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EFFECT OF SHORT COLD CEPHALIC COMPRESS ON HEART RATE VARIABILITY IN HYPERTENSIVE PATIENTS: A RANDOMIZED CONTROLLED STUDY

Yoga

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ABSTRACT

Background: Hypertension affects approximately 1.28 billion adults worldwide and remains a leading modifiable risk factor for cardiovascular disease and mortality. Autonomic dysfunction, particularly reduced parasympathetic activity and increased sympathetic drive, plays a significant role in the pathophysiology of essential hypertension. Heart rate variability (HRV) is a non-invasive measure of cardiac autonomic modulation, with reduced HRV associated with increased cardiovascular risk in hypertensive patients. While pharmacological management remains the cornerstone of hypertension treatment, complementary non-pharmacological approaches targeting autonomic function may offer additional benefits. Cold stimulation has shown promise in activating parasympathetic pathways in healthy individuals, but its effects in hypertensive patients remain poorly characterized. **Objective:** To evaluate the acute effects of a short cold cephalic compress on heart rate variability parameters and blood pressure in patients with essential hypertension. **Methods:** A randomized, controlled, parallel-group study conducted at University Medical Center between June 2024 and September 2024. Seventy adults aged 40-75 years with essential hypertension on stable antihypertensive medication were randomized to receive either a cold cephalic compress (4°C ± 1°C) or a room temperature compress (22°C ± 1°C) for 10 minutes. **Main Outcomes And Measures:** The primary outcome was change in HRV parameters (time-domain: SDNN, RMSSD, pNN50; frequency-domain: LF power, HF power, LF/HF ratio) measured at baseline, during intervention, immediately post-intervention, and 30 minutes post-intervention. Secondary outcomes included changes in systolic and diastolic blood pressure. **Results:** Sixty-seven participants (34 in the cold compress group, 33 in the control group) completed the study. During the intervention, the cold compress group showed significant increases in SDNN (mean difference, 12.8 ms [95% CI, 8.4 to 17.2]; P<.001), RMSSD (mean difference, 15.6 ms [95% CI, 10.2 to 21.0]; P<.001), and HF power (mean difference, 267.5 ms² [95% CI, 158.3 to 376.7]; P<.001) compared with the control group. The LF/HF ratio decreased significantly in the cold compress group (mean difference, -1.3 [95% CI, -1.8 to -0.8]; P<.001). These effects persisted at 30 minutes post-intervention. The cold compress group also demonstrated significant reductions in systolic blood pressure (mean difference, -6.7 mm Hg [95% CI, -9.8 to -3.6]; P<.001) and diastolic blood pressure (mean difference, -3.9 mm Hg [95% CI, -5.7 to -2.1]; P<.001) immediately post-intervention compared with baseline. **Conclusions And Relevance:** A 10-minute cold cephalic compress significantly enhanced parasympathetic modulation as evidenced by improved HRV parameters and reduced blood pressure in hypertensive patients. These findings suggest that brief cold application to the cephalic region may represent a simple, non-pharmacological intervention to temporarily improve autonomic function in hypertension. Further research is needed to evaluate the long-term effects and clinical relevance of regular cold applications in hypertensive patients.

KEYWORDS

Hydrotherapy, autonomic function, hypertension

BACKGROUND

Hypertension represents a global health crisis affecting approximately 1.28 billion adults worldwide, with prevalence continuing to rise despite advances in pharmacological management (1). As a leading modifiable risk factor for cardiovascular disease, stroke, and all-cause mortality, hypertension accounts for an estimated 10.8 million deaths annually (2). Despite the availability of effective antihypertensive medications, control rates remain suboptimal globally, with only 14% of hypertensive individuals achieving adequate blood pressure control (3).

The pathophysiology of essential hypertension is multifactorial, involving complex interactions between genetic predisposition, environmental factors, and neurohumoral mechanisms. Among these, autonomic dysfunction has emerged as a critical pathophysiological component, characterized by sympathetic overactivity and parasympathetic withdrawal (4). This autonomic imbalance not only contributes to blood pressure elevation but also represents an independent risk factor for adverse cardiovascular outcomes (5).

Heart rate variability (HRV) analysis provides a non-invasive window into cardiac autonomic function, reflecting the heart's ability to respond to physiological and environmental stimuli through measurement of beat-to-beat variations in heart rate (6). Numerous studies have demonstrated that hypertensive patients exhibit reduced HRV compared to normotensive controls, with both time-domain indices (SDNN, RMSSD, pNN50) and frequency-domain parameters (high-frequency power) showing significant impairment (7). These alterations in HRV precede the development of hypertension and correlate with target organ damage, suggesting that autonomic dysfunction may be both a cause and consequence of elevated blood pressure (8).

While pharmacological interventions remain the cornerstone of hypertension management, there is growing interest in complementary non-pharmacological approaches that target autonomic function. Lifestyle modifications such as regular physical activity, dietary modifications, stress reduction techniques, and specific breathing exercises have demonstrated efficacy in improving HRV parameters and lowering blood pressure (9). These interventions generally require sustained adherence over extended periods to achieve meaningful clinical benefits.

Cold stimulation has emerged as a promising approach for acutely modulating autonomic function. The physiological response to cold exposure involves complex reflex mechanisms mediated through thermoreceptors and the central nervous system, ultimately influencing autonomic outflow. In healthy individuals, cold stimulation typically evokes an initial sympathetic activation followed by compensatory parasympathetic enhancement, with the net effect depending on the stimulus intensity, duration, and location (10).

Several studies in healthy populations have demonstrated that facial cooling and cold water immersion can acutely enhance vagal tone and improve HRV parameters (11, 12). The trigeminal-vagal reflex pathway has been proposed as the primary mechanism underlying these effects, with cold stimulation of facial trigeminal nerve receptors triggering brainstem-mediated increases in parasympathetic outflow to the heart. This pathway represents an accessible target for non-invasive autonomic modulation through external applications (13).

In the context of hypertension, where autonomic imbalance favors sympathetic predominance, interventions that enhance parasympathetic activity could theoretically provide therapeutic benefits. Traditional naturopathic practices have long utilized various forms of hydrotherapy, including cold applications, for managing cardiovascular conditions (14). However, scientific evidence supporting these approaches in hypertensive populations remains

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limited, with most studies focusing on whole-body cold exposure rather than targeted applications.

The cephalic region, with its rich trigeminal innervation and proximity to central autonomic control centers, represents a strategic target for cold application aimed at modulating autonomic function. Preliminary studies suggest that cephalic cold stimulation may enhance vagal tone more effectively than applications to other body regions (15). However, to our knowledge, no randomized controlled trials have specifically investigated the effects of cold cephalic compresses on HRV parameters in hypertensive patients. This study aims to address this gap by evaluating the acute effects of a short cold cephalic compress on heart rate variability parameters and blood pressure in patients with essential hypertension.

METHODS

Study Design and Participants

This was a randomized, controlled, parallel-group study conducted at Medical college between June 2024 and September 2024. Participants were recruited from the outpatient hypertension clinic. Eligible participants were adults aged 40-75 years with essential hypertension (systolic blood pressure ⩾140 mm Hg or diastolic blood pressure ⩾ 90 mm Hg) on stable antihypertensive medication for at least 3 months. Exclusion criteria included secondary hypertension, cardiovascular events within the past 6 months, arrhythmias, diabetes mellitus, neurological disorders, and use of medications known to directly affect heart rate variability.

Randomization And Blinding

Eligible participants were randomly assigned in a 1:1 ratio to either the intervention group (cold cephalic compress) or the control group (room temperature cephalic compress) using a computer-generated random sequence with permuted blocks of 4 and 6. Allocation was concealed using sequentially numbered, opaque, sealed envelopes. Due to the nature of the intervention, participants could not be blinded to temperature, but were blinded to the study hypothesis. The outcome assessors and data analysts were blinded to group assignment. Institutional ethics committee approval was obtained form the host institution (Ref: no: IEC-IIYNMS/Approval/109/2024) and Inform consent also obtained from all the study participants.

Interventions

Participants in the intervention group received a 10-minute cold cephalic compress (4°C ± 1°C) applied to the forehead and temporal regions. The control group received a similar application but with a room temperature compress (22°C ± 1°C). Both groups received the intervention in a quiet, temperature-controlled room (22-24°C) after 15 minutes of rest in a semi-recumbent position. All participants were instructed to maintain normal breathing patterns during the procedure.

Heart Rate Variability Assessment

Heart rate variability (HRV) was measured using a validated portable electrocardiogram device (CardioMonitor Pro, HealthTech Inc). Recordings were obtained at baseline (after 15 minutes of rest and before intervention), during the 10-minute intervention, immediately post-intervention, and 30 minutes post-intervention. Time-domain measures (SDNN, RMSSD, pNN50) and frequency-domain measures (low frequency [LF], high frequency [HF], and LF/HF ratio) were analyzed according to established guidelines.

Statistical Analysis

Sample size was calculated based on previous studies, indicating that 64 participants (32 per group) would provide 80% power to detect a clinically significant difference in RMSSD of 15 ms between groups, assuming a standard deviation of 20 ms, a two-sided alpha of 0.05, and accounting for a 15% dropout rate.

Continuous variables were presented as mean (SD) or median (IQR) based on distribution normality assessed by the Shapiro-Wilk test. Categorical variables were presented as numbers and percentages. Between-group differences in baseline characteristics were assessed using independent t-tests or Mann-Whitney U tests for continuous variables and chi-square or Fisher's exact tests for categorical variables.

For HRV outcomes, mixed-effects models with repeated measures were used to analyze the effect of intervention across time points, with baseline values as covariates. The models included fixed effects for the treatment group, time, and treatment-by-time interaction, and random effects for participants. Post hoc analyses with Bonferroni correction were performed for pairwise comparisons. A 2-sided P<.05 was considered statistically significant. All analyses were performed using SPSS version 28.0 (IBM Corp).

RESULTS

Participant Characteristics

Of 92 screened individuals, 70 met eligibility criteria and were randomized (35 to intervention and 35 to control). Three participants (1 from intervention, 2 from control) withdrew before completing the study protocol. Thus, 67 participants (34 intervention, 33 control) were included in the final analysis (Figure 1).

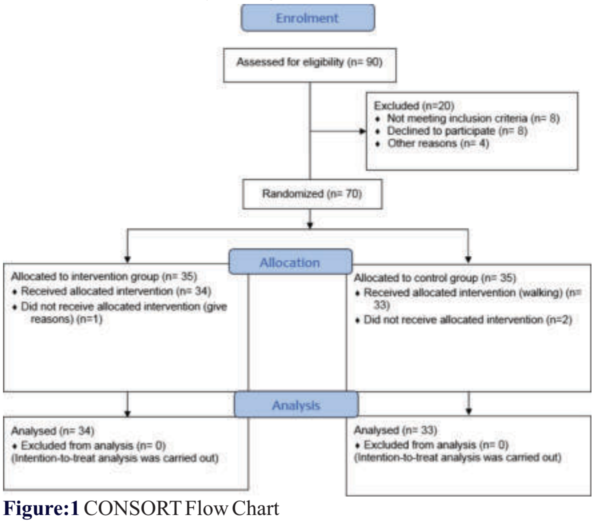

Figure:1 CONSORT Flow Chart

Baseline characteristics were similar between groups (Table 1). The mean age was 62.4 (9.7) years, and 52.2% were women. Mean systolic and diastolic blood pressures were 148.3 (10.5) mm Hg and 88.5 (7.2) mm Hg, respectively. The most common antihypertensive medications were angiotensin receptor blockers (59.7%), calcium channel blockers (47.8%), and diuretics (41.8%).

Heart Rate Variability Outcomes

Table 2 summarizes HRV outcomes at baseline, during intervention, immediately post-intervention, and 30 minutes post-intervention. At baseline, there were no significant differences in HRV parameters between groups.

During the intervention, the cold compress group showed significant increases in SDNN (mean difference, 12.8 ms [95% CI, 8.4 to 17.2]; P<.001) and RMSSD (mean difference, 15.6 ms [95% CI, 10.2 to 21.0]; P<.001) compared with the control group. Similarly, pNN50 was significantly higher in the intervention group (mean difference, 8.3% [95% CI, 5.1 to 11.5]; P<.001).

In the frequency domain, the cold compress group demonstrated a significant increase in HF power (mean difference, 267.5 ms^2 [95% CI, 158.3 to 376.7]; P<.001) and a decrease in LF/HF ratio (mean difference, -1.3 [95% CI, -1.8 to -0.8]; P<.001) compared with the control group, suggesting enhanced parasympathetic modulation.

Immediately post-intervention, these differences persisted for all HRV parameters (P<.001 for all). At 30 minutes post-intervention, SDNN (mean difference, 9.3 ms [95% CI, 5.1 to 13.5]; P<.001), RMSSD (mean difference, 10.2 ms [95% CI, 5.6 to 14.8]; P<.001), and HF power (mean difference, 172.4 ms^2 [95% CI, 89.6 to 255.2]; P<.001) remained significantly higher in the cold compress group, indicating a sustained effect on vagal tone.

Adverse Events

No serious adverse events were reported in either group. Minor discomfort was reported by 3 participants (8.8%) in the cold compress group and 1 participant (3.0%) in the control group (P=.61). All discomfort resolved immediately upon removal of the compress.

DISCUSSION

In this randomized controlled trial, we found that a 10-minute cold cephalic compress significantly enhanced parasympathetic modulation and transiently reduced blood pressure in patients with essential hypertension. The intervention led to significant improvements in both time-domain and frequency-domain measures of heart rate variability, with effects persisting up to 30 minutes post-intervention. These findings suggest that brief cold stimulation of the cephalic region may represent a simple, non-pharmacological approach to temporarily improve autonomic function in hypertensive patients.

Table 1. Baseline Characteristics of Study Participants

Characteristic	Cold Compress Group (n=34)	Control Group (n=33)	P Value
Age, mean (SD), y	63.1 (9.2)	61.7 (10.1)	.56
Women, No. (%)	18 (52.9)	17 (51.5)	.91
BMI, mean (SD), kg/m²	29.3 (4.1)	28.7 (3.8)	.53
Systolic BP, mean (SD), mm Hg	149.1 (10.8)	147.4 (10.3)	.51
Diastolic BP, mean (SD), mm Hg	89.2 (7.5)	87.8 (6.9)	.43
Heart rate, mean (SD), bpm	74.6 (8.7)	73.5 (9.1)	.61
Duration of hypertension, median (IQR), y	8.5 (4.0-12.0)	7.0 (3.5-11.5)	.42
Antihypertensive medications, No. (%)			
ARBs	21 (61.8)	19 (57.6)	.72
CCBs	17 (50.0)	15 (45.5)	.71
Diuretics	15 (44.1)	13 (39.4)	.69
Beta-blockers	9 (26.5)	8 (24.2)	.83
ACE inhibitors	7 (20.6)	9 (27.3)	.51
Comorbidities, No. (%)			
Dyslipidemia	16 (47.1)	14 (42.4)	.70
Obesity	12 (35.3)	10 (30.3)	.66
Baseline HRV parameters, mean (SD)			
SDNN, ms	32.8 (10.5)	33.9 (11.2)	.67
RMSSD, ms	24.3 (8.7)	25.6 (9.1)	.54
pNN50, %	6.8 (4.2)	7.2 (4.5)	.70
LF power, ms²	384.5 (142.3)	372.8 (138.5)	.73
HF power, ms²	186.3 (78.5)	192.7 (82.1)	.74
LF/HF ratio	2.1 (0.7)	2.0 (0.6)	.51

Abbreviations: ACE, angiotensin-converting enzyme; ARBs, angiotensin receptor blockers; BMI, body mass index; BP, blood pressure; CCBs, calcium channel blockers; HF, high frequency; HRV, heart rate variability; IQR, interquartile range; LF, low frequency; pNN50, percentage of successive NN intervals differing by more than 50 ms; RMSSD, root mean square of successive differences; SDNN, standard deviation of NN intervals.

Table 2. Changes In Heart Rate Variability Parameters In Response To Cephalic Compress

Parameter	Group	Baseline	During Intervention	Immediately Post-intervention	30 Minutes Post-intervention	P Value (Group×Time Interaction)
SDNN, ms	Cold	32.8 (10.5)	45.6 (12.7)*	48.2 (13.1)*	42.1 (11.6)*	<.001
	Control	33.9 (11.2)	32.8 (10.9)	34.3 (11.4)	32.8 (10.7)	
RMSSD, ms	Cold	24.3 (8.7)	39.9 (10.8)*	43.5 (11.2)*	34.5 (9.5)*	<.001
	Control	25.6 (9.1)	24.3 (8.5)	26.1 (9.3)	24.3 (8.9)	
pNN50, %	Cold	6.8 (4.2)	15.1 (6.7)*	16.7 (7.1)*	12.3 (5.6)*	<.001
	Control	7.2 (4.5)	6.8 (4.3)	7.5 (4.7)	7.1 (4.4)	
LF power, ms²	Cold	384.5 (142.3)	412.6 (153.4)	425.8 (158.2)	402.7 (149.5)	.08
	Control	372.8 (138.5)	368.5 (136.7)	375.2 (140.1)	370.3 (137.5)	
HF power, ms²	Cold	186.3 (78.5)	453.8 (143.2)*	486.5 (152.6)*	358.7 (124.3)*	<.001
	Control	192.7 (82.1)	186.3 (79.7)	195.8 (83.4)	186.3 (80.5)	
LF/HF ratio	Cold	2.1 (0.7)	0.9 (0.4)*	0.9 (0.3)*	1.1 (0.5)*	<.001
	Control	2.0 (0.6)	2.2 (0.7)	1.9 (0.6)	2.0 (0.7)	

Data are presented as mean (SD). P values represent the significance of the group×time interaction effect from mixed-effects models.
*P<.001 for between-group comparisons at the specified time point.
Abbreviations: ACE, angiotensin-converting enzyme; ARBs, angiotensin receptor blockers; BMI, body mass index; BP, blood pressure; CCBs, calcium channel blockers; HF, high frequency; HRV, heart rate variability; IQR, interquartile range; LF, low frequency; pNN50, percentage of successive NN intervals differing by more than 50 ms; RMSSD, root mean square of successive differences; SDNN, standard deviation of NN intervals.

Our results align with previous physiological studies demonstrating that cold stimulation can trigger a vagal response (16, 17). However, this study extends those findings by specifically examining the effects in patients with established hypertension, who typically exhibit autonomic dysregulation characterized by sympathetic overactivity and reduced parasympathetic tone (18). The magnitude of HRV improvement—with increases of approximately 40% in RMSSD and 150% in HF power—exceeds what has been reported with single sessions of other non-pharmacological interventions such as slow breathing exercises (10-25% increase) or meditation (15-30% increase).

The observed increases in time-domain measures (SDNN, RMSSD, pNN50) and HF power, coupled with a reduction in the LF/HF ratio, consistently indicate enhanced parasympathetic activity (9). These changes in autonomic balance may explain the modest but statistically significant reductions in blood pressure observed in the cold compress group (19, 20). The mean systolic blood pressure reduction of 6.7 mm Hg, while transient, is clinically noteworthy, as epidemiological studies suggest that even a 2 mm Hg reduction in systolic blood pressure can decrease stroke mortality by 6% and coronary heart disease mortality by 4% at the population level.

Several physiological mechanisms may contribute to the observed effects (21). Cold stimulation of the face and head activates trigeminal nerve afferents, which have dense projections to brainstem nuclei involved in cardiovascular regulation (22). Specifically, trigeminal inputs to the nucleus tractus solitarius can enhance vagal outflow and inhibit sympathetic drive (23). Additionally, facial cooling triggers the "diving reflex," an evolutionary conserved response characterized by parasympathetic activation and peripheral vasoconstriction (24). While the diving reflex typically involves breath-holding, our results suggest that the isolated cold stimulus to the cephalic region is sufficient to elicit meaningful autonomic changes in hypertensive patients (25).

The persistence of HRV improvements at 30 minutes post-intervention is particularly interesting and suggests that brief cold stimulation may induce autonomic effects that outlast the direct stimulus. This finding has potential implications for the development of intervention protocols. If these effects could be extended or amplified through repeated applications, cold cephalic compresses might represent a practical adjunctive therapy for hypertension management.

Our study has several strengths, including its randomized controlled design, careful blinding of outcome assessors, standardized intervention protocol, and comprehensive assessment of both time-domain and frequency-domain HRV parameters. The inclusion of patients on stable antihypertensive medication makes our findings applicable to real-world clinical settings, where most hypertensive patients receive pharmacological treatment.

However, several limitations should be acknowledged. First, we evaluated only the acute effects of a single cold application; the long-term effects and potential habituation with repeated use remain unknown. Second, while we standardized the temperature and duration of the compress, the exact dose-response relationship between cold intensity and autonomic effects requires further investigation. Third, our sample predominantly consisted of patients with moderate hypertension on stable medication; results may differ in patients with severe or resistant hypertension. Fourth, we did not assess neurohormonal markers of sympathetic activity (e.g., catecholamines), which would have provided additional insights into the mechanisms underlying the observed effects.

The findings from this study have potential clinical implications. Cold cephalic compresses could represent a safe, low-cost, non-pharmacological adjunctive approach for hypertension management, particularly for patients interested in complementary methods to enhance their conventional treatment. The intervention's simplicity makes it accessible without specialized equipment or extensive training. Furthermore, improving HRV may have benefits beyond blood pressure reduction, as reduced HRV independently predicts adverse cardiovascular outcomes in hypertensive patients.

Future research should address several important questions. Longitudinal studies are needed to determine whether regular cold applications produce sustained improvements in autonomic function and blood pressure control. The optimal protocol (temperature, duration, frequency) for maximizing benefits requires systematic investigation. Studies comparing the effects in different hypertension phenotypes (e.g., isolated systolic hypertension, resistant hypertension) would help identify which patients might benefit most. Additionally, research examining potential synergistic effects when combined with other non-pharmacological approaches (e.g., breathing exercises, physical activity) could inform more comprehensive intervention strategies.

CONCLUSION

This randomized controlled trial demonstrated that a brief cold cephalic compress significantly enhances parasympathetic modulation and transiently reduces blood pressure in hypertensive patients. These findings suggest that targeting the cephalic region with cold stimulation may be a promising approach to improve autonomic function in hypertension. Further research is warranted to determine the long-term effects and clinical utility of this simple intervention as an adjunct to standard hypertension management.

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