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SERUM MAGNESIUM AND CALCIUM IMBALANCE AND HYPERTENSION AMONG ADULTS IN SOUTHEASTERN NIGERIA: A COMPARATIVE STUDY

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ABSTRACT

Magnesium and calcium are important regulators of vascular function, yet evidence on their imbalance among hypertensive adults in Southeastern Nigeria remains limited. This study assessed the prevalence and distribution of serum magnesium and calcium imbalance among treated hypertensive, treatment-naïve hypertensive and normotensive adults. This comparative baseline analysis included 135 adults aged 30–65 years, with 45 participants in each group. Participants were recruited from selected healthcare facilities in Nnewi North and Ekwusigo Local Government Areas, Anambra State. Serum magnesium and calcium were determined using Xylidyl Blue and o-cresolphthalein complexone methods, respectively. Categorical variables were compared using chi-square tests, while continuous variables were analysed using one-way ANOVA. Cramér's V quantified association strength. Hypertensive participants were older and had greater body weight and BMI than normotensive controls (all $p < 0.001$), whereas sex distribution and height were comparable. Magnesium imbalance occurred in 22.2% of treated hypertensives, 33.3% of treatment-naïve hypertensives and 0% of normotensive controls ($\chi^2 = 17.18$, $p = 0.00019$; Cramér's $V = 0.36$). Calcium imbalance occurred in 17.8%, 22.2% and 0%, respectively ($\chi^2 = 10.77$, $p = 0.0046$; Cramér's $V = 0.28$). Pairwise comparisons showed no significant difference between treated and treatment-naïve hypertensive groups, but both differed significantly from normotensive controls. Serum magnesium and calcium imbalance was significantly associated with hypertension status, with magnesium showing the stronger association. Prospective studies with larger samples and adjustment for age, sex, BMI, diet, medication use and other potential confounders are warranted to clarify temporal relationships and clinical significance and to assess potential clinical implications.

Keywords: Serum Magnesium; Serum Calcium; Mineral Imbalance; Hypertension; Normotensive Adults.

1 INTRODUCTION

Hypertension is a major public health problem and an important contributor to cardiovascular morbidity and mortality worldwide. The global burden of hypertension remains substantial, with an estimated 1.28 billion adults aged 30–79 years affected, and a disproportionate share of the burden occurring in low- and middle-income countries. Although hypertension is readily detectable and treatable, substantial gaps remain in diagnosis, treatment and control, particularly in resource-constrained settings. (WHO, 2023; WHO, 2021) Recent evidence from Africa continues to demonstrate a high and increasing burden of hypertension, with age, urbanisation, excess body weight and other cardiometabolic risk factors contributing to the disease burden. (Otowoyo et al., 2025; Chen et al., 2026) In Nigeria, hypertension control remains an important public health challenge despite recent improvements in primary-care approaches to treatment (Ogungbe et al., 2024) Consequently, identification of potentially modifiable biological and nutritional factors associated with elevated blood pressure remains important, particularly in populations where access to comprehensive cardiovascular assessment may be limited.

Electrolytes and mineral elements play important roles in maintaining cardiovascular and vascular homeostasis. Among these, magnesium and calcium are of particular physiological interest because of their involvement in vascular smooth-muscle function, cellular signalling, membrane excitability and regulation of vascular tone. Magnesium influences several cellular and vascular processes, including calcium-channel activity, endothelial nitric oxide signalling and sympathetic activity, mechanisms that may affect vascular resistance and blood pressure. (Alshanbleh et al., 2025) Calcium, meanwhile, is a central intracellular messenger in vascular smooth-muscle cells, where changes in cytosolic calcium concentration regulate vascular contraction and vascular diameter. Recent evidence indicates that calcium signalling within

vascular smooth-muscle and endothelial cells is closely involved in the regulation of vascular tone and blood pressure. [7,8] Disturbances in the concentrations or homeostasis of these minerals may therefore have implications for vascular resistance and blood pressure regulation.

Magnesium imbalance has attracted increasing attention in the context of hypertension. Magnesium depletion has been proposed to contribute to hypertension through effects on vascular tone, endothelial function, sympathetic activity, renal electrolyte handling and inflammatory pathways. (Alshanbleh et al., 2025; Conolly & Saxton, 2024) Recent systematic-review evidence further supports an inverse association between circulating magnesium concentration and hypertension, although considerable heterogeneity among studies indicates that the relationship is not necessarily uniform across populations. (10) Similarly, calcium is central to vascular smooth-muscle contraction and relaxation because intracellular Ca^{2+} signalling regulates the contractile state of vascular smooth-muscle cells. (Moradmand et al., 2026; Yoshiaki). Evidence from a recent Cochrane systematic review indicates that increasing calcium intake produces small reductions in systolic and diastolic blood pressure among normotensive individuals, suggesting that calcium availability may have a role in blood-pressure regulation and the prevention of hypertension. (Cormick et al., 2022). Nevertheless, the biological and clinical significance of altered serum calcium concentrations may differ from that of dietary calcium intake, and the magnitude and direction of associations may vary between populations and clinical settings.

The relationship between magnesium, calcium and hypertension is particularly relevant in sub-Saharan Africa. Recent systematic reviews indicate that approximately one in three adults in the region has hypertension, with substantial variation between populations and a clear increase in prevalence with advancing age and excess body weight. (Otowoyo et al., 2025; Chen et al., 2026) The region is also undergoing rapid demographic, nutritional and epidemiological transitions, accompanied by increasing urbanisation and the growing burden of obesity and other non-communicable disease risk factors. (Otowoyo

et al., 2025; Chen et al., 2026). These factors may influence both mineral status and cardiovascular health. However, routine assessment of serum magnesium and calcium is not consistently incorporated into the clinical evaluation of patients with hypertension, and population-specific evidence concerning mineral disturbances among hypertensive adults in Southeastern Nigeria remains limited. This gap is important because circulating mineral concentrations may be influenced by dietary intake, renal handling, comorbidities and other clinical factors.

An additional consideration is whether mineral imbalance differs according to hypertension and treatment status. Individuals with established hypertension who are receiving antihypertensive treatment may have a different biochemical profile from newly diagnosed or treatment-naïve hypertensive individuals. Contemporary hypertension management commonly involves several pharmacological classes, including thiazide or thiazide-like diuretics, angiotensin-converting enzyme inhibitors or angiotensin-receptor blockers, and calcium-channel blockers. (Carey et al., 2022) Some antihypertensive therapies, particularly diuretics, can influence electrolyte and mineral handling, making treatment status a potentially relevant consideration when interpreting biochemical measurements in hypertensive

populations. (Martins et al., 2023; Jo et al., 2023) Comparing treated hypertensive individuals with newly diagnosed or treatment-naïve hypertensive individuals and normotensive controls may therefore provide useful information about the distribution of mineral disturbances across different stages of the hypertensive spectrum. Such comparisons may also help distinguish abnormalities potentially associated with hypertension itself from differences that may occur in relation to treatment or other clinical characteristics.

The present study was conducted among adults recruited from selected healthcare facilities in Nnewi North and Ekwusigo Local Government Areas of Anambra State, Nigeria. The study included three groups: hypertensive patients receiving treatment, newly diagnosed or treatment-naïve hypertensive patients, and normotensive controls. The study population comprised 135 adults aged 30–65 years, with 45 participants

in each group. Baseline assessment included demographic and anthropometric characteristics and laboratory determination of serum magnesium and calcium, among other biochemical parameters. The thesis findings indicate significant differences in age, body weight and body mass index between hypertensive participants and normotensive controls, while magnesium and calcium imbalance were more frequently observed among hypertensive participants.

Therefore, this study aimed to determine the prevalence and distribution of serum magnesium and calcium imbalance among treated hypertensive adults, treatment-naïve hypertensive adults and normotensive controls in Southeastern Nigeria, and to examine the association between these mineral disturbances and hypertension status. By characterising these differences, the study seeks to contribute population-specific evidence on the potential relationship between mineral homeostasis and hypertension and to provide a basis for further investigation of magnesium and calcium status in cardiovascular risk assessment.

2 MATERIALS AND METHODS

2.1 Study Design

This study was based on a comparative baseline analysis of participants enrolled in a prospective clinical investigation of magnesium and calcium status in adults with hypertension. For the present manuscript, the analysis was restricted to baseline demographic, anthropometric and biochemical data in order to examine the prevalence and distribution of serum magnesium and calcium imbalance according to hypertension status.

Participants were classified into three groups: Group A, comprising adults with diagnosed hypertension who were receiving antihypertensive medication; Group B, comprising newly diagnosed or treatment-naïve adults with hypertension who had not commenced antihypertensive treatment; and Group C, comprising normotensive adults serving as controls. The three-group design permitted comparison of mineral status across treated hypertension, untreated hypertension and normotension.

2.2 Study Setting

The study was conducted in selected healthcare facilities in Nnewi North and Ekwusigo Local Government Areas of Anambra State, Southeastern Nigeria. Participants were recruited from outpatient clinics, hospitals and community health centres within the study areas. The documented recruitment sites included SEOF Clinic, Oraifite; Adol Paul Hospital, Nnewi/Utuh; and Uru Primary Health Centre, Umudim, Nnewi.

2.3 Study Population

The study population consisted of adults aged 30–65 years. The hypertensive groups comprised adults with clinically diagnosed hypertension, including individuals receiving antihypertensive treatment and newly diagnosed or treatment-naïve individuals. The control group comprised adults with normal blood pressure recruited from the same general environment as the hypertensive participants.

2.4 Participant Groups

Participants were stratified according to their hypertension and treatment status as follows:

- **Group A (treated hypertensive group):** adults with diagnosed hypertension who were currently receiving antihypertensive medication.
- **Group B (treatment-naïve hypertensive group):** newly diagnosed hypertensive adults who had not commenced antihypertensive therapy.
- **Group C (normotensive control group):** adults with normal blood pressure who served as the reference group.

The parent study enrolled 45 participants in each group, giving a total sample of 135 participants.

2.5 Sample Size

The sample size in the parent study was calculated using a two-sample comparison-of-means approach, based on an anticipated 5-mmHg difference in blood pressure, a standard deviation of 12 mmHg, a significance level of 0.05 and approximately 80% statistical power. A 20% allowance for potential attrition

was incorporated, resulting in a target sample of 45 participants per group and a total sample of 135 participants.

For the present manuscript, all 135 participants with available baseline magnesium and calcium measurements were included in the comparative analysis.

2.6 Eligibility Criteria

Adults aged 30–65 years who met the relevant clinical classification for one of the three study groups were eligible for participation. Hypertensive participants included both individuals receiving treatment and treatment-naïve or newly diagnosed individuals, while normotensive participants were recruited from the same geographical environment.

Participants with conditions likely to substantially influence mineral homeostasis or the interpretation of the study outcomes were excluded. These included severe kidney disease, pregnancy, contraindications to magnesium or calcium supplementation and major comorbid conditions such as previous stroke, myocardial infarction, liver disease or kidney disease.

Additional screening was undertaken through structured history-taking, clinical assessment, physical examination and targeted laboratory investigations where clinically indicated. The study protocol also specified exclusion of individuals with significant cardiovascular, hepatic or renal disease in order to minimise potential confounding.

2.7 Sampling and Recruitment

A comparative stratified sampling approach was used. Eligible participants were consecutively recruited and subsequently classified into the appropriate study group according to their clinical status and blood

pressure classification. The study therefore comprised three strata representing treated hypertension, treatment-naïve hypertension and normotension.

Prior to enrolment, potential participants underwent screening to establish eligibility. A structured interviewer-administered questionnaire was used to obtain relevant sociodemographic and clinical information, while clinical and laboratory assessments were used where necessary to confirm eligibility.

2.8 Sociodemographic and Anthropometric Assessment

Baseline sociodemographic information included age and sex, together with relevant clinical and lifestyle information obtained through the study questionnaire. Medical history and current medication use were also documented.

Anthropometric measurements included body weight and height. Body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared:

$$\text{BMI} = \text{weight (kg)} / \text{height}^2 (\text{m}^2)$$

These variables were included because age and body composition may differ according to hypertension status and may act as potential confounding factors in analyses examining the relationship between mineral status and hypertension.

2.9 Blood Pressure Measurement

Blood pressure was assessed using a standard mercury sphygmomanometer according to a standardised measurement procedure. Accurate and standardised blood-pressure measurement is essential for the appropriate identification and management of hypertension. (WHO, 2021). Participants were seated in a quiet environment and allowed to rest for at least 5 minutes before measurement. The participant's back was supported, feet were placed flat on the floor, legs were uncrossed and the arm was supported at heart level.

An appropriately sized cuff was applied to the upper arm. Systolic blood pressure (SBP) was recorded at the appearance of the first Korotkoff sound (Phase I), while diastolic blood pressure (DBP) was recorded at disappearance of the

Korotkoff sounds (Phase V). Two measurements were obtained at intervals of at least 2 minutes, and the average was recorded as the participant's blood pressure measurement. The same arm was used throughout the assessment.

Mean arterial pressure (MAP) was derived using the following equation:

$$\text{MAP} = \text{DBP} + 1/3(\text{SBP} - \text{DBP})$$

or equivalently:

$$\text{MAP} = \text{DBP} + 1/3(\text{PP}),$$

where PP represents pulse pressure.

2.10 Blood Sample Collection

Venous blood samples were collected from participants under aseptic conditions using standard venepuncture procedures. Approximately 5 mL of venous blood was obtained from the antecubital vein

using a sterile disposable syringe and needle and transferred into appropriately labelled lithium-heparin containers.

The samples were gently mixed and transported promptly to the laboratory. They were centrifuged at 3,000 revolutions per minute for 10 minutes, after which the separated plasma was carefully collected for biochemical analysis.

2.11 Laboratory Determination of Serum Magnesium and Calcium

Serum magnesium and calcium concentrations were determined using standard spectrophotometric methods with a calibrated digital spectrophotometer and reagent kits used according to the manufacturers' instructions.

Magnesium concentration was determined using the Xylidyl Blue colorimetric method. In this method, magnesium reacts with Xylidyl Blue under alkaline conditions to form a coloured complex, with the intensity of the colour measured spectrophotometrically being proportional to the magnesium concentration in the specimen.

Calcium concentration was determined using the o-cresolphthalein complexone (OCPC) method. Calcium ions react with o-cresolphthalein complexone in an alkaline medium to form a coloured complex, and the resulting absorbance was measured spectrophotometrically to determine calcium concentration.

Serum sodium, potassium and total protein were also determined as part of the parent study. These variables were available for consideration as additional biochemical characteristics and potential covariates where appropriate. Total protein was determined using the Biuret method.

2.12 Quality Assurance

The spectrophotometer was calibrated and blanked before analysis, and reagent blanks, standards and test specimens were prepared according to the relevant reagent-kit instructions. Quality-control sera were analysed alongside study specimens, while laboratory equipment and procedures were standardised throughout the analytical process.

Laboratory analyses were performed at Divzar Medical and Diagnostic Services, Nnewi, by an experienced medical laboratory scientist.

2.13 Definition and Classification of Mineral Imbalance

Serum magnesium and calcium status was classified according to the laboratory reference ranges used for the study. Participants whose serum magnesium concentration was below the applicable laboratory reference range were classified as having magnesium imbalance, while those with values within the reference range were classified as having normal magnesium status. (WHO) Similarly, participants whose serum calcium concentration was below the laboratory reference range were classified as having calcium imbalance.

The use of laboratory-specific reference intervals is important because substantial variation exists in the reference ranges used for serum magnesium, and differences in lower reference limits may influence the identification of magnesium deficiency or hypomagnesemia. (WHO, 2021)

The source thesis confirms that laboratory reference ranges were used to identify participants with reduced magnesium or calcium concentrations. However, the specific numerical lower and upper reference limits are not clearly stated in the available methodological text. Therefore, the final journal manuscript should

report the exact laboratory reference ranges used in the original laboratory report or study records rather than introducing values from an external source.

2.14 Statistical Analysis

Data were analysed using IBM SPSS Statistics version 25. Continuous variables were summarised using means and standard deviations, while categorical variables were presented as frequencies and percentages.

For the present manuscript, baseline characteristics were compared across the three study groups. One-way analysis of variance (ANOVA) was used for continuous variables that satisfied the assumptions for parametric comparison. Where the overall ANOVA was statistically significant, appropriate post-hoc pairwise comparisons were undertaken to identify the groups responsible for the observed differences. Categorical variables were compared using the chi-square test.

The prevalence of magnesium and calcium imbalance was calculated for each study group and compared using Pearson's chi-square test. The magnitude of association between mineral imbalance and study-group status was assessed using Cramér's V. Where appropriate, effect estimates with 95% confidence intervals were calculated to provide measures of the strength and precision of observed associations.

Age, sex, body weight and BMI were evaluated as potentially relevant demographic and anthropometric factors. Where the available individual-level data permitted, multivariable modelling was planned to assess whether the association between mineral imbalance and hypertension status persisted after adjustment for relevant covariates.

All statistical tests were two-sided, and statistical significance was set at $p < 0.05$.

2.15 Ethical Considerations

Ethical approval for the parent study was obtained from the appropriate ethical review authority of Nnamdi Azikiwe University Teaching Hospital (NAUTH), Nnewi. Participants were informed about the purpose and procedures of the study in a language they could understand, and written informed consent was obtained before enrolment. Participation was voluntary, and participants were permitted to withdraw from the study at any time without penalty. Confidentiality and protection of participant information were maintained throughout the study.

3 RESULTS

Table 1: Sociodemographic and anthropometric characteristics of participants by study group

Variable	Group A: Treated HTN (n=45)	Group B: Treatment-naïve HTN (n=45)	Group C: Normotensive (n=45)	Overall p-value
Age (years), mean $\pm$ SD	58.13 $\pm$ 6.98	55.42 $\pm$ 7.21	43.11 $\pm$ 9.79	<0.001
Sex, n (%)				0.91
Male	24 (53.3%)	26 (57.8%)	25 (55.6%)	
Female	21 (46.7%)	19 (42.2%)	20 (44.4%)	
Weight (kg), mean $\pm$ SD	78.5 $\pm$ 10.2	80.3 $\pm$ 9.8	68.4 $\pm$ 8.7	<0.001
Height (m), mean $\pm$ SD	1.68 $\pm$ 0.07	1.69 $\pm$ 0.06	1.70 $\pm$ 0.08	0.42
BMI (kg/m ²), mean $\pm$ SD	27.8 $\pm$ 3.6	28.1 $\pm$ 3.9	23.6 $\pm$ 2.8	<0.001

Abbreviations: HTN, hypertension; BMI, body mass index; SD, standard deviation.

Table 1 shows that the hypertensive groups were significantly older and had higher body weight and BMI than the normotensive group ($p < 0.001$), whereas height did not differ significantly among the groups ($p = 0.42$). Age, weight and BMI therefore showed clear differences between hypertensive and normotensive participants. In contrast, sex

distribution was comparable across the three groups ($p=0.91$), indicating no significant sex imbalance. Overall, the groups were similar in sex and height but differed substantially in age, weight and BMI.

Table 2: Prevalence of serum magnesium and calcium imbalance according to hypertension status

Mineral status	Group A: Treated HTN (n = 45)	Group B: Treatment-naïve HTN (n = 45)	Group C: Normotensive (n = 45)	χ^2	df	p-value	Cramér's V
Magnesium imbalance	10 (22.2%)	15 (33.3%)	0 (0.0%)	17.18	2	0.00019	0.36
Calcium imbalance	8 (17.8%)	10 (22.2%)	0 (0.0%)	10.77	2	0.0046	0.28

Abbreviations: HTN = hypertension; df = degrees of freedom. Statistical significance was set at $p < 0.05$. Cramér's V represents the strength of association between mineral imbalance and hypertension status.

Table 2 shows that magnesium and calcium imbalance was more prevalent among hypertensive participants than normotensive controls. Magnesium imbalance occurred in 22.2% of treated hypertensives and 33.3% of treatment-naïve hypertensives, compared with 0% among normotensive controls. Similarly, calcium imbalance occurred in 17.8% and 22.2% of treated and treatment-naïve hypertensives, respectively, with no cases among normotensive controls. Both magnesium ($\chi^2 = 17.18$, $p = 0.00019$; Cramér's $V = 0.36$) and calcium ($\chi^2 = 10.77$, $p = 0.0046$; Cramér's $V = 0.28$) showed statistically significant associations with hypertension status, with magnesium demonstrating the stronger association.

Table 3: Pairwise comparison of serum magnesium and calcium imbalance across study groups

Mineral	Comparison	Adjusted p-value	Significance
Magnesium	Treated HTN (Group A) vs treatment-naïve HTN (Group B)	1.000	NS
Magnesium	Treated HTN (Group A) vs normotensive (Group C)	0.003	**
Magnesium	Treatment-naïve HTN (Group B) vs normotensive (Group C)	<0.001	***
Calcium	Treated HTN (Group A) vs treatment-naïve HTN (Group B)	1.000	NS
Calcium	Treated HTN (Group A) vs normotensive (Group C)	0.030	*
Calcium	Treatment-naïve HTN (Group B) vs normotensive (Group C)	0.009	**

Abbreviations: HTN, hypertension; NS, not significant. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 3 shows that there were no significant differences in magnesium or calcium imbalance between treated and treatment-naïve hypertensive participants ($p=1.000$ for both). However, both hypertensive groups differed significantly from the normotensive controls, with magnesium imbalance significantly higher in treated hypertensives ($p=0.003$) and treatment-naïve hypertensives ($p < 0.001$), while calcium imbalance was also significantly higher in treated ($p=0.030$) and treatment-naïve hypertensives ($p=0.009$). Overall, these findings suggest that the

observed mineral imbalances were more closely associated with hypertension status than with antihypertensive treatment.

Table 4: Magnitude of association between serum magnesium and calcium imbalance and hypertension status

Mineral status	χ^2	p-value	Cramér's V	Effect-size interpretation	Overall finding
Magnesium imbalance	17.18	<0.001	0.36	Moderate	Significant association with hypertension
Calcium imbalance	10.77	0.0046	0.28	Small-to-moderate	Significant association with hypertension

Table 4 quantifies the strength of the observed associations using Cramér's V. Magnesium imbalance demonstrated a moderate association with hypertension status ($V = 0.36$), whereas calcium imbalance demonstrated a smaller-to-

moderate association ($V = 0.28$). Both associations were statistically significant. The findings therefore indicate that magnesium imbalance had the stronger association with hypertension in this study, although both minerals demonstrated meaningful associations with hypertensive status..

Table 5: Pairwise comparison of magnesium and calcium imbalance across study groups

Mineral	Comparison	p-value	Significance	Interpretation
Magnesium	Group A vs Group B	1.000	ns	No significant difference between treated and treatment-naïve hypertensives
Magnesium	Group A vs Group C	0.003	**	Significantly greater imbalance in treated hypertensives than in normotensive controls
Magnesium	Group B vs Group C	<0.001	***	Significantly greater imbalance in treatment-naïve hypertensives than in normotensive controls
Calcium	Group A vs Group B	1.000	ns	No significant difference between treated and treatment-naïve hypertensives
Calcium	Group A vs Group C	0.030	*	Significantly greater imbalance in treated hypertensives than in normotensive controls
Calcium	Group B vs Group C	0.009	**	Significantly greater imbalance in treatment-naïve hypertensives than in normotensive controls

Table 5 provides the detailed pairwise comparisons underlying the overall associations reported in Table 2. There was no significant difference in either magnesium or calcium imbalance between treated and treatment-naïve hypertensive participants. In contrast, both hypertensive groups showed significantly greater magnesium and calcium imbalance than the normotensive group. The strongest pairwise evidence was observed for magnesium in treatment-naïve hypertensive

participants versus normotensive controls ($p < 0.001$). Collectively, the findings suggest that the presence of hypertension, rather than antihypertensive treatment status, was the principal group distinction associated with mineral imbalance.

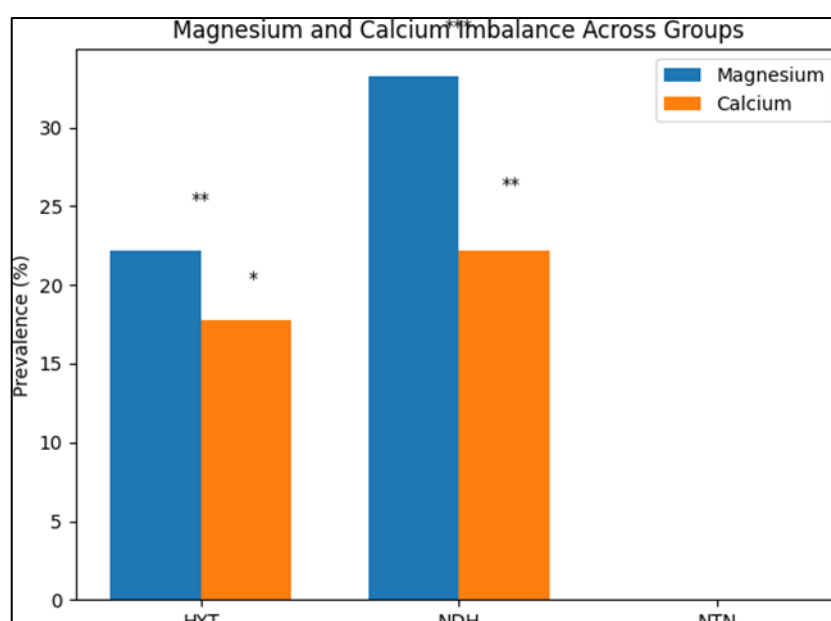


Figure 1: Visual Descriptive Statistics of Magnesium and Calcium Imbalance

Figure 1 shows that serum magnesium and calcium imbalance was more prevalent among hypertensive participants than normotensive controls. Magnesium imbalance was highest among treatment-naïve hypertensive participants (33.3%), followed by treated hypertensives (22.2%), while no imbalance was observed among normotensive

participants. Similarly, calcium imbalance occurred in 22.2% of treatment-naïve hypertensives and 17.8% of treated hypertensives, compared with 0% in normotensive controls. Overall, the figure demonstrates a more pronounced pattern of

magnesium imbalance than calcium imbalance among hypertensive participants, particularly in the treatment-naïve group.

4 DISCUSSION

The present study demonstrates a significant association between serum magnesium and calcium imbalance and hypertension status among adults in Southeastern Nigeria. Magnesium imbalance was identified in 22.2% of treated hypertensive participants and 33.3% of treatment-naïve hypertensive participants, whereas no imbalance was observed among normotensive controls. Calcium imbalance showed a similar pattern, occurring in 17.8% of treated hypertensives and 22.2% of treatment-naïve hypertensives, compared with 0% among controls.

The stronger association observed for magnesium is particularly noteworthy. Magnesium imbalance had a Cramér's V of 0.36, compared with 0.28 for calcium, indicating a moderate association for magnesium and a smaller-to-moderate association for calcium. Both associations were statistically significant. The present finding is consistent with the epidemiological evidence reported by Amani Tirani et al. (2025), whose systematic review and meta-analysis of 22 observational studies found an inverse association between circulating magnesium concentration and hypertension, with higher circulating magnesium associated with lower odds of hypertension. However, the substantial heterogeneity observed across the included studies indicates that the strength of this relationship may differ according to population and study characteristics. The biological plausibility of the present finding is further supported by AlShanableh and Ray (2024), who described several mechanisms through which magnesium may influence blood pressure, including modulation of vascular tone, calcium-channel activity, endothelial nitric oxide synthase activity, sympathetic tone, renal potassium handling and inflammatory pathways.

The findings concerning calcium are also biologically plausible. Suzuki et al. (2024) explained that calcium signalling in vascular smooth-muscle and endothelial cells is central to the regulation of vascular diameter and systemic blood flow, while disturbances in calcium signalling may promote enhanced vasoconstriction

and vascular remodelling associated with hypertension. Similarly, Daghbouche-Rubio et al. (2022) reported that vascular tone is strongly influenced by intracellular calcium concentrations and that alterations in ion-channel function can affect vascular smooth-muscle contraction, vascular tone and blood pressure. These mechanisms provide a plausible physiological basis for the association between calcium imbalance and hypertension observed in the present study. Nevertheless, the current findings should be interpreted as an association rather than evidence that altered serum calcium directly causes hypertension.

Importantly, there was no significant difference in both magnesium or calcium imbalance between treated and treatment-naïve hypertensive participants. In contrast, both hypertensive groups differed significantly from normotensive controls. For magnesium, the differences were significant for treated versus normotensive participants ($p=0.003$) and treatment-naïve versus normotensive participants ($p<0.001$). Calcium showed corresponding differences at $p=0.030$ and $p=0.009$, respectively. This pattern suggests that mineral imbalance may be more closely related to hypertension status than simply to whether antihypertensive treatment has been initiated. The absence of a significant difference between treated and treatment-naïve participants should, however, be interpreted cautiously because treatment duration, specific antihypertensive drug classes, dosage, dietary intake, renal function and other factors that can influence mineral homeostasis were not fully incorporated into the present comparative analysis.

The demographic findings also require consideration. Hypertensive participants were significantly older and had greater body weight and BMI than normotensive controls, while sex and height were comparable. These differences are potentially important because age and adiposity are established determinants of blood pressure and cardiovascular risk. Recent evidence from Chen et al. (2026) demonstrated a positive association between age and hypertension prevalence and reported progressively higher blood-pressure levels across older age groups in a large systematic review and meta-analysis of adults in sub-Saharan Africa. [22] Therefore, the greater age observed among hypertensive participants in the present study may

partly contribute to the observed differences in mineral status and hypertension. Similarly, differences in body weight and BMI may represent important sources of confounding because excess adiposity is closely associated with hypertension and cardiometabolic dysfunction. Consequently, the present analysis establishes an association but does not demonstrate that magnesium or calcium imbalance causes hypertension.

The study should also be interpreted in light of its comparative baseline design, relatively modest sample size and recruitment from selected healthcare facilities in two local government areas. These characteristics may limit the generalisability of the findings to the wider population of adults in Southeastern Nigeria. In addition, the available manuscript does not provide individual-level data necessary for fully adjusted multivariable modelling. The observed associations may therefore be influenced by residual confounding from age, BMI, dietary mineral intake, renal function, comorbidities, antihypertensive medication type and other unmeasured factors.

The interpretation of serum magnesium imbalance also requires caution because reference ranges for serum magnesium are not completely standardised. Rosanoff et al. (2022) reported substantial variation in serum magnesium reference ranges among laboratories and argued that differences in lower reference limits may result in under-recognition of low magnesium status. Therefore, the prevalence of magnesium imbalance observed in the present study should be interpreted specifically in relation to the laboratory reference range used for participant classification. This consideration is particularly important when comparing the present findings with studies conducted in other populations or laboratories using different analytical methods and reference limits.

Overall, the findings provide population-specific evidence that serum magnesium and calcium imbalance are more frequently observed among hypertensive adults than normotensive controls in the study

population. The stronger association observed for magnesium is consistent with recent epidemiological and mechanistic evidence linking magnesium status with blood-pressure regulation, while the calcium findings are biologically compatible with the established role of calcium signalling in vascular smooth-muscle contraction and vascular tone. However, the cross-sectional comparative nature of the baseline analysis, modest sample size and absence of complete multivariable adjustment mean that causal conclusions cannot be drawn. Consequently, the findings should not be interpreted as evidence that correcting mineral imbalance will necessarily prevent or treat hypertension. Prospective studies with larger and more diverse populations, detailed dietary assessment, renal-function evaluation, medication-specific analyses and longitudinal measurements of serum magnesium and calcium are warranted to clarify the temporal and causal relationships between mineral homeostasis and hypertension.

5 CONCLUSION

Serum magnesium and calcium imbalance was significantly more prevalent among hypertensive adults than normotensive controls in the studied population. Magnesium imbalance was more frequent than calcium imbalance and demonstrated the stronger association with hypertension status. The absence of significant differences between treated and treatment-naïve hypertensive participants further suggests that the observed abnormalities may be associated primarily with hypertension rather than treatment status. However, the cross-sectional baseline comparison cannot establish causality or determine whether mineral imbalance precedes hypertension.

Recommendations

- Routine consideration of serum magnesium and calcium assessment may be warranted in selected hypertensive patients, particularly where clinical or nutritional factors suggest possible mineral disturbance.
- Larger multicentre studies involving diverse populations in Southeastern Nigeria and other Nigerian regions should be conducted to determine the generalisability of these findings.
- Future prospective studies should determine whether magnesium and calcium abnormalities precede the development of hypertension or arise as a consequence of the disease.
- Future analyses should adjust for important potential confounders, particularly age, sex, BMI, dietary intake, renal function, comorbidities and antihypertensive medication use.
- Interventional trials are recommended to determine whether correction of documented magnesium or calcium deficiency produces clinically meaningful improvements in blood pressure and cardiovascular risk.
- Researchers should report the exact laboratory reference ranges used to define magnesium and calcium imbalance to improve reproducibility and facilitate comparison between studies. The uploaded manuscript specifically notes that these numerical reference limits were not clearly stated in the available methodological text.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declared no conflict of interest.

Statement of ethical approval

Ethical approval for the study was obtained from the appropriate ethical review authority of Nnamdi Azikiwe University Teaching Hospital ethical committee.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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