

## The Effect of Foot Bath with Magnesium Sulfate on Blood Pressure Stability in Hypertensive Patients

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**Abstract.** Fluctuations in blood pressure (BPV) can increase the risk of heart related problems. Simple, non-medical treatments, like foot baths with magnesium sulfate ( $\text{MgSO}_4$ ), may help lower blood pressure and promote overall heart health. To analyze the effect of foot baths with  $\text{MgSO}_4$  on the mean and short-term variability of systolic blood pressure (SBP) and diastolic blood pressure (DBP) in hypertensive patients. A randomized controlled trial was conducted at the Maos Community Health Center (July–August 2025) with 60 hypertensive patients randomly assigned to intervention (foot immersion with 2%  $\text{MgSO}_4$ ) or control (plain water). Blood pressure and variability (RMSSD, ARV, CV%) were measured across 15 sessions and analyzed using Repeated Measures ANCOVA ( $p < 0.05$ ). The mean SBP was significantly lower in the intervention group (140.1 vs 155.4 mmHg;  $p < 0.001$ ;  $d = 1.26$ ). RMSSD (9.6 vs 12.7;  $p < 0.001$ ) and ARV (7.4 vs 10.7;  $p < 0.001$ ) were significantly lower in the intervention group, indicating better SBP stability. ANCOVA revealed a significant group effect on RMSSD ( $F = 11.31$ ;  $p = 0.0014$ ;  $\eta^2 = 0.17$ ) and ARV ( $F = 17.50$ ;  $p = 0.0001$ ;  $\eta^2 = 0.24$ ). DBP did not show significant differences. Foot baths with  $\text{MgSO}_4$  reduced the average SBP and improved short-term SBP stability. This intervention has potential as a complementary non-pharmacological therapy for hypertension.

**Keywords:** ARV, Blood Pressure Variability, Foot Bath, Hypertension, Magnesium Sulfate, RMSSD

### 1 Introduction

High blood pressure remains one of the leading contributors to global morbidity and mortality. Traditionally, clinical management has emphasized the reduction of mean systolic and diastolic blood pressure; however, recent evidence highlights that blood pressure variability (BPV) is an equally important determinant of cardiovascular outcomes, including stroke, myocardial infarction, and overall mortality [1][2][3]. Magnesium, an essential mineral, plays a physiological role in vascular regulation through mechanisms such as smooth muscle relaxation, modulation of calcium influx, and anti-inflammatory effects. Several studies have demonstrated the benefits of oral magnesium supplementation in lowering blood pressure [4][5][6]. Nevertheless, lim-

ited evidence exists regarding the effectiveness of transdermal magnesium delivery, such as foot baths with magnesium sulfate ( $\text{MgSO}_4$ ), in influencing BPV. Although some preliminary findings suggest that magnesium ions ( $\text{Mg}^{2+}$ ) may be absorbed through the skin in measurable amounts [7], the clinical relevance of this pathway remains under debate. Foot baths with  $\text{MgSO}_4$  are hypothesized to provide dual benefits: potential transdermal magnesium absorption and a relaxation effect associated with immersion in warm water. However, to minimize confounding from thermal effects, the present study employs plain water at room temperature as a control condition, ensuring that any observed differences can be attributed primarily to magnesium exposure rather than heat-induced vasodilation or relaxation. This approach addresses a major methodological gap noted in previous trials that did not adequately control for placebo effects. As a non-invasive and accessible intervention,  $\text{MgSO}_4$  foot baths may offer a novel strategy for stabilizing blood pressure, particularly by reducing both mean systolic/diastolic levels and short-term BPV [8][9][10]. Accordingly, this study aims to evaluate the impact of  $\text{MgSO}_4$  foot baths compared with plain water foot baths on SBP, DBP, and short-term variability in patients with hypertension.

## 2 Methods

This study employed a randomized controlled trial (RCT) design to evaluate the effect of foot immersion with magnesium sulfate ( $\text{MgSO}_4$ ) on blood pressure stability among patients with chronic hypertension. The trial was conducted at the Maos Community Health Center, Cilacap Regency, Indonesia, between July 22 and August 22, 2025.

A total of 60 participants were recruited from the Chronic Disease Management Program (Prolanis) using probability random sampling. Inclusion criteria were: (1) a confirmed medical diagnosis of chronic hypertension by a physician, (2) age between 40–70 years, (3) absence of wounds or dermatological conditions on the lower extremities, and (4) not receiving other complementary therapies (e.g., herbal, relaxation-based, or dietary interventions) that could influence blood pressure. Exclusion criteria included irregular antihypertensive medication use and inability to complete the intervention protocol. After baseline assessment, participants were randomly allocated into two groups: the intervention group (immersion with 2%  $\text{MgSO}_4$  solution,  $n = 30$ ) and the control group (immersion in plain water at room temperature,  $n = 30$ ). The use of plain water as a control was intended to isolate the specific effect of magnesium ions while minimizing confounding effects of heat-induced vasodilation or relaxation.

The intervention consisted of foot immersion in room-temperature water (with or without 2%  $\text{MgSO}_4$ ) for approximately 20 minutes per session, administered every two days for a total of 15 sessions. All procedures were conducted at the same time of day (late afternoon) to control for circadian influences on blood pressure.

Blood pressure was measured immediately after each 20-minute immersion using a validated automatic sphygmomanometer, the Omron HEM-Series, which complies with the European Society of Hypertension validation protocol. Measurements were

performed in a seated position, with participants resting for at least 5 minutes post-immersion before recording. For accuracy, three consecutive readings were taken at one-minute intervals, and the average of the three readings was used for analysis. Short-term blood pressure variability (BPV) was operationally defined using standardized indices: Root Mean Square of Successive Differences (RMSSD), Average Real Variability (ARV), and the Coefficient of Variation (CV%). These indices were calculated from repeated blood pressure values obtained across the intervention period, consistent with established recommendations for short-term BPV assessment [3][11].

Data analysis was conducted using Repeated Measures ANCOVA to assess within- and between-group differences over time, adjusting for age and sex as covariates. The model examined longitudinal changes in systolic blood pressure (SBP), diastolic blood pressure (DBP), and short-term variability indices. Statistical significance was set at  $p < 0.05$ .

2.1 Ethical Statement

This study was approved by the Health Research Ethics Committee of Muhamadiyah University Purwokerto, registration number KEPK/UMP/187/VII/2025. All procedures followed the ethical standards for research, and all participants provided informed consent in accordance with established guidelines.

3 Results and Discussion

3.1 Respondent Characteristics

Table 1. Participant Details by Group

| Variable          | Control (n=30)          | Intervention (n=30)     |
|-------------------|-------------------------|-------------------------|
| Age (years), M±SD | 55.4 ± 8.7              | 54.2 ± 7.9              |
| Gender (M/F)      | 17 (56.7%) / 13 (43.3%) | 16 (53.3%) / 14 (46.7%) |

In both groups, the average age was quite similar, with the control group averaging about 55 years old, and the intervention group about 54 years. Both groups had a mix of men and women, with the control group consisting of 17 men and 13 women, and the intervention group having 16 men and 14 women. The distribution of age and gender was similar between the two groups, meaning that any differences in results were more likely due to the treatment rather than demographics

3.2 Blood Pressure Differences Between Groups

Table 2. Average Blood Pressure by Group

| Variable | Control (M±SD) | Intervention (M±SD) | p-value | Cohen's d |
|----------|----------------|---------------------|---------|-----------|
| SBP_mean | 155.4 ± 9.2    | 140.1 ± 8.9         | <0.001  | 1.26      |
| DBP_mean | 91.6 ± 6.0     | 88.6 ± 7.0          | 0.159   | 0.37      |

On average, the group that received the foot bath treatment had significantly lower systolic blood pressure (SBP) compared to the control group. The intervention group’s average SBP was 140.1 mmHg, while the control group’s was 155.4 mmHg, which was a clear and meaningful difference. The diastolic blood pressure (DBP) was also a bit lower in the intervention group, but the difference wasn’t statistically significant.

3.3 Blood Pressure Reduction in Both Groups

Table 3. How Much Blood Pressure Decreased in Each Group

| Variable | Control (M±SD) | Intervention (M±SD) | Difference (Control Intervention) | Test                       | p-value | Interpretation                              |
|----------|----------------|---------------------|-----------------------------------|----------------------------|---------|---------------------------------------------|
| SBP      | 155.4 ± 9.2    | 140.1±8.9           | 15.3mmHg                          | Independent t-test (Welch) | <0.001  | Significant decrease, large effect (d=1.26) |
| DBP      | 91.6 ± 6.0     | 88.6 ± 7.0          | 3.0 mmHg                          | Independent t-test (Welch) | 0.159   | Not significant                             |

The intervention group had a significant drop in systolic blood pressure (SBP), lowering by an average of 15.3 mmHg compared to the control group. This decrease was statistically significant and substantial. However, while the intervention group did have a slight reduction in diastolic blood pressure (DBP), the difference wasn’t large enough to be considered statistically significant.

3.4 Blood Pressure Variability

Table 4. Variability in Blood Pressure by Group

| Variable   | Control (M±SD) | Intervention (M±SD) | p-value | Cohen’s d |
|------------|----------------|---------------------|---------|-----------|
| SBP_RMSSD  | 12.7 ± 3.1     | 9.6 ± 2.8           | <0.001  | 1.14      |
| SBP_ARV    | 10.7 ± 2.9     | 7.4 ± 2.1           | <0.001  | 1.39      |
| SBP_CV (%) | 5.7 ± 1.2      | 6.9 ± 1.3           | 0.004   | -0.78     |
| DBP_RMSSD  | 7.8 ± 2.0      | 7.6 ± 2.1           | 0.79    | 0.07      |
| DBP_ARV    | 6.3 ± 1.7      | 5.5 ± 1.5           | 0.19    | 0.34      |
| DBP_CV (%) | 6.7 ± 1.3      | 7.9 ± 1.5           | 0.033   | -0.56     |

The foot bath treatment resulted in a noticeable improvement in the stability of systolic blood pressure (SBP). The intervention group showed significantly lower variability in both RMSSD and ARV compared to the control group, meaning their blood pressure was more stable. Interestingly, there was a slight increase in the coefficient of variation (CV%) for SBP in the intervention group, but this was largely due to the significant decrease in average SBP rather than an increase in variability. For diastolic

blood pressure (DBP), the results were less clear, as no significant changes were observed in either RMSSD, ARV, or CV%.

3.5 Covariate Analysis

Table 5. ANCOVA Results for Blood Pressure Variability

| Dependent Variable | F     | p-value | Partial $\eta^2$ |
|--------------------|-------|---------|------------------|
| SBP_RMSSD          | 11.31 | 0.0014  | 0.17             |
| SBP_ARV            | 17.50 | 0.0001  | 0.24             |
| SBP_CV             | 11.36 | 0.0014  | 0.17             |
| DBP_RMSSD          | 0.07  | 0.790   | 0.001            |
| DBP_ARV            | 0.44  | 0.509   | 0.008            |
| DBP_CV             | 6.23  | 0.016   | 0.10             |

This table shows the results of a statistical analysis (ANCOVA) that adjusted for age and gender to see how the foot bath treatment affected blood pressure variability. Here’s a breakdown of the findings:

1. SBP\_RMSSD (Systolic Blood Pressure Variability – RMSSD): The foot bath treatment significantly reduced the variability in systolic blood pressure, with a strong effect ( $F = 11.31$ ,  $p = 0.0014$ ,  $\eta^2 = 0.17$ ). This means the treatment helped stabilize systolic blood pressure more effectively.
2. SBP\_ARV (Systolic Blood Pressure Variability – ARV): There was a similar significant reduction in systolic blood pressure variability measured by ARV ( $F = 17.50$ ,  $p = 0.0001$ ,  $\eta^2 = 0.24$ ). This also indicates that the treatment helped reduce fluctuations in systolic blood pressure.
3. SBP\_CV (Systolic Blood Pressure Variability – CV%): While the variability percentage (CV%) for systolic blood pressure showed a small improvement, it still had a significant effect ( $F = 11.36$ ,  $p = 0.0014$ ,  $\eta^2 = 0.17$ ), which supports the positive impact of the treatment on blood pressure stability.
4. DBP\_RMSSD (Diastolic Blood Pressure Variability – RMSSD): There was no significant effect on diastolic blood pressure variability ( $F = 0.07$ ,  $p = 0.790$ ), suggesting the foot bath didn’t impact the stability of diastolic blood pressure in this study.
5. DBP\_ARV (Diastolic Blood Pressure Variability – ARV): No significant change was found in the diastolic blood pressure fluctuations measured by ARV ( $F = 0.44$ ,  $p = 0.509$ ).
6. DBP\_CV (Diastolic Blood Pressure Variability – CV%): However, there was a slight improvement in the CV% for diastolic blood pressure ( $F = 6.23$ ,  $p = 0.016$ ,  $\eta^2 = 0.10$ ), suggesting a small but positive impact on diastolic pressure variability.

After adjusting for age and gender, the intervention effects remained significant for SBP RMSSD and ARV with medium to large effect sizes ( $\eta^2=0.17-0.24$ ). This strengthens the conclusion that MgSO<sub>4</sub> foot baths help stabilize systolic blood pressure independent of age and gender.

This study demonstrated that foot baths with magnesium sulfate ( $\text{MgSO}_4$ ) significantly reduced systolic blood pressure (SBP) and improved blood pressure stability in patients with hypertension, as reflected by reductions in RMSSD and ARV indices. These findings support earlier evidence that magnesium has blood pressure-lowering effects, particularly on systolic values [12][13]. The effect on diastolic blood pressure (DBP), however, was less pronounced, consistent with previous reports that magnesium is generally more effective in reducing SBP than DBP due to differential mechanisms regulating these two parameters [14][15].

The novelty of this study lies in its focus on transdermal magnesium application through foot baths, an approach that has received limited scientific attention compared with oral supplementation or relaxation-based therapies. While preliminary studies suggest that magnesium ions ( $\text{Mg}^{2+}$ ) can be absorbed through the skin [7], the extent of clinically meaningful absorption remains debated [6]. By including a plain water control group at room temperature, this study was able to minimize confounding effects related to warmth-induced vasodilation or relaxation, thereby strengthening the internal validity of the findings.

From a physiological perspective, magnesium contributes to blood pressure regulation by promoting vascular smooth muscle relaxation, modulating calcium influx, and enhancing parasympathetic activity, all of which reduce peripheral vascular resistance [16][12]. The observed reduction in SBP fluctuations is clinically important because short-term blood pressure variability (BPV) has been strongly linked with increased cardiovascular risk, including stroke, heart failure, and target organ damage [11][17]. In our trial, reductions in RMSSD and ARV indicated enhanced short-term stability, aligning with previous evidence that these indices are reliable markers of BPV [3][13].

Interestingly, the coefficient of variation (CV%) for SBP slightly increased in the intervention group. This outcome likely reflects the substantial reduction in mean SBP rather than true instability in blood pressure values. Such findings underscore that RMSSD and ARV are more robust indicators of short-term BPV, while CV% may be disproportionately influenced by mean blood pressure levels. Similar interpretations have been reported in previous studies evaluating BPV indices [13].

Overall, the reduction of SBP variability observed in this trial is clinically meaningful, as BPV has emerged as an independent predictor of cardiovascular outcomes beyond average blood pressure values [18][19]. By demonstrating that  $\text{MgSO}_4$  foot baths can improve both SBP levels and short-term variability, this study provides evidence for the potential role of non-invasive, low-cost interventions in hypertension management.

### **Study Limitations.**

Despite promising findings, this study has several limitations. The intervention lasted for only 15 sessions, which may not be sufficient to capture long-term effects. Furthermore, serum or urinary magnesium levels were not measured, making it difficult to directly link observed changes in BPV with transdermal magnesium absorption. The sample also consisted primarily of older adults with established hypertension, limiting generalizability to younger or lower-risk populations. Future studies should

incorporate longer follow-up periods, biochemical assessments of magnesium levels, and more diverse participant groups to strengthen the evidence base.

#### **Clinical Implications.**

MgSO<sub>4</sub> foot baths represent a simple, affordable, and non-invasive complementary approach to hypertension management. They may be easily implemented in community-based health centers and primary care settings. Standardized guidelines regarding concentration, temperature, frequency, and duration of immersion will be important to ensure safety and maximize benefits. Given the rising interest in topical magnesium therapies, this intervention could be integrated into broader lifestyle-based strategies for blood pressure control [20].

#### **Future Research Directions.**

Further research should explore the long-term cardiovascular outcomes of MgSO<sub>4</sub> foot baths, including their impact on sustained BPV reduction and incidence of major events such as stroke and myocardial infarction. Continuous or ambulatory blood pressure monitoring would provide more comprehensive insights into diurnal and nocturnal BPV patterns [21]. Additionally, multi-center RCTs with larger, more diverse populations are needed to validate the generalizability of these findings.

## **4 Conclusion**

This study demonstrates that foot baths with magnesium sulfate (MgSO<sub>4</sub>) can significantly reduce systolic blood pressure (SBP) and improve its stability in individuals with hypertension. These findings suggest that foot baths may serve as a simple, safe, and affordable complementary therapy for managing high blood pressure. The observed reduction in blood pressure variability, particularly as measured by RMSSD and ARV, highlights the potential role of magnesium sulfate in promoting greater hemodynamic stability and lowering long-term cardiovascular risk.

While the outcomes are promising, further research with longer intervention periods, larger sample sizes, and multicenter designs is necessary to validate these results. Future studies should also investigate the long-term cardiovascular implications, including the prevention of complications such as stroke and heart disease.

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