5	A: drug + shadowboxing + HINTMW (38–40 °C) B: drug	Shadowboxing: 30 min HINTMW: half an hour after the shadowboxing, 15 min/treatment for 10 days	BP: before and after each HINTMW	Taken after 5 min of rest with a calibrated mercury sphygmomanometer; patient in recumbent position; measured twice from the upper right arm, and the average value was recorded
Zhang (2016)	No details on randomization A: 40 B: 40	35/45	45–76	A: drug + nutrition therapy + HINTMW (37–38 °C) B: drug	20–30 min/treatment, 2 times/day for 8 weeks	BP: A: before and after each HINTMW B: 9–10 a.m.	A: 15 min rest in the recumbent position; measured 3 times; the average value was recorded B: measured once by full-time medical staff
Luo (2017)	Random number table A: 61 B: 61	58/64	28–79	A: drug + usual care + mental nursing + medication guide + HINTMW (37–38 °C) B: drug + usual care	15–20 min/treatment, 2–3 times/day; the total time was unclear	BP: before and after each HINTMW	After HINTMW, lay down and took a rest for 15–30 min, then measured the BP
Yang (1997)	No details on randomization A: 45 B: 45	3/87	> 31	A: HINTMW (< 39–42 °C) B: drug	< 15–20 min/treatment, 3 months	BP: A: before and after each HINTMW B: every morning	A: half an hour after the HINTMW
Su (2015)	No details on randomization A: 45 B: 45	34/56	60 ± 6.9	A: drug + diabetes diet + HINTMW (37–38 °C) B: drug + diabetes diet	Start at 2 p.m., 15 min/treatment, once a day for 30 days	Blood glucose (fasting and after breakfast), BP (morning, noon, evening), BMI, liver and kidney functions (before and after the whole treatment)	BP: measured by Shanghai Jade Rabbit mercury column blood pressure meter in the morning, noon, and evening; the average value was recorded

HINTMW head-out immersion in natural thermal mineral water, *BP* blood pressure, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *BMI* body mass index, *CRP* C-reactive protein, *RBC* red blood cells, *Hct* hematocrit, *Hb* hemoglobin, *RDW* red blood cell width distribution, *TC* total cholesterol, *TG* triglycerides, *LDL-C* serum low-density lipoprotein cholesterol, *HDL-C* serum high-density lipoprotein cholesterol

Table 2 The BP and results of the included studies in the review

Trial	Baseline BP		BP after treatment		Results
	SBP	DBP	SBP	DBP	
Naumann et al. (2015, 2016)	24-h ambulatory: A: 139 ± 13 (mmHg) B: 137 ± 11 (mmHg) C: 139 ± 8 (mmHg)	24-h ambulatory: A: 88 ± 9 (mmHg) B: 88 ± 10 (mmHg) C: 86 ± 8 (mmHg)	Week 24: A: 139 ± 11 (mmHg) B: 138 ± 11 (mmHg) C: 136 ± 12 (mmHg)	Week 24: A: 88 ± 8 (mmHg) B: 86 ± 10 (mmHg) C: 85 ± 10 (mmHg)	No significant differences in SBP or DBP between the groups after either 4 or 24 weeks. No significant differences between the groups in BMI, waist circumference, blood lipids, fasting blood glucose, and CRP. There was no loss to follow-up. No treatment-related adverse events.
Peng (1994)	A: 22.55 ± 2.03 (kPa) B: 23.74 ± 2.41 (kPa)	A: 13.05 ± 1.50 (kPa) B: 14.19 ± 1.60 (kPa)	A: 19.19 ± 1.33 (kPa) B: 19.72 ± 1.88 (kPa)	A: 10.56 ± 0.96 (kPa) B: 11.38 ± 1.28 (kPa)	There were significant differences in BP before and after treatment in both groups ($P < 0.01$). The DBP decrease in group A was greater ($P < 0.05$). The SBP decrease in group B was greater ($P < 0.01$).
Li and Jin (2014)	A: 163.0 ± 9.8 (mmHg) B: 161.2 ± 8.5 (mmHg)	A: 102.2 ± 5.0 (mmHg) B: 102.1 ± 4.9 (mmHg)	A: 138.0 ± 9.8 (mmHg) B: 158.3 ± 8.7 (mmHg)	A: 81.0 ± 6.8 (mmHg) B: 99.5 ± 6.0 (mmHg)	After treatment, BP in group A decreased significantly but not significantly in group B. The decrease in group A was significantly greater than that in group B ($P < 0.01$).
He (2009)	A: 22.45 ± 2.08 (kPa) B: 22.04 ± 2.48 (kPa)	A: 12.99 ± 1.39 (kPa) B: 13.04 ± 1.55 (kPa)	A: 17.63 ± 1.62 (kPa) B: 17.81 ± 1.89 (kPa)	A: 11.25 ± 0.77 (kPa) B: 12.08 ± 0.88 (kPa)	After treatment, the BP in group A decreased significantly, and there was a significant difference between two groups ($P < 0.05$). The effective rate of group A was higher than that of group B, and the difference was statistically significant ($P < 0.05$).
Fang et al. (2014) and Hu et al. (2013)	A: 157 ± 15 (mmHg) B: 154 ± 16 (mmHg)	A: 101 ± 10 (mmHg) B: 99 ± 11 (mmHg)	A: 131 ± 13 (mmHg) B: 137 ± 10 (mmHg)	A: 86 ± 5 (mmHg) B: 88 ± 4 (mmHg)	After treatment, the RBC, Hct, Hb, and RDW of group A were significantly different from those of group B and before treatment ($P < 0.05$). BP: The total effective rate of group A was higher than that of group B, and the total effective rate of the two groups was significantly different ($P < 0.05$).
Liu et al. (2017)	A: 150.9 ± 8.6 (mmHg) B: 151.2 ± 8.4 (mmHg)	A: 98.2 ± 5.4 (mmHg) B: 97.9 ± 5.6 (mmHg)	A: 124.8 ± 6.5 (mmHg) B: 142.3 ± 6.9 (mmHg)	A: 71.1 ± 4.5 (mmHg) B: 87.4 ± 4.3 (mmHg)	After treatment, BP in group A was significantly lower than that in group B; the difference was statistically significant ($P < 0.05$). The total effective rate and the total satisfaction rate of group A were significantly higher than those of group B ($P < 0.05$).
Liu and Hu (2009)	A: 22.65 ± 1.77 (kPa) B: 22.85 ± 2.70 (kPa)	A: 10.99 ± 0.53 (kPa) B: 11.03 ± 0.74 (kPa)	A: 18.23 ± 1.28 (kPa) B: 19.80 ± 0.97 (kPa)	A: 10.31 ± 0.72 (kPa) B: 10.67 ± 0.64 (kPa)	After treatment, BP decreased significantly in both groups. There was a significant difference between group A and group B after treatment, and the decrease in group A was greater than that in group B ($P < 0.01$). After treatment, the blood lipid parameters were significantly different in group A and group B ($P < 0.01$).
Li et al. (2013)	A: 135.0 ± 12.0 (mmHg) B: 134.0 ± 15.0 (mmHg)	A: 79.0 ± 7.5 (mmHg) B: 80.0 ± 11.0 (mmHg)	A: 128.0 ± 11.0 (mmHg) B: 132.0 ± 13.0 (mmHg)	A: 72.0 ± 9.0 (mmHg) B: 78.0 ± 13.0 (mmHg)	There were significant differences in BP before and after treatment between the two groups ($P < 0.05$). There was a significant difference in the effective rate between two groups after treatment; the effective rate in group A was significantly greater than that in group B ($P < 0.05$).

Table 2 (continued)

Trial	Baseline BP		BP after treatment		Results
	SBP	DBP	SBP	DBP	
Zhang (2016)	A: 168.31 ± 18.24 (mmHg) B: 169.96 ± 16.81 (mmHg)	A: 95.61 ± 12.42 (mmHg) B: 96.23 ± 13.31 (mmHg)	A: 128.93 ± 10.12 (mmHg) B: 138.31 ± 11.12 (mmHg)	A: 76.83 ± 14.23 (mmHg) B: 83.35 ± 13.93 (mmHg)	The total effective rate was higher in group A than in group B, but there was no significant difference. After treatment, BP decreased in both groups; the decrease in group A was greater, and the difference was statistically significant ($P < 0.05$). There were no adverse reactions.
Luo (2017)	A: 163.58 ± 12.58 (mmHg) B: 164.04 ± 12.47 (mmHg)	A: 100.77 ± 9.96 (mmHg) B: 101.02 ± 9.98 (mmHg)	A: 121.35 ± 10.38 (mmHg) B: 138.95 ± 11.68 (mmHg)	A: 84.06 ± 7.11 (mmHg) B: 95.52 ± 7.78 (mmHg)	After treatment, the BP of both groups showed a downward trend, and BP was significantly lower in group A ($P < 0.05$). Treatment compliance was also greater in group A.
Yang (1997)	> 21.32 kPa	> 11.9 kPa	Effective was defined as the decrease of SBP ≥ 1.30 kPa or the decrease of DBP ≥ 0.65 kPa; effective rate of group A was 91.1% and group B was 71.1%		The effective rate of group A was higher than that of group B ($P < 0.05$).
Su (2015)	A: 155 ± 6.16 (mmHg) B: 150 ± 4.19 (mmHg)	No data	A: 126 ± 2.41 (mmHg) B: 138 ± 3.17 (mmHg)	No data	After the treatment, blood glucose, BP, and BMI decreased, and there were significant differences in blood glucose and BP between group A and group B. Before and after treatment, no abnormalities in liver and kidney functions were found, and there were no adverse reactions and no withdrawal.

BP blood pressure, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *BMI* body mass index, *CRP* C-reactive protein, *RBC* red blood cells, *Hct* hematocrit, *Hb* hemoglobin, *RDW* red blood cell width distribution

Data are shown as mean ± standard deviation

for the use of public baths, such as open wounds; immersion in thermoneutral water (> 1 per week) in the past 2 months; pregnancy; and participation in other interventional studies (Naumann et al. 2015, 2016). The exclusion criteria in another study were damages to the heart, brain, kidney, or other parenchymal organs; secondary hypertension due to kidney disease; endocrine disorders; and aortic malformation (Li and Jin 2014). One study established the exclusion criteria as mental disorders, malignant tumors, and severe liver or kidney disease (Liu et al. 2017), while another one set the criterion as previous history of stroke or cardiac surgery (Li et al. 2013). Two studies excluded patients with secondary hypertension, bronchial asthma, diabetes mellitus, gout, cardiac insufficiency, sick sinus syndrome, atrioventricular block and other organic heart diseases, other serious medical diseases, and abnormal liver and kidney functions (Liu and Hu 2009; Fang et al. 2014 and Hu et al. 2013).

Assessment of risk of bias

All the studies had high risk of bias in overall judgment, especially in "bias due to deviations from intended interventions" and "bias in measurement of the outcome" parts (Table 3).

Research design

One study had three treatment arms (Naumann et al. 2015, 2016), and the other 11 studies had two treatment arms. One study grouped patients by randomization codes and used blinding (Naumann et al. 2015, 2016); three studies grouped patients by a random number table (Fang et al. 2014 and Hu et al. 2013; Liu et al. 2017; Luo 2017); and the other studies provided no details. The data management and analysis of one study were performed with blinding to the treatment allocation (Naumann et al. 2015, 2016). Single-blind method was applied in one study, with the participants not knowing the design of the study (Liu and Hu 2009). The use of single-blind method was mentioned in one study but without the description of details (Li et al. 2013).

Baseline

Three studies did not describe the baseline characteristics of the participants. Baseline comparisons between groups in the remaining studies included age, sex, weight, body mass index (BMI), BP, etiology of disease, occupation, severity of illness, blood glucose level, blood lipid level, education level, and living habits. Except for the study by Naumann et al. (2015, 2016), which showed statistically significant differences in fasting blood glucose level and the use of antihypertensive medication at baseline among the 3 groups, there were no statistically significant differences in the baseline characteristics between the 2 groups in the other 11 studies.

Intervention

One study set two intervention groups as intervention group 1 and intervention group 2 undergoing the HINTMW at different frequencies, while the control group was advised to practice relaxation at home. All groups were given written information about nonpharmacological methods to reduce BP and advised to follow the instructions (Naumann et al. 2015, 2016).

One study combined HINTMW with natural convalescent factor therapy as the intervention. Natural convalescent factor therapy refers to, among others, the maintenance of indoor air circulation, a quiet and comfortable environment, and regular life; reduction of adverse stimuli; exposure to ornamental features in various landscapes; and rest in areas rich in negative oxygen ions. The control group did not receive the above interventions (Li and Jin 2014).

In one study, both groups underwent basic recuperation, while only the intervention group received HINTMW and psychotherapy. The basic recuperation included general psychotherapy, physical therapy, general balneotherapy, and landscape therapy. In addition, three lectures were given to all patients in the early, middle, and late stages of the whole treatment, the content of which included basic information about hypertension, the principle and effect of floating therapy, the principle and effect of balneotherapy, and how to deal with life events, as well as other mental health–related topics. Instructions were given to patients to relax their muscles and guide their inner thoughts. Psychotherapy refers to a psychological therapy delivered with light music before and during HINTMW, in which the therapists used gentle, soothing language as a psychological treatment and guided patients into a state of deep relaxation (Liu et al. 2017).

Two studies combined HINTMW with exercises: low-intensity aerobic exercise (Liu and Hu 2009) and shadowboxing (Li et al. 2013). The control groups in both studies did not receive the above interventions.

One study combined HINTMW with nutrition therapy. Nutrition therapy refers to reducing the intake of sodium salt; reducing dietary fat; supplementing the diet with appropriate amounts of high-quality protein, minerals, and potassium and calcium; eating more fresh vegetables and fruits; and taking adequate vitamin supplements (Zhang 2016).

The intervention of one study was comprehensive nursing care, including HINTMW, mental nursing, and medication guiding (Luo 2017).

In one study, because the participants had diabetes, they all received diabetes-related treatments and diets (Su 2015).

Table 3 The included studies' assessment of risk of bias

Trial	Bias arising from the randomization process	The effect of adhering to intervention	Bias due to missing outcome data	Bias in measurement of the outcome	Bias in selection of the reported result	Overall risk-of-bias judgment
Naumann et al. (2015, 2016)	Low risk	High risk	Low risk	Some concerns	Low risk	High risk
Peng (1994)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Li and Jin (2014)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
He (2009)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Fang et al. (2014) and Hu et al. (2013)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Liu et al. (2017)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Liu and Hu (2009)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Li et al. (2013)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Zhang (2016)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Luo (2017)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Yang (1997)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk
Su (2015)	Some concerns	High risk	Low risk	High risk	Some concerns	High risk

Four studies used HINTMW as the only intervention (Peng 1994; He 2009; Fang et al. 2014 and Hu et al. 2013; Yang 1997).

It should be noted that not all the participants in the study by Naumann et al. (2015, 2016) received antihypertensive drugs; some participants only continued the practices they had been using before entering the study. Also, the participants in the intervention group of Yang's (1997) study did not take antihypertensive drugs. Participants in the other 10 studies took antihypertensive drugs.

Some studies described instructions regarding HINTMW. Two studies stated the details that immersion was prohibited on an empty stomach or after a full meal; the duration of immersion should not be too long; immersion should be stopped if any discomfort occurred during bathing; immersion was prohibited for patients with severe heart failure, respiratory failure, and cardio-cerebrovascular disease; and companions were required for older and weaker patients (He 2009; Fang et al. 2014 and Hu et al. 2013). Two studies reported that participants should immerse slowly; the temperature of the water should be increased gradually according to the condition and tolerance of participants; when immersed in the water, the participants should adopt a sitting or semi-lying position and keep the anterior cardiac region above the water; the skin color and sweating condition of the participants should be observed; participants should get out of the water if their breathing and pulse markedly increased or if they experienced temporary limb numbness, palpitations, sweating, shortness of breath, dizziness, or other symptoms during the treatment; participants should sit up or stand up slowly to avoid postural hypotension; and they should dry themselves with a towel immediately after immersion (Luo 2017; Yang 1997).

The temperature of the immersion water was mainly between 37 and 40 °C, with the lowest temperature being 34–36 °C in the study by Naumann et al. (2015, 2016). Each immersion time was less than 60 min, ranging between 15 and 30 min in most studies. Immersion frequency ranged from 3 to 5 times per week to 2–3 times per day. The total intervention time ranged from 10 days to 24 weeks. Six studies continued for no more than 1 month and five studies continued for more than 1 month, while one study had no defined duration (Luo 2017).

Outcome measures

The outcome measures of these studies included BP, BMI, relevant indicators of erythrocyte count, waist circumference, blood lipid levels, fasting blood glucose, C-reactive protein (CRP), satisfaction, and liver and kidney function. There were some differences in the measurement of BP. The morning home BP, morning office BP, and 24-h ambulatory BP were measured before the intervention, during the intervention (at 4 weeks), and after the intervention (at 24 weeks) in one study (Naumann et al. 2015, 2016). The BP was measured before and after the whole treatment in three studies (Peng 1994; Li and Jin 2014;Liu et al. 2017). In the remaining studies, the BP was measured daily or before and after each HINTMW.

Results

The results of Naumann et al. showed no significant differences in BP between the groups after either 4 or 24 weeks, with no significant differences between the groups in BMI, waist circumference, blood lipid level, fasting blood glucose, or CRP. The results of Peng (1994) showed that the effect of reducing DBP in the intervention group was greater than that in the control group, while the effect of reducing SBP in the control group was greater than that in the intervention group.

The results of other studies showed that the antihypertensive effects in the intervention groups were greater than those in the control groups. Five studies (He 2009; Fang et al. 2014 and Hu et al. 2013; Liu et al. 2017; Yang 1997; Li et al. 2013) showed that the effective rate in the intervention groups was higher than that in the control groups, and the differences were statistically significant. Zhang's (2016) study showed that the total effective rate in the intervention group was higher than that in the control group, but there was no significant difference. The term "effective" meant, in He's (2009) study, that the BP decreased; in Li et al.'s (2013) study, that the decrease in DBP or SBP was more than 5%; in Yang's (1997) study, that the SBP decreased by no less than 1.30 kPa or the DBP decreased by no less than 0.65 kPa; and in the other three studies (Fang et al. 2014 and Hu et al. 2013; Liu et al. 2017; Zhang 2016), that the DBP decreased by less than 10 mmHg but the DBP dropped to a normal range, or the DBP decreased by more than 10 mmHg, or the SBP decreased at least by 30 mmHg.

In one study (Fang et al. 2014 and Hu et al. 2013), after the treatment, the red blood cells (RBC), hematocrit (Hct), hemoglobin (Hb), and red blood cell width distribution (RDW) values of the intervention group were significantly different from before treatment and were different from those of the control group. One study showed that the blood lipid parameters after treatment in the intervention group were significantly different from those in the control group (Liu and Hu 2009). In one study (Su 2015), after the treatment, blood glucose level and BMI decreased, and the decrease in blood glucose level was greater in the intervention group than in the control group; before and after treatment, no abnormalities in liver and kidney functions were found.

In one study, the total satisfaction rate in the intervention group (98.57%) was significantly higher than that in the control group (81.43%) (Liu et al. 2017). Regarding the treatment compliance of the two groups, the intervention group was more compliant than the control group (Luo 2017), according to the number of patients who adhered to the medical treatment, recommended weight control, reasonable diet, regular review, and other compliance behavior.

No adverse reactions or withdrawals were reported.

Discussion

This review included 12 randomized controlled trials and 14 articles. We found only in one study HINTMW was used as the only intervention compared with drug therapy to investigate whether HINTMW has a direct therapeutic effect on hypertension (Yang 1997). The interventions in 10 studies were based on medication while HINTMW was only reported to be effective as an adjuvant therapy. However, the interventions in 8 studies were HINTMW combined with other methods, and the results showed the combined effect of all the treatments.

The results of Naumann et al. showed the intervention of HINTMW had no significant effects. The reason is that in his study the duration of the intervention was the longest of all the studies included, but the water temperature for HINTMW was the lowest and the participants in his control group were also advised to practice relaxation at home. Most of the studies included were written in Chinese, and there might be publication bias because Chinese studies tended to report positive results.

Many factors affect hypertension, such as eating habits, smoking and drinking, lifestyle habits, exercise, and mood (Carretero and Oparil 2000), all of which should be controlled or monitored to reduce their impact on the outcomes. Hypertension is also greatly affected by emotions, so the use of blinding is very important. A placebo design, such as an intervention of tap water immersion in a control group, is needed.

Most Chinese studies we included in this review did not give specific descriptions of randomization methods and information of allocation masking, so more importance should be attached to these problems in study design and reporting. The included Chinese studies also described little clear information about compliance with the intervention, leading to the assessment of intervention bias at high risk. In the included Chinese studies, a mercury sphygmomanometer was used to measure the blood pressure, so if the blood pressure measurers knew the grouping of the participants, bias would occur in outcome measurement. Therefore, it is suggested that blinding should be adopted for blood pressure measurers or electronic sphygmomanometer should be used to measure the blood pressure.

Conclusion

The aim of this review was to summarize the current available information on the clinical effects of head-out immersion in natural thermal mineral water in the management of hypertension. We included 12 trials and 14 articles in the review, with 12 articles written in Chinese and 2 in English. Our results showed that natural thermal mineral water immersion alone, or immersion as an adjuvant therapy to medication, or immersion combined with other interventions had no adverse effects on hypertensive patients and generally had positive effects. However, it is difficult to compare the outcomes of various studies as the baseline characteristics of the patients in these studies were heterogeneous, and the interventions differed in type, intensity, and length of time; furthermore, the treatment protocols in some studies consisted of different combinations of modalities. Therefore, additional RCTs with high methodological quality that evaluate the therapeutic effectiveness of

natural thermal mineral water immersion on hypertension are needed to provide robust evidence.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Ablin JN, Häuser W, Buskila D (2013) Spa treatment (balneotherapy) for fibromyalgia—a qualitative-narrative review and a historical perspective. Evid Based Complement Alternat Med 2013(2):638050

Aburto NJ, Hanson S, Gutierrez H, Hooper L, Elliott P, Cappuccio FP (2013) Effect of increased potassium intake on cardiovascular risk factors and disease: systematic review and meta-analyses. BMJ 346: f1378

Antonelli M, Donelli D (2018) Effects of balneotherapy and spa therapy on levels of cortisol as a stress biomarker: a systematic review. Int J Biometeorol:1–2), 1-12

Blumenthal JA, Babyak MA, Hinderliter A et al (2010) Effects of the DASH diet alone and in combination with exercise and weight loss on blood pressure and cardiovascular biomarkers in men and women with high blood pressure: the ENCORE study. Arch Intern Med 170:126–135

Carlson DJ, Dieberg G, Hess NC, Millar PJ, Smart NA (2014) Isometric exercise training for blood pressure management: a systematic review and meta-analysis. Mayo Clin Proc 89:327–334

Carretero OA, Oparil S (2000) Essential hypertension: Part I: Definition and etiology. Circulation 101(3):329–335

Christensen P, Clemensen P, Andersen PK, Henneberg SW (2000) Thermodilution versus inert gas re-breathing for estimation of effective pulmonary blood flow. Crit Care Med 28(1):51–56

Christie JL, Sheldahl LM, Tristani FE, Wann LS, Sagar KB, Levandoski SG, Ptacin MJ, Sobocinski KA, Morris RD (1990) Cardiovascular regulation during head-out water immersion exercise. J.appl.physiol 69(2):657–664

Cornelissen VA, Smart NA (2013) Exercise training for blood pressure: a systematic review and meta-analysis. J Am Heart Assoc 2:e004473

Ercegrukavina T, Stefanovski M (2014) Effects of Sulphate-Sulphide Mineral Water "Mlječanica" in Patients with Hypertension. Materia Socio Medica 26(6): 364–365

Fang L, Hu DY, Wang JS et al (2014) Observation of curative effect of Xingcheng mineral spring bath adjuvant medication on essential hypertension. Chin J Phys Med Rehabilitation 36(1) (in Chinese)

Gabrielsen A, Sørensen VB, Pump B, Galatius S, Videbæk R, Bie P, Warberg J, Christensen NJ, Wroblewski H, Kastrup J, Norsk P (2000) Cardiovascular and neuroendocrine responses to water immersion in compensated heart failure. AJP Heart Circ Physiol 279(4):H1931–H1940

Hao WP, Feng YH, Cheng JF, Li Q, Chai GD (2013) Study on sulfuretted hydrogen mineral bath to treat hypertension and hyperhomocysteinemia. Chin J Convalescent Med 22(4):295–297 (in Chinese)

He JH (2009) Therapeutic effect of nitrendipine combined with mineral spring bath. Chin J Convalescent Med 18(2):116–117 (in Chinese)

He FJ, Li J, MacGregor GA (2013) Effect of longer term modest salt reduction on blood pressure: Cochrane systematic review and meta-analysis of randomised trials. BMJ 346:f1325

Hu PC, Wang RR, Shang ZH et al (2000) Floating therapy in treatment of patients with primary hypertension. Chin Ment Health J 14(6):414–416 (in Chinese)

Hu DY, Fang L, He D, Wang JS, Li GM, Shao DM et al (2013) Effect of Xingcheng mineral spring bath combined with levamlodipine benzenesulfonate on essential hypertension. Chin J Convalescent Med 22(8):682–683 (in Chinese)

Inder JD, Carlson DJ, Dieberg G, McFarlane JR, Hess NCL, Smart NA (2016) Isometric exercise training for blood pressure management: a systematic review and meta-analysis to optimize benefit. Hypertens Res 39:88–94

Su K (2015) Effects of spring immersiom on blood glucose and blood pressure in type 2 diabetic patients combined with hypertension. The 9th Beijing International Forum on Rehabilitation (in Chinese)

Kuliński W (2015) Hydrobalneological methods in modern medical treatment. Med Stud 1:1–5

Lewington S, Clarke R, Qizilbash N et al (2002) Age-specific relevance of usual blood pressure to vascular mortality: a meta-analysis of individual data for one million adults in 61 prospective studies. Lancet 360:1903–1913

Li Y, Jin J (2014) Effect of natural convalescent factors on blood pressure in patients with hypertension in Kunming hot spring area. ChinJ Convalescent Med 23(2):120–121 (in Chinese)

Li D, Zhang W, Men HY et al (2013) Specialized convalescent measures–Taijiquan combined with mineral spring bath for rehabilitation of hypertensive convalescents. Chin J Convalescent Medicine 22(4): 321–322 (in Chinese)

Liu MJ, Hu DY (2009) Effect of exercises combined with mineral bath on blood pressure and blood fat in patients with primary hypertension. Chin J Convalescent Med 18(9):774–776 (in Chinese)

Liu HZ, Zhang W, Liu HH (2017) Effect of Xingcheng hot spring bath on blood pressure control and improvement of clinical symptoms in middle-aged hypertensive patients. Chinese Journal of Convalescent Medicine 26(4) (in Chinese)

Luo HY (2017) Nursing effect observation of comprehensive nursing applied to radon spring hydrotherapy combined with drug treatment for hypertension. Journal of Clinic Nursing's Practicality 2(40) (in Chinese)

Manzur F, Rico A, Romero JD, Rodriguez-Martinez CE (2018) Efficacy and safety of valsartan or chlorthalidone vs. combined valsartan and chlorthalidone in patients with mild to moderate hypertension: the VACLOR study. Clin Med Insights Cardiol 12:1179546818796482. https://doi.org/10.1177/1179546818796482

Miller T (2015) Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet 386: 2287–2323

Naumann J, Bureau N, Schmidt S, Sadaghiani C, Huber R (2015) A single center three-arm parallel-group, randomized controlled study to evaluate antihypertensive effects of frequent immersion in thermoneutral water. Int J Cardiol 188:73–75

Naumann J, Sadaghiani C, Bureau N, Schmidt S, Huber R (2016) Outcomes from a three-arm randomized controlled trial of frequent immersion in thermoneutral water on cardiovascular risk factors. BMC Complement Altern Med 16(1):250

Neter JE, Stam BE, Kok FJ, Grobbee DE, Geleijnse JM (2003) Influence of weight reduction on blood pressure: a meta-analysis of randomized controlled trials. Hypertension 42:878–884

Nishimura M, Onodera S (2000) Effects of supine floating on heart rate, blood pressure and cardiac autonomic nervous system activity. J Gravit Physiol A J Int Soc Gravit Physiology 7(2):P171

Peng GX (1994) Observation on curative effect of mineral spring bath combined with compound hypotensive tablets in treating 43 cases of hypertension. J Convalescence and Rehabilitation 1:27–28 (in Chinese)

Rapsomaniki E, Timmis A, George J, Pujades-Rodriguez M, Shah AD, Denaxas S, White IR, Caulfield MJ, Deanfield JE, Smeeth L, Williams B, Hingorani A, Hemingway H (2014) Blood pressure

and incidence of twelve cardiovascular diseases: lifetime risks, healthy life-years lost, and age-specific associations in 1.25 million people. Lancet 383:1899–1911

Resch KL, Just U (1994) Possibilities and limits of CO_2 balneotherapy. Wiener medizinische Wochenschrift 144(3):45–50

Roerecke M, Kaczorowski J, Tobe SW, Gmel G, Hasan OSM, Rehm J (2017) The effect of a reduction in alcohol consumption on blood pressure: a systematic review and meta-analysis. Lancet Public Health 2:e108–e120

Rühle PF, Klein G, Rung T et al (2018) Impact of radon and combinatory radon/carbon dioxide spa on pain and hypertension: results from the explorative RAD-ON01 study. Mod Rheumatol 29(1):1–22

Sik Park K, Kyu Choi J, Saeng Park Y (1999) Cardiovascular regulation during water immersion. APPL HUM SCI J Physiol Anthropol 18(6):233–241

Smith D (1998) Cardiac effects of water immersion in healthy volunteers. Echocardiography 15:35–42

Stadeager C, Johansen LB, Warberg J, Christensen NJ, Foldager N, Bie P, Norsk P (1992) Circulation, kidney function, and volume-regulating hormones during prolonged water immersion in humans. J Appl Physiol 73(2):530–538

Whelton PK, Carey RM, Aronow WS, Casey Jr DE, Collins KJ, Dennison Himmelfarb C, DePalma SM, Gidding S, Jamerson KA, Jones DW, MacLaughlin EJ, Muntner P, Ovbiagele B, Smith Jr SC, Spencer CC, Stafford RS, Taler SJ, Thomas RJ, Williams Sr KA, Williamson JD, Wright Jr JT (2017) ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. J Am Coll Cardiol pii: S0735-1097(17)41519-1, https://doi.org/10.1016/j.jacc.2017.11.006, 71, e127, e248

Yamaoka K, Mitsunobu F, Hanamoto K et al (2004) Biochemical comparison between radon effects and thermal effects on humans in radon hot spring therapy. J Radiat Res 45(1):83–88

Yang LY (1997) Observation on curative effect of radon spring bath on hypertension. Chin J Convalescent Med (1):79–80 (in Chinese)

Zhang ZA (2016) Observation of curative effect of comprehensive physiotherapy on patients with essential hypertension. Women's Health Res 13:80、82 (in Chinese)