Original Article

Relationship between Body Mass Index and Minerals in Male Japanese Adults

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Abstract

In order to examine possible relationship between minerals and body mass index (BMI), we measured hair concentrations of 24 bio-elements including essential minerals and toxic metals in over 1500 male Japanese adults aged 20-60 years. Several essential minerals were found to be significantly high and positively or inversely correlated to BMI. The best BMI-correlated element was potassium (K) with the highest regression coefficient of $r = 0.240$, followed by mercury (Hg) ($r = 0.207$), molybdenum (Mo) ($r = 0.202$), sodium (Na) ($r = 0.170$), boron (B) ($r = 0.144$), selenium (Se) ($r = 0.138$) and aluminum (Al) ($r = 0.131$) with the p-value of $p < 0.0000$ for every element. Using the regression line of BMI = 2.23 Log Hg + 14.95 obtained, a 10-fold increase in mercury level was estimated to associate with a 2.2-point increment in BMI. The most inverse-correlated mineral to BMI was magnesium (Mg) ($r = -0.264$), followed by calcium (Ca) ($r = -0.248$) and zinc (Zn) ($r = -0.166$, $p < 0.0000$), which are representative competitive bio-elements against mercury.

These findings suggest possibility that some minerals contribute to regulation of BMI, and higher dietary mercury intake is associated with the increase of BMI in male Japanese adults. Dietary intake of the competitive minerals against mercury, such as Mg, Ca and Zn, may be useful for controlling human body weights.

Keywords : body mass index, mercury, magnesium, calcium, zinc, mineralomics

Introduction

For the last several years, we have been measuring scalp hair mineral concentrations in near 40 thousand people ranging from infant to elderly, in order to assess the relationship between minerals and physical or mental disorder. In previous study on hair toxic metal levels in a total of 5846 Japanese, we reported that there are two types in accumulation profile of toxic metals, and that infants and children are under high exposure to the 3 toxic metals such as lead, cadmium and aluminum [1].

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Mercury, especially organic methylmercury is well known to accumulate in kidney, liver and fat-rich tissues like brain and adipose tissue, and to show age-dependent increase in Japanese adults [1-3]. This toxic metal is well known to not only inhibit various enzymatic reactions and metabolic processes but also enhance lipid peroxidation, progression of atherosclerosis, and the risk of myocardial infarction [4-7], and Minamata disease [8].

The purpose of this study was to examine possible role of toxic metals and essential minerals in obesity, which is the key risk factor of cardiovascular diseases and metabolic syndromes. In this study, 24 minerals in hair were determined in over 1500 of male Japanese adults aged 20-60 years, and the relationship between the mineral status "mineralome" and body mass index (BMI) was examined.

Materials and Methods

Materials

Scalp hair samples (about 0.2 g) were collected on the basis of informed consent from 1552 male subjects aged 20-60 years old in the Tokyo metropolitan district, and used for mineral analysis. All of the data obtained are held secure in such a form as to ensure anonymity.

Hair mineral analysis

Hair sample of 75 mg was weighed into 50ml plastic tube, and washed twice with acetone and then with 0.01% Triton solution, in accordance with the procedures recommended by the Hair Analysis Standardization Board [9]. The washed hair sample was mixed with 10 ml of 6.25% tetramethylammonium hydroxide (TMAH, Tama Chemical) and 50 μl of 0.1% gold solution (SPEX Certi Prep.), and then dissolved at 75 ℃ by shaking for 2 hours. After cooling the solution to room temperature and adjusting its volume gravimetric, the obtained solution was used for mineral analysis. The mineral concentrations were measured with inductively coupled plasma mass spectrometry (ICP-MS ; Agilent-7500i and 7500c) [10], and were expressed as ng/g hair (ppb) or μg/g (ppm).

Body mass index

Body mass index (BMI) was calculated by dividing body weight (kg) by height (m) squared, using those self-reported values written in the questionnaires.

Statistical analysis

The hair mineral levels were distributed in lognormal manner, and so the geometric rather than arithmetic means were used as representative of hair mineral levels. For statistical analysis, the values of mineral levels were converted to the logarithm. Statistical significance was determined using the Welch's t-test.

Results

Twenty-four mineral concentrations in the hair of 1552 male Japanese adults aged 20-60 years were measured with ICP-MS (Table 1), and the association between their body mass index (BMI) and hair bio-element levels was examined. The representative scattered plots exhibiting the relationship between BMI and the two minerals with the highest positive or inverse regression coefficient are shown in Fig. 1 and Fig. 2. The results of regression analysis between BMI and each of the 24 elements examined are shown in Table 2. The most correlated mineral to BMI with the highest regression coefficient was potassium (K ; r = 0.240), followed by mercury (Hg ; r = 0.207), molybdenum (Mo ; r = 0.202), sodium (Na ; r = 0.170), boron (B ; r = 0.144), selenium (Se ; r = 0.138), and aluminum (Al ; r = 0.131), with the low p-value of $p < 0.0000$ for every element. Arsenic (As) and phosphorus (P) also tended to be positive-correlated with BMI ($p < 0.01$). In contrast, the most inverse-related mineral to

Table 1 Hair mineral levels in male Japanese adults[#].

	Hair mineral level		
	Geomean	Minimum	Maximum
Na	27,395	816	1,461,000
K	22,082	357	472,000
Mg	50,206	4,567	1,077,000
Ca	424,077	64,270	7,434,000
Cr	122	1	5,555
Mo	32	5	402
Mn	128	9	49,690
Fe	5,796	1,644	1,550,000
Cu	20,390	5,649	575,900
Zn	139,175	44,290	911,700
P	152,593	67,800	743,600
Se	576	34	64,090
V	21	0.6	1,084
Co	15	0.3	4,812
Ni	225	7	7,953
B	383	13	16,550
Ge	92	38	18,680
Br	3,554	50	1,194,000
I	428	8	215,940
Cd	13	0.2	1,359
Hg	4,153	53	49,160
Al	3,703	44	123,600
Pb	540	37	28,160
As	46	2	1,290

(Unit : ppb)

[#]The geomean values were calculated from the data of male Japanese adults aged 20-60 years (N = 1552).

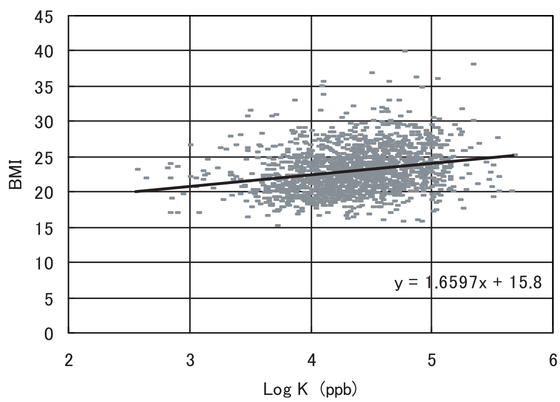

Fig. 1 Relationship between body mass index and hair potassium level in male Japanese adults. The abscissa is expressed the logarithmic value of hair potassium concentration. The regression equation was obtained from the data of 1552 male Japanese adults.

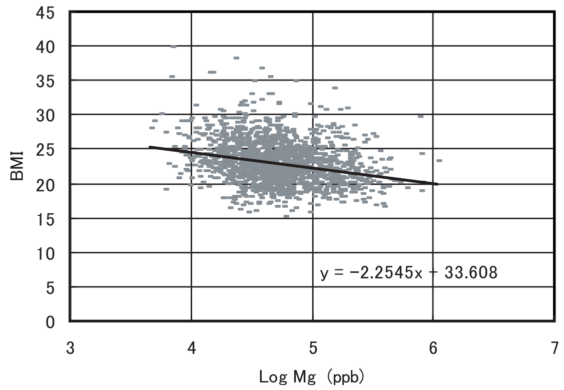

Fig. 2 Relationship between body mass index and hair magnesium level in male Japanese adults. The abscissa is expressed the logarithmic value of hair magnesium concentration. The regression equation was obtained from the data of 1552 male Japanese adults.

BMI was magnesium (Mg ; r = -0.264), and the followings were calcium (Ca ; r = -0.248), and zinc (Zn ; r = -0.166), with p <0.0000 for every element.

The regression line between BMI and mercury or zinc was calculated BMI = 2.23 Log Hg + 14.95 or BMI = -4.27 Log Zn + 44.98, respectively (Fig. 3 A and B). Using these regression lines, we estimated a 2.2 BMI increment associated with an increase in concurrent hair mercury levels from 1.0 to 10 ppm, and a 2.1 BMI decrement associated with an increase in the zinc levels from 100 to 330 ppm.

These results indicate that the persons with high BMI values have some mineral imbalance in the body, namely high mono-valence electrolyte levels and/or low di-valence electrolyte levels, and also high mercury levels and/or low zinc levels.

Discussion

Hair mineral analysis has been used in forensic medicine, in screening populations for toxic metal poisoning and in monitoring environmental pollutants [11-13]. Furthermore, its diagnostic use for individual disease and symptom has been tried, but remains to be confirmed scientifically [14]. Our previous studies clarified that hair levels of some toxic metals such as lead, cadmium and aluminum are extraordinarily high in infants and children [1], and also that autistic children are suffered from a global mineral deficiency in various essential trace elements [10].

Body-mass index (the weight in kilograms divided by the square of the height in meters) is known to be associated with overall mortality. Especially, a high BMI is a high risk factor, and is reported to be one of the most predictive of death from cardiovascular disease in men (relative risk, 2.90) [15]. Therefore, in this study the association between the main risk factor BMI and minerals were examined.

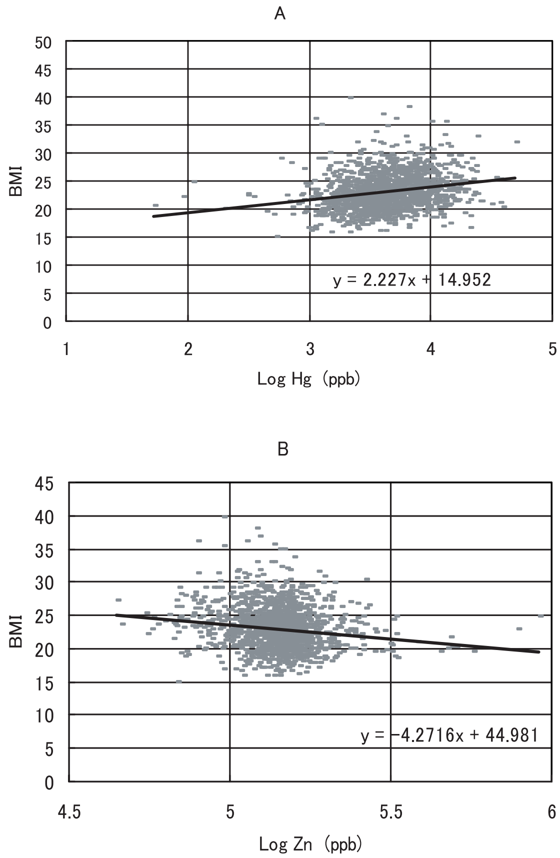

Fig. 3 Relationship between body mass index and hair mercury (3A) or zinc level (3B) in male Japanese adults. The abscissa is expressed the logarithmic value of hair mercury or zinc concentration. The regression equation was obtained from the data of 1552 male Japanese adults.

This paper demonstrated that there are high-significant, positive or negative relationships between BMI and the four principal electrolyte levels in hair (Fig. 1, 2 and Table 2). Mono-cation electrolytes, potassium and sodium, were high-significantly correlated positively to the BMI value. In contrast, di-cation electrolytes, magnesium and calcium, correlated inversely with BMI value ; the higher these element levels, the lower BMI value. These findings suggest the possibility that these four electrolytes play a pivotal role in controlling the body weight and BMI, and low dietary intake of Mg and Ca may lead to increase BMI.

It is well accepted that magnesium ion, Mg^{2+}, is essential for myriad biochemical processes and regulates various Ca^{2+} -induced physiological responses. Cardiovascular system is modulated by mineral balance of Ca/Mg

Table 2 Relationship between BMI and Minerals.

Mineral	r value	P value	Significance
K	0.240	0.0000	****
Hg	0.207	0.0000	****
Mo	0.202	0.0000	****
Na	0.170	0.0000	****
B	0.144	0.0000	****
Se	0.138	0.0000	****
Al	0.131	0.0000	****
As	0.089	0.0003	***
P	0.078	0.0019	**
Cr	0.065	0.0137	*
Pb	0.055	0.0391	*
I	0.053	0.0436	*
Fe	0.048	0.0891	
V	0.046	0.0848	
Mn	0.046		
Co	0.046		
Br	0.033		
Cd	0.026		
Ge	0.006		

Mineral	r value	P value	Significance
Mg	−0.264	0.0000	****
Ca	−0.248	0.0000	****
Zn	−0.166	0.0000	****
Ni	−0.055	0.0319	*
Cu	−0.027		

*: $p < 0.05$
**: $p < 0.01$
***: $p < 0.001$
****: $p < 0.0001$

and Na/K and the disorder of mineral homeostasis relates to the pathogenesis of hypertension and arteriosclerosis. Furthermore, dietary Ca/Mg intake ratio has been reported to relate to the incidence of heart attack events, and a decreased risk for cardiovascular diseases reported to relate to the hardness of drinking water, particularly to its magnesium contents [16-18]. In addition, hypomagnesemia is reported to be common in hospitalized patients, especially in elderly patients with coronary artery disease (CAD) and/or those with chronic heart failure, and is associated with increased mortality from CAD [19-21].

Shechter et al. [19,20] demonstrated the therapeutic effect of oral magnesium supplementation in double blind clinical study. Witte et al [22,23] reported that long-term multiple micronutrient supplementation can improve LV volumes and LVEF and QOL scores in elderly patients with heart failure due to LV systolic dysfunction. Dairy higher-calcium diet is also reported to attenuate weight gain and accelerate fat loss to a greater degree than do supplemental sources of calcium [24]. Higher dietary calcium intake is known to inhibit lipogenesis and promote lipolysis, lipid oxidation and thermogenesis. Thus, evidence is accumulating that a strategy of long-term micronutrient supplementation might improve symptoms and cardiac function in elderly patients with chronic heart failure [22,23].

Wang et al. [14] recently reported that Ca, Mg, Fe and Zn concentrations in hair from adult females are inversely related to BMI, whereas Cu, K and Na are positively related to BMI. Their findings are almost coincident with those of our study, although in our study with male adults no significant correlation was observed between BMI and Fe or Cu.

In the toxic metals measured, mercury exhibited a high -significant correlation to BMI value with the regression coefficient of $r = 0.207$ ($BMI = 2.23 \text{ Log Hg} + 14.95$; $p < 0.0000$) (Fig.3A), and followed by aluminum, arsenic and lead (Table 2). Using this regression line, a 10-fold increase in hair mercury level was estimated to associate with a 2.2-point increment in BMI. Mercury is considered to be toxic at any level in the body, and at high concentrations causes liver and kidney damage and also neurological symptoms/disorders [8]. In addition, this toxic metal is well known to not only inhibit various enzymatic reactions and metabolic processes including lipid metabolism but also enhance lipid peroxidation, progression of atherosclerosis and the risk of myocardial infarction [5-7]. Much of mercury accumulated in body is derived from dental amalgam fillings [25,26] and dietary intake of Hg-contaminated food, for example, fishes (especially large fishes) and shellfishes [2,4]. Salonen et al. [4,5] reported that a high intake of mercury from non-fatty freshwater fish and the consequent accumulation of mercury in the body is associated with an increased risk of acute myocardial infarction. This increased risk has been proposed to be due to the promotion of lipid peroxidation by mercury [4].

It is noted that zinc, a representative competitor element against mercury, is negatively correlated to BMI (BMI = -4.27 Log Zn + 44.98) in contrast to mercury (Fig. 3B). The estimated BMI increment associated with an increase in hair mercury level from 1 to 10 ppm was 2.2-point. While, associated with an increase in the zinc from 100 to 330 ppm, a 2.1 BMI decrement was estimated. These findings suggest the possibility that the intake of mercury induces an increase in BMI, and the intake of appropriate amount of zinc leads to improve the increased BMI.

Conclusions

In this study, a high-significant and positive or inverse relationship between BMI and some essential minerals was demonstrated in male Japanese adults. In addition, mercury was found to positively correlate to BMI values, and a 10-fold increase in mercury level was estimated to associate with a 2.2-point increment in BMI. These findings suggest that the body weight of male Japanese is partly regulated by electrolytes, trace bio-elements and their balance in body, and also affected by dietary and/or environmental mercury intake. Thus, it is noted that well-adjusted balance of body minerals and a sustaining balance of the mineral levels are effective for controlling individual body weight and for maintaining health.

Hair mineral analysis provides global information of "mineralomics" about the deficiency/excess profile of multiple bio-elements that contribute to various physiological and/or adverse events in the human body, and therefore is useful for health and risk assessment.

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