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ORIGINAL ARTICLE

Differences in metal and metalloid content in the hair of normo- and hypertensive postmenopausal women

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This study was performed on scalp hair samples from postmenopausal women (n=26; 12 normotensives and 14 hypertensives) to determine the relationship between blood pressure and metal and metalloids in hair samples. Hair concentrations of Al, Ba, Cd, Co, Cr, Mn, Mo, Ni, Pb, Sb, Se, Sr and V were measured using inductively coupled plasma mass spectrometry, whereas Ca, Cu, Fe, K, Mg, Na and Zn concentrations were measured by inductively coupled plasma optical emission spectrometry. Methods were optimized and then validated using certified reference material GBW 09101 human hair. Although Cd, Co and Mo levels in hypertensive volunteers were significantly higher than in normotensive individuals ($P<0.05$), the concentrations of Fe, Mn, Na (all $P<0.05$) and K ($P<0.001$) were significantly lower. Concentrations of K ($P<0.001$; $P<0.001$) were negatively correlated with systolic and diastolic blood pressure. The concentration of Co ($P=0.004$; $P<0.001$) displayed a positive correlation with both types of pressure, whereas Cu ($P=0.013$) and Ni ($P<0.001$) concentrations correlated significantly with diastolic blood pressure and Mn negatively correlated with systolic blood pressure ($P=0.031$). Overweight and hypertension concurred in 27% of volunteers. This concurrence did not modify differences in hair mineral levels attributed to hypertension. The present results indicate that scalp hair concentrations of certain metals and metalloids can be used as biomarkers for hypertension in postmenopausal women.
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Keywords: blood pressure; hair minerals; metals and metalloids; postmenopausal women

INTRODUCTION

Cardiovascular disease (CVD) is a major global health problem. The incidence of CVD is very high in the elderly population, and the study of its pathogenesis is of great importance.[1] The Framingham study identified the major CVD risk factors as high blood pressure, high blood cholesterol, smoking, obesity, diabetes and physical inactivity and contributed a great deal of valuable information on the effects of related factors such as blood triglyceride and HDL cholesterol levels, age, gender and psychosocial conditions.[2] Although hypertension affects the elderly of both sexes,[3] it is thought that the high incidence of arterial hypertension in postmenopausal women may be due partially to decreased estrogen levels. Estrogens have a direct vasodilating effect, which improves endothelial function.[4]

Some major minerals and trace elements are essential for human health (for example, Fe, Zn, Cr), although they are potentially harmful when consumed in large quantities. Other metals, such as As, Pb, Cd and Hg, have no known beneficial biological function, and long-term exposure to them may be toxic, even at low doses. Magnesium deficiency increases muscle catabolism and cardiovascular risk.[5] Imbalances of zinc, copper, magnesium and manganese affect blood pressure and are associated with hypertension.[6]

Medical physiology studies have indicated correlations between the microelement content of body tissues and metabolism.[7] Trace elements have been implicated in the etiology of CVD,[8,9] with several examples showing the multi-level impact of trace elements on arterial blood pressure. The toxic properties of various heavy metal ions, including Cd, Pb, Hg and Tl, can cause hypertension by stimulating hormone-induced vasoconstriction and affecting renal tubular function.[8,9] In addition to genetic factors, the contents of certain elements in food and water are of great importance in hypertension. The genetic variability of the population and the different degree of efficiency in the homeostasis of numerous cations have made the study of hypertension difficult.[10]

The mineral status of individuals is determined conventionally by the analysis of biological samples, most often blood. However, human scalp hair has been used increasingly as a biomonitor of the levels and oscillations of major minerals and trace elements to estimate environmental exposure levels and assess nutritional status, as well as to

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diagnose illness.[8,11–13] Furthermore, mineral levels in hair are less sensitive to immediate intake than those in blood and may therefore be a more accurate biological indicator of the nutritional status of certain elements. However, alongside its potential advantages, hair analysis also has a number of disadvantages; contamination by dust or sweat and age, sex and place of residence can all affect results.[14] Moreover, hair has been found to be an acceptable biomarker of mineral excretion and body mineral content. To the best of our knowledge, few studies on hair mineral levels in postmenopausal women are available.

The present paper hypothesizes that hair mineral composition varies between normo- and hypertensive women, making it a suitable biomarker of blood pressure. The aims of this study were to determine (a) differences in hair mineral composition between normo- and hypertensive postmenopausal women and (b) the possible relationship between hair mineral content and blood pressure.

METHODS

Study participants

This study was designed to be descriptive and non-inferential. Taking into account the influence of sex, age, body mass index (BMI) and smoking on blood pressure,[15] volunteers had to fulfill the following eligibility criteria: (a) age, women $\geqslant$45 years; (b) postmenopausal; (c) BMI $\geqslant 18\,kg\,m^{-2}$; and (d) regular dietary habits and orderly lifestyle.

Exclusion criteria included (a) previous cardiovascular, metabolic or systemic disease; (b) treatment with any lipid-lowering, antihypertensive or anti-inflammatory drugs and hormone replacement therapy; and (c) smoking habit.

Thirty volunteers were selected among 40 nuns recruited in two enclosed convents. Two volunteers were excluded owing to ongoing use of drug therapy. Three volunteers were 45-years old but were considered premenopausal. Five participants suffered from white coat hypertension. In addition, two volunteers were excluded for habitual use of hair cosmetics, and another two were excluded for very short scalp hair that prevented hair sample collection. Thus, a total of 26 nuns—12 normotensive and 14 hypertensive—were studied.

Study protocols were approved by an Ethics Committee of the Universidad Complutense de Madrid and all procedures were in accordance with the Helsinki Declaration. Participants provided informed consent before the start of the study.

Anthropometric measurements

Trained personnel obtained body weight and height using standardized methodology. BMI (weight (kg)/height^2 (m)) was also calculated. Systolic and diastolic blood pressures were measured using a standard mercury sphygmomanometer following WHO recommendations.[16]

Mineral concentrations in hair samples

Sampling and treatment. Scalp hair samples (1–3 cm) were taken from the occipital region by cutting hair 2 cm from the hair root using stainless steel scissors without vanadium and stored in plastic bags. The samples were washed to ensure accurate assessment of endogenous metal content. The washing procedure was carried out according to IAEA recommendations.[17] Hair samples were first washed with ultrapure water, then washed three times with acetone and finally washed once with ultrapure water. The samples were then oven dried at 100 °C.

A 250 ± 0.1 mg portion of each sample was weighed and introduced into a high-pressure, enclosed, Teflon decomposition vessel. Five milliliters of a 2.5:0.25 HNO_3 and H_2O_2 (v/v) mixture was carefully added to each sample and the vessels were gently shaken, sealed and digested in a microwave oven at 330 W for 10 min. Finally, the acid digests were brought up to 5 ml with ultrapure water. The final concentrations of each element studied were expressed as $\mu g\,g^{-1}$ of dry material weight.

Reagents. De-ionized water with a resistivity of $\geqslant 18\,M\Omega\,cm^{-1}$ obtained using a MilliQPLUS 185 system, Millipore (St Quentin-en-Yvelines, France) was used to prepare all standard and sample solutions. Suprapur grade (Merck, Darmstadt, Germany) 65% HNO_3 and 30% w/v H_2O_2 were used for sample dissolution. Multi-element standard solutions were obtained from Merck. A high-purity argon (>99.999%) plasma torch from Linde Gas (Gargenville, France) was used. Certified Reference Material GBW 09101 Human Hair (Shanghai Institute of Nuclear Research Academia Sinica) was used to validate our analytic methods.

Instrumentation. Acid digestion of the hair samples was performed using a commercial high-pressure laboratory microwave oven, Milestone Ethos 1600 Microwave Labstation, (Sorisole, Italy) operating at a frequency of 2450 Hz, with an energy output of 900 W. Maximum operating temperature and pressure were 150 °C and 100 bar, respectively.

A VARIAN UltraMass Quadrupole inductively coupled plasma mass spectrometer, ICP-MS, Varian Scientific Instruments (Lake Forest, IL, USA), was used for analytical determinations of trace and ultra-trace elements. The instrumental parameters were optimized with a solution containing $10\,\mu g\,l^{-1}$ of Be, Ba, Ce, Co, In, Pb, Mg, Tl and Th from Inorganic Ventures (Lakewood, NJ, USA).

An inductively coupled plasma optical emission spectrometer (ICP-OES) equipped with axial and radial viewing plasma configuration, ICP-OES Perkin Elmer Model Optima 3300 DV (Palo Alto, CA, USA) operating a 40 MHz free-running ratio frequency and provided with an autosampler TRACYC44, was used for analytical determination of major elements. The nebulization system was equipped with a Scott double-pass spray chamber and a chemical-resistant G. The polychromator was an Echelle grating with a spectral range of 165–782 nm and a resolution of 0.006 nm at 200 nm. The detector was a segmented-array charge-coupled detector with 235 sub-arrays.

Analytical methods. Multi-element analysis of Al, Ba, Cd, Co, Cr, Mn, Mo, Ni, Pb, Sb, Se, Sr and V in digested hair samples was performed with ICP-MS spectrometry. Other elements were analyzed with ICP-OES spectrometry using the multi-element method described by Sevillano *et al.*[18] Elements with the highest isotopic abundance, free from isobaric and polyatomic interference, were selected for ICP-MS spectrometry. When ICP-OES spectrometry was used, possible interference and selection of analytical lines were checked to select three of the most sensitive spectral lines.

The validation process of the methods based on ICP-OES and ICP-MS techniques was performed according to EURACHEM guidelines[19] with regard to accuracy, precision, sensitivity and linearity using the experimental setting that provided the optimal conditions. According to these guidelines, intra-assay and inter-assay imprecision, measured as variation coefficients, should be below 5 and 10%, respectively. The sensitivity of the determination of each chemical element was expressed as the slope of the linear regression equation. Linearity was assessed by the correlation coefficients of calibration curves and was considered acceptable when $r \geqslant 0.9995$. Detection limits were calculated on the basis of the 3s criterion for 10 replicate measurements of blank solutions subjected to the same treatment as the samples.

Statistical analysis

This study was designed to have a power of 80% to detect a 25% relative difference between mineral hair concentrations in normo- and hypertensive subjects considering a pooled s.d. of 25% for most minerals using the Mann–Whitney *U*-test for group comparison (PASS 2008 program; NCSS, Kaysville, UT, USA). The statistical power would be ~65% when groups with 7–11 participants classified according to BMI and blood pressures were compared (normal weight–normotensive *vs.* overweight–hypertensive).

Statistical significance of the data was determined using the Mann–Whitney *U*-test. Spearman's rank correlation coefficient provided a technical description of the correlations between data obtained by different methods of measurement. The SPSS statistical package (version 15.0, Chicago, IL, USA) was used to analyze the data.

RESULTS

The analytical results of Reference Material GBW 09101 concurred with the certified values, confirming the reliability of the used method. Precision obtained for both ICP-MS and ICP-OES was considered adequate because intra-assay and inter-assay precision ranged from 0.5

Table 1 Basal anthropometrical characteristics of normotensive and hypertensive postmenopausal women

	Normotensive women (n=12)	*Hypertensive women (n=14)*	*Significance (P)*
Age (years)	64.1 ± 9.3	69.8 ± 10.4	NS
Weight (kg)	53.3 ± 8.6	60.5 ± 7.6	<0.1
Height (m)	1.52 ± 0.6	1.54 ± 0.07	NS
BMI (kg m^{-2})	22.99 ± 2.66	25.55 ± 3.25	<0.1
Blood pressure			
Systolic (mm Hg)	119.29 ± 8.52	154.17 ± 12.41	<0.001
Diastolic (mm Hg)	68.21 ± 12.34	79.58 ± 11.37	<0.01

Abbreviations: BMI, body mass index; n, number of subjects; NS, non-significant.
Data are mean ± standard deviation.

to 6.7% and from 3.2 to 12.8%, respectively. Method linearity for every element was excellent, with correlation coefficients of calibration curves higher than 0.9995. The detection limits, which ranged from 0.003 μg g^{-1} (Sb) to 0.32 μg g^{-1} (Al), were appropriate for the determination of hair mineral content.

Age data and some anthropometric characteristics of this population are specified in Table 1. Forty-six percent of postmenopausal women in our study were hypertensive, with systolic and/or diastolic blood pressures ⩾140 mm Hg and/or ⩾90 mm Hg. Significant differences ($P<0.05$) were observed with regard to weight and BMI between normo- and hypertensive women. Volunteers with high blood pressure had significantly higher ($P<0.001$) systolic and ($P<0.01$) diastolic pressure than normotensive participants.

Metal and metalloid hair concentrations of the population studied are shown in Table 2. Volunteers with high blood pressure presented significantly ($P<0.05$) higher levels of Cd, Co, and Mo and tended to display higher levels of Pb than normotensive females. Furthermore, Ca/Mg and Zn/Cu ratios of hypertensive subjects were higher than those of normotensive women. Concentrations of Fe ($P<005$), Na ($P<0.05$), Mn ($P<0.05$) and K ($P<0.001$) in the hair of hypertensive women were significantly lower than those in normotensive individuals. Moreover, K concentrations were significantly negatively correlated with systolic blood pressure ($r=-0.650$; $P<0.001$) and diastolic blood pressure ($r=-0.679$; $P<0.001$) (Figure 1). Co was significantly correlated with systolic ($r=0.588$; $P=0.004$) and diastolic ($r=0.768$; $P<0.001$) blood pressure. Mn negatively correlated with systolic blood pressure ($r=-0.423$; $P=0.031$). Cu ($r=0.481$; $P=0.013$) and Ni ($r=0.625$; $P<0.001$) correlated significantly with diastolic blood pressure.

Table 3 shows metal and metalloid concentrations in the hair of volunteers with BMI <25 kg m^{-2} and normal blood pressure and for overweight volunteers (BMI ⩾25 kg m^{-2}) and volunteers with high blood pressure. Overweight and hypertensive individuals displayed significantly lower (at least $P<0.05$) Fe, Na, Mn and K concentrations, a lower Fe/Cu ratio, and higher ($P<0.05$) concentrations of Co than their normotensive–normal weight counterparts.

Table 2 Metal and metalloid hair levels (μg g^{-1}) of normotensive and hypertensive postmenopausal women

	Normotensive women (n=12)	*Hypertensive women (n=14)*	*Significance (P)*
Al	9.75 (4.22, 12.75)	8.23 (3.16, 12.98)	NS
Ba	0.36 (0.19, 0.43)	0.24 (0.21, 0.32)	NS
Ca	374 (279, 460)	413 (295, 544)	NS
Cd	0.019 (0.017, 0.036)	0.033 (0.021, 0.044)	<0.05
Co	0.017 (0.013, 0.026)	0.033 (0.022, 0.32)	<0.05
Cr	0.36 (0.28, 0.56)	0.27 (0.24, 0.51)	NS
Cu	10.9 (10.3, 12.3)	12.1 (9.8, 13.1)	NS
Fe	17.1 (14.2, 21.2)	12.1 (9.8, 15.8)	<0.05
K	21.1 (13.7, 30.9)	6.1 (4.8, 13.1)	<0.001
Mg	36.1 (24.9, 40.7)	26.7 (19.1, 46.5)	NS
Mn	0.16 (0.11, 0.37)	0.08 (0.06, 0.11)	<0.05
Mo	0.18 (0.16, 0.78)	0.41 (0.22, 1.15)	<0.05
Na	63.4 (40.5, 93.8)	20.8 (12.5, 64.8)	<0.05
Ni	0.76 (0.59, 1.05)	0.89 (0.74, 1.05)	NS
Pb	1.04 (0.71, 2.31)	1.26 (0.66, 1.94)	NS
Sb	0.036 (0.021, 0.046)	0.041 (0.018, 0.055)	NS
Se	0.57 (0.41, 0.68)	0.61 (0.53, 0.71)	NS
Sr	0.60 (0.38, 1.57)	1.05 (0.57, 1.68)	NS
V	0.046 (0.035, 0.081)	0.039 (0.024, 0.066)	NS
Zn	214 (187, 232)	221 (162, 242)	NS
K/Na	0.44 (0.23, 0.51)	0.50 (0.20, 0.70)	NS
Ca/Mg	9.7 (8.0, 15.2)	16.0 (13.2, 19.6)	<0.05
Zn/Cu	15.3 (13.8, 21.8)	19.3 (14.2, 21.5)	<0.05
Fe/Cu	1.48 (1.06, 2.18)	1.07 (0.84, 1.32)	<0.05

Abbreviations: n, number of subjects; NS, non-significant.
Values are median (minimum, maximum).

DISCUSSION

Elevated body weight and BMI are normally associated with high blood pressure.[20] None of the participants was obese; most of the normotensive volunteers (73%) had BMI <25 kg m^{-2}, whereas about 64% of hypertensives had BMI ⩾25 kg m^{-2}. This in part explains the differences in body weight and BMI among hypertensives and normotensives in this study. High levels of insulinemia have been shown to decrease natriuresis.[21] Moreover, hyperinsulinemia and hyperglycemia can increase tubular sodium re-absorption and cause hypertension.

The present results suggest clear differences in hair concentrations of some metals and metalloids between normo- and hypertensive individuals. The mechanisms responsible for these differences are unclear, but they may be similar to those described for the kidney and/or may be related to metal and metalloid levels in plasma. Hair is formed from matrix cells present in a bulb-shaped follicle located in the dermis. During growth, hair is exposed to circulating blood and extracellular fluids; certain chemicals, including metals, can then diffuse into cells, reach the hair root and eventually the hair strand, where they are fixed.[22] Moreover, according to Kenouch *et al.*[23] aldosterone targets human skin, which expresses mineralocorticoid receptors and displays 11β-hydroxysteroid dehydrogenase activity.

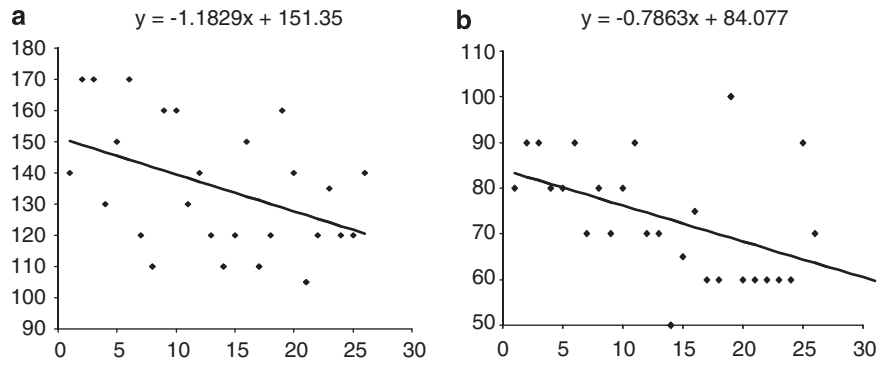

Figure 1 Linear regression between hair potassium levels and blood pressure. (**a**) Systolic blood pressure ($r=-0.650$; $P<0.001$; $n=26$). (**b**) Diastolic blood pressure ($r=-0.679$; $P<0.001$; $n=26$).

The present results regarding Cd levels in hair concur with those of Tang *et al.*[1] who found that concentrations of Cd in serum and hair samples, but not in fingernails, differed significantly between controls and hypertensive females. Cd is harmful to human health, and earlier publications have reported that high levels of Cd cause hypertension.[24] Afridi *et al.*[8,12] described higher Cd levels in scalp hair of myocardial infarction patients. According to Eum *et al.*[25] Cd increases blood pressure by raising plasma renin activity and modifying catecholamine metabolism or by inducing sodium retention by directly influencing proximal renal tubules. Moreover, Cd-induced oxidative stress damages kidney proteins, including the Na^+/K^+ ATPase,[26] which in turn raises blood pressure in rats.[27] Ca may mitigate some of the toxicity ascribed to Cd.[8] Hypertensive women in this study tended to present higher Ca values than normotensive subjects, which could partially explain the fact that none of the hypertensive volunteers had systolic blood pressure $\geqslant 180$ mm Hg.

Like Cd, Pb tends to accumulate in the body and has important interactions with other divalent cations such as Fe(II) and Zn(II). Lead-induced hypertension can result from damaged renal tubules, elevating the concentration of catecholamines with concomitant impairment of baroreceptors, direct vasoconstriction and increased blood volume.[7,27] Hypertensive women in this study tended to display higher levels of Pb than normotensive females.

The hair of hypertensive women contained $\sim$100% more Co than that of their normotensive counterparts, suggesting that hair may be an active route of Co excretion. Co enhances the activity of hypoxia-inducible factor,[28] and administration of Co reduces proteinuria as well as kidney damage on histological examination. Co upregulates renal hypoxia-inducible factor expression and increases the expression of hypoxia-inducible factor-regulated genes such as erythropoietin, vascular endothelial growth factor and heme oxygenase-1.

Magnesium intensifies the outflow of Ca from cells, and activates important enzymes that participate in phosphorylation and other metabolic processes and compete with Ca for many of its functions.[29] The relationship between Mg deficiency and arterial hypertension has not yet been fully established.[8,30] Concentrations of Mg in hair did not differ significantly between normotensive and hypertensive subjects.

Manganese concentrations in hair were significantly lower in hypertensive than in normotensive women. Hair levels of Mn were also significantly lower in hypertensive individuals with high BMI than in hypotensive individuals with normal BMI. Manganese activates nitric oxide synthase (NOS I), which converts L-arginine into L-citrulline and NO^*, and produces O_2^- in the absence of L-arginine. Nitric oxide has been implicated in many physiopathological conditions, including hypertension[30] and weight gain. Greenstein *et al.*[31] found that adipocytes secrete adiponectin and provided the first functional evidence that adiponectin is a physiological modulator of local vascular tone that acts by increasing nitric oxide bioavailability. This capacity is lost in obesity, leading to hypoxia, inflammation and oxidative stress.

Vanadium is considered to have antiatherosclerotic properties.[10] Hypertensive women tended to present ($P<0.1$) lower levels of V in hair than their normotensive counterparts.

McCord[32] indicated that increased iron levels in humans (for example, excessive iron intake and abnormal iron metabolism) as well as low levels of iron in hair are correlated with hypertension. Hypertensive women in the study had 30% less Fe in hair than their normotensive counterparts.

Molybdenum is a cofactor involved in the activation of the enzyme xanthine oxidase, which generates oxyradicals associated with increased arteriolar tone observed in hypertensive individuals.[33] This finding explains, at least in part, the higher concentrations of Mo found in the hair of hypertensive postmenopausal women.

Chromium inhibits atherosclerosis by improving lipid and carbohydrate metabolism.[8] Anderson[34] found that Cr deficiency causes disorders of lipid metabolism. Chromium values obtained from hair samples in this study indicate, as did those of Tang *et al.*[1] in serum, hair and fingernails, that hypertensive individuals have lower concentrations of Cr than their normotensive counterparts.

The relationship between Na levels and hypertension has been extensively studied.[35] Any mechanism that decreases Na excretion increases Na retention, which in turn raises blood pressure levels.[36] As commented earlier, hair is formed from matrix cells present in the dermis, and human skin appears to be a target for aldosterone.[23] It may be hypothesized that the Na content of the hair of hypertensive postmenopausal women was lower than that of their normotensive counterparts owing to the role of aldosterone in retaining Na in the hair follicles and limiting its excretion.

The present results concerning hair K concentrations seem paradoxical, taking into account previous comments relating aldosterone with Na in hair follicles. However, the lower concentration of hair K in those women could be a consequence of their higher excretion of K through urine. Although we are far from understanding the mechanism involved, it can be hypothesized that K excretion through hair may decrease in hypertensive women to compensate for the hypertensive effect of Na retention. Indeed, we found that hypertensive and normotensive women displayed similar K/Na ratios.

Elliot *et al.*[37] found that dietary Ca and Mg values are inversely correlated with blood pressure. Increased urinary excretion of Ca has been thought to be a probable cause of increased levels of

Table 3 BMI, blood pressure and hair levels ($\mu g\,g^{-1}$) of metals and metalloids in normoweight–normotensive and overweight–hypertensive postmenopausal women

	Normotensive–normoweight women (n=11)	*Hypertensive–overweight women (n=7)*	*Significance (P)*
BMI ($kg\,m^{-2}$)	21.9 (19.6–24.28)	27.7 (25.4–29.89)	<0.001
Systolic blood pressure (mm Hg)	117.7 (105–130)	152.9 (140–170)	<0.001
Diastolic blood pressure (mm Hg)	66.8 (50–89)	75.0 (60–90)	<0.05
Al	12 (0.38, 15.30)	8.23 (1.66, 19.90)	NS
Ba	0.36 (0.09, 0.70)	0.24 (0.11, 0.36)	NS
Ca	381 (196, 1102)	401 (174, 840)	NS
Cd	0.019 (0.01, 0.23)	0.034 (0.01, 0.05)	NS
Co	0.018 (0.01, 0.040)	0.033 (0.02, 0.51)	<0.05
Cr	0.35 (0.18, 0.63)	0.27 (0.12, 0.57)	NS
Cu	10.8 (9.44, 16.1)	11.8 (6.83, 13.2)	NS
Fe	17.3 (11.2, 44.6)	12.1 (9.8, 15.8)	<0.01
K	23.0 (4.67, 67.5)	6.05 (4.69, 28.9)	<0.05
Mg	38.1 (18.7, 45.6)	24.3 (5.86, 46.5)	NS
Mn	0.19 (0.08, 0.65)	0.08 (0.04, 0.35)	<0.05
Mo	0.18 (0.11, 1.61)	0.38 (0.12, 1.99)	NS
Na	87.1 (29.0, 130)	17.6 (9.75, 97.4)	<0.01
Ni	0.63 (0.51, 1.35)	0.83 (0.68, 1.26)	NS
Pb	1.01 (0.25, 3.70)	1.17 (0.11, 4.49)	NS
Sb	0.029 (0.02, 0.26)	0.048 (0.01, 0.10)	NS
Se	0.54 (0.03, 0.73)	0.55 (0.35, 0.82)	NS
Sr	0.56 (0.11, 2.78)	0.91(0.45, 1.48)	NS
V	0.047 (0.03, 0.12)	0.043 (0.02, 0.09)	NS
Zn	219 (108, 274)	193 (94.5, 234)	NS
K/Na	0.46 (0.10, 1.23)	0.50 (0.10, 0.74)	NS
Ca/Mg	9.36 (5.0, 24.0)	16.7 (13.0, 29.0)	NS
Zn/Cu	16.7 (11.4, 25.4)	15.6 (11.2, 23.8)	NS
Fe/Cu	1.62 (1.03, 20.7)	0.93 (0.73, 3.39)	<0.01

Abbreviations: BMI, body mass index; n, number of subjects; NS, non-significant.
Values are median (minimum, maximum).

parathormone. The elevated incidence of CVD in westernized countries has been related to their high dietary Ca/Mg ratio.[38] The Ca/Mg ratio of hypertensive women was almost twice that of normotensive counterparts.

An imbalance in Zn and Cu status may be a risk factor in human CVD and hypertension. However, Vivoli *et al.*[39] found no significant differences in values of Zn and Cu in serum and urine or in Zn- or Cu-dependent serum enzyme activities between hypertensive and normotensive individuals. Tubeck[40] found that serum, lymphocyte and bone levels of Zn decrease with arterial hypertension, whereas Zn concentrations in the heart, erythrocytes, kidney, liver, suprarenal gland and spleen increase. In our study, the Zn/Cu ratio was 26% higher in hypertensive women. According to Ripa and Ripa,[41] low plasma values of Zn, together with high plasma levels of Cd, are frequently found in essential hypertension. However, Sukumar and Subramanian[42] reported significantly lower hair levels of Zn in hypertensive females than in controls.

The significant correlations found in this study between hair levels of some minerals and blood pressure also support earlier reported study results. Taneja and Mandal[6] found positive correlations between serum levels of Zn, Mg and Mn with systolic and diastolic blood pressure, but negative and positive non-significant correlations between serum Cu concentrations and systolic and diastolic blood pressure, respectively.

Obese individuals present higher insulin levels than normal weight individuals,[43] and insulin has been proved to exert antinatriuretic effects,[44] explaining the high prevalence of hypertension among the obese. None of the women included in this study was obese; thus, insulin resistance was not prevalent in the population studied. In other words, the blood pressure–BMI concurrence did not increase the differences in metal and metalloid concentrations compared with those observed after considering only blood pressure (Table 3 *vs.* Table 2).

In conclusion, the present results show that among postmenopausal women, normotensive and hypertensive individuals differ with regard to the content of several minerals and trace elements in their hair. Levels of some of these elements, including Cd, Co, Fe, K, Mn, Mo and Na, can be used as biomarkers to assess blood pressure in postmenopausal women. Further research is necessary to clarify the mechanisms by which blood pressure and hair mineral excretion may be related.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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