Body Mass Index (nutritional status) and concentrations of Ca, Cu, Fe, Mg, Zn, K, Na in the hair of young men from Tanzania

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Abstract

Background: Excess body weight has become a problem of a medical, social and cultural nature that affects a large share of the populations in nearly all countries worldwide. Little is known about the relationship between the concentrations of mineral levels in hair vs. body weight in Africans. The aim of this study was to examine the correlations between the concentrations of Ca, Cu, Fe, Mg, Zn, K, and Na in hair vs. body weight in young men from Tanzania.
Methods: The participants were young men (aged 16.60 ± 1.92) from Tanzania (n = 91). Concentrations of Ca, Cu, Fe, Mg, Zn, K and Na in hair were measured and assessed for correlations between the levels of these trace elements and in underweight and normal weight.
Results: A statistically significant relationship of moderate intensity was found between Cu vs. body weight, BMI, Ca, Zn, Fe. Backward stepwise regression analysis for the whole group indicates that the variables included account for 27% (adjusted $R^2 = 0.27$) of the variation in BMI. All the variables included in the equation account for 22% of BMI variation in participants with normal body weight, and for 26% in underweight participants.
Conclusions: Analysis of mineral concentrations in hair can help uncover nutritional deficiencies. It can be particularly useful in studying isolated or remote communities. Expanding the body of knowledge on the influence of mineral concentrations on body weight may contribute to halting global weight gain, which is a multi-faceted and seemingly unstoppable phenomenon at the moment.

Body Mass Index (status odżywienia) a zawartość pierwiastków Ca, Cu, Fe, Mg, Zn, K, Na we włosach u młodych mężczyzn z Tanzanii

Słowa kluczowe pierwiastki śladowe, Ca, Cu, Fe, Mg, Zn, K, Na, BMI, odżywianie

Streszczenie

Nadmierna masa ciała jest obecnie problemem medycznym, społecznym, kulturowym, dużej części mieszkańców niemal wszystkich krajów. Mało jest badań o zależności pomiędzy zawartością pierwiastków w organizmie człowieka a masą ciała (stanem odżywienia) wśród ludności afrykańskiej. Celem prezentowanych badań było zbadanie współzależności między zawartością pierwiastków: Ca, Cu, Fe, Mg, Zn, K i Na we włosach a masą ciała u młodych mężczyzn z Tanzanii. Badani to młodzi mężczyźni (16.60 ±1.92 lat) z Tanzanii. Oznaczono zawartość Ca, Cu, Fe, Mg, Zn, K i Na we włosach i zbadano stopień korelacji pomiędzy zawartością analizowanych pierwiastków a kategorią BMI. Istotną statystycznie zależność, o średnim natężeniu wykazywała Cu vs. masy ciała, BMI, Ca, Zn, Fe. Wszystkie zmienne uwzględnione w równaniu regresji w 22% wyjaśniły zmienność BMI w grupie osobników o prawidłowej masie ciała, a w 26% dla badanych z niedowagą. Analiza zawartości pierwiastków we włosach może być cennym źródłem istotnych informacji o niedoborach żywieniowych lub nieprawidłowym odżywianiu. Uzupełnienie informacji o wpływie zawartości pierwiastków na masę ciała, może pomóc zapobiec globalnemu tyciu, które jest zjawiskiem wielowątkowym i trudnym obecnie do zahamowania.

Introduction

The evolution of research has been accompanied by the legal adoption of biomonitoring in many countries (The EU 2000; U.S. EPA 1979) as a reliable method for assessing the influence of chemical substances on living organisms. Non-invasive medical tests use information obtained from hair, nails, saliva, urine, faeces, etc.

The lifecycle of hair means that the analysis of its mineral content provides information about extended periods of life (Dean et al. 2001). For this reason, hair is not only becoming an increasingly popular research material in biomonitoring targeted at revealing the presence of harmful substances, but can also be used to indicate health status and nutritional deficiencies (Marshall 2008). Analysis of mineral concentrations in hair is an interesting non-invasive diagnostic method.

The levels of microelements in the human body are determined by such factors as sex (Barbieri et al. 2011), calendar age (Park et al. 2007), race (Hambidge et al. 1972; Kidwell et al. 2000), health status, synergistic and antagonistic relationships between elements (Kim et al. 2010) and many other (Sukumar 2002). Mineral levels in the human body must be tightly regulated, seen as significant deviations from the normal levels may lead to serious metabolic disorders, weakening of immune processes, endocrine problems (Miekeley et al. 2001), stunted growth, problems with maintaining normal weight, or even death (Mertz and Underwood 1987). Elements such as Ca, Cu, Fe, Mg, Zn, K and Na determine the strength, direction and intensity of metabolic processes.

Approx. 25% of enzymes in the human body require trace elements for metabolic processes to be activated and to function properly (Tapiero et al. 2003; Tapiero, Tew 2003; Marletta, Spiering 2003; Vanaelst et al. 2013). The presence of minerals in the human body is crucial for regulating electrolyte balance, transmitting nerve impulses, muscle function, bone formation and growth, as well as general development. The absorption and utilisation of minerals depends on the presence and bioavailability of nutrients in the diet.

During intensive growth, maintaining the right levels of minerals in the human body is of special importance. Adequate supply is a significant factor in ensuring normal growth, starting from prenatal development, through childhood to maturity. Sufficient mineral levels in the body at each ontogenetic stage are needed for immune and physiological processes (Chandra 2002).

Zinc is an integral part of more than 200 enzymes and plays a significant role in cell regeneration (Shankar, Prasad 1998). It is responsible for stabilising cellular membranes and collagen synthesis. It is also involved in the development of the nervous system, synaptic transmission, biochemistry of vision and wound healing (The Nutrition 2014). Hambidge et al. (1972) demonstrated that low Zn levels in hair go hand in hand with impaired growth, anorexia and hypogeusia (taste impairment). Iron is responsible for transporting oxygen to the cells, as well as necessary for energy production, collagen synthesis and immune response regulation (Requirements 1988) and together with copper it is required to synthesise haemoglobin. Iron is also one of the key components of cytochrome C, which is responsible for electron transfer between mitochondria.

Excessive iron levels interfere with the absorption of other minerals. Maintaining body levels of iron in proper homoeostasis is essential, because iron deficiency leads to anaemia, while iron overload causes serious disorders, such as haemochromatosis (Andrews 1999). Excessive concentrations of Fe in the body may indirectly affect fatty acid oxidation and mitochondrial ATP production (Pinhas-Hamiel et al. 2003). Copper is a cofactor for antioxidant enzymes and stabilises cellular membranes (Linder, Hazaegh-Azam 1996). Like iron, it is involved in the oxidation of fatty acids and mitochondrial ATP production. Many foreign substances in foodstuffs hinder Cu absorbability from food, hence copper deficiency is relatively common (The Nutrition 2014). It has been suggested that zinc has an antagonistic effect on copper absorption. Calcium plays an important role in muscle physiology, it regulates water balance in cells, is one of the main components of bones and teeth, as well as affecting the nervous and muscular system, and featuring in blood pressure regulation and bone metabolism. Calcium is also necessary in the processes of blood coagulation, muscle contraction, and hormone secretion; it affects enzyme activity and is an element of cell membranes, regulating their permeability (The Nutrition 2014). Studies have also demonstrated that calcium is involved in reducing body fat and in carbohydrate metabolism (Teegarden 2003; Bueno et al. 2008; Zhu et al. 2013). Magnesium is involved in muscle and nerve function. It is responsible for the proper function of the heart muscle. It plays an important role in many processes taking place in the living body. Magnesium participates in metabolic pathways occurring within a cell. It acts as an activator for various enzymes, and is thus involved in metabolising carbohydrates, nucleic acids and proteins (Rubin 2005).

Deficiencies of essential minerals compromise an individual's health status at each ontogenetic stage. Those at the highest risk include children and young people during intensive growth. Researchers have suggested that mineral deficiencies or insufficient mineral intake is indirectly responsible for approx. 7.3% of all illnesses on the global scale (Barany et al. 2002). The influence of trace elements on metabolic processes and body-weight implications in populations with a high level of economic and social development are quite well documented. On the other hand, there have been few studies exploring the relationship between the mineral content in the human body and nutritional status in communities where malnutrition or even famine are commonplace, particularly in Sub-Saharan Africa (Müller, Krawinkel 2005; World Bank 2013).

The objective of this study is to investigate the relationship between the levels of Ca, Cu, Fe, Mg, Zn, K and Na in hair and nutritional status defined according to BMI in young men from Mafinga, Tanzania.

Materials and methods

The material used in the biochemical analysis (n = 91) for the hair content of Ca, Cu, Fe, Mg, Zn, K and Na was collected from secondary school students from the town of Mafinga, altitude 2,300 m a.s.l. Lat (DMS) 7° 15' 0S and Long (DMS) 35° 4' 0E, Iringa district, Tanzania.

Anthropometry

Anthropometric tests included measurements of body height (B-v) (in cm) and weight (in kg). All students belonged to the Bantu language group. They had been staying at the school's boarding house for no less than a year and were given meals at the school canteen. Body height measurements (B-v) were performed with an anthropometer measuring range 0–2000 mm (DKSH Switzerland Ltd., Zürich), in compliance with anthropometric technique, while body weight was measured using SOEHNLE (model 63671 Chicago Silver Body Balance Scale B000FL3H3G, Germany) electronic weighing scales with an accuracy of 100 g. The body mass index was calculated (BMI = kg/m^2) and used to assign participants to predefined categories. BMI calculations were used to determine the participants' nutritional status. Three groups were identified according to BMI (Physical status 1995): low body weight group (malnutrition) BMI < 18.5 (n = 14); normal body weight group (healthy nutrition) BMI ≥ 18.5 < 25.0 (n = 74); and excess weight group (overweight) BMI ≥ 25.0 (n = 3). Due to the small number of overweight individuals (none of the participants in the study group were found to be obese), the comparative analysis included the low weight group and normal weight group.

Statistical analysis

The results were analysed using the software package Statistica made by StatSoft, Inc. (2011). The arithmetic mean value, standard deviation (SD) and min–max range were calculated for Ca, Mg, Cu, Fe, Zn, K, Na levels and the anthropometric variables. Pearson's correlation (r) analysis was performed to investigate the extent to which trace elements demonstrated dependence on anthropometric measurements. The level of significance was taken as $p \leq 0.05$. To find out whether the minerals under investigation were present in different concentrations in underweight individuals as opposed to those with normal weight, backward stepwise multiple regression analysis was performed.

Analysis of the content of chemical elements in hair

After collecting the hair samples in Tanzania, the analysis for the levels of Ca, Cu, Fe, Mg, Zn, K and Na was conducted at a specialist laboratory in Poland at the Pomeranian Medical University of Szczecin, Department of Biochemistry.

Hair samples were obtained from individuals whose hair had not been coloured or treated. Samples (50–100 mg) were collected from the nape of the neck. The hair was placed in ultrasonic bath of distilled deionised water (Milli-Q purification system, Millipore) for one hour. Thereafter it was washed twice using acetone and allowed to dry overnight in a laminar flow hood at 25°C. Hair was digested in a teflon vessel with 1 ml of 65% HNO_3, 1 ml of 70% $HClO_4$ (Nowak 1996; Nowak, Kozłowski 1998). The samples were then left to dissolve for 48 h in a laminar flow hood at 25°C. Afterwards, the samples were subject to 30-minute mineralization using a BM-1S/II microwave mineraliser (Plazmotronika, Wrocław, Poland). The samples were evaporated to dryness in N_2 and the residue was taken up in 10% HNO_3 to volume of 5 ml distilled deionised water. Concentrations of Fe, Ca, Mg, Zn and Cu were analysed by Atomic Absorption Spectrometry (AAS-Solar 969) in an air-acetylene flame, calibrated with standard solutions (Merck, Germany). The calibration curve was determined automatically by the computer connected to the spectrometer. Elemental determinations were carried out in an air-acetylene flame with lamps of the following wavelengths: Ca – 422.7 nm (0.5% solution of lanthanum was added as a buffer solution); Mg – 285.2 nm (0.1% solution of lanthanum or strontium was added as a buffer), Fe – 248.3 nm; Zn – 213.9 nm; Cu – 324.7 nm. Control assays were carried out every 10 samples.

Ethical approval

This research was approved by the authorities of University of Szczecin and the data were collected by the author. The schools principals, guardians and the participants from the schools where the measurements took place did not know of any law requiring ethical committee approval for a study involving anonymous, non-invasive data collection. Written consent could not be obtained, thus participants gave verbal consent and were told that their participation was voluntary and that they could quit at any time, without loss of monetary compensation. Obtaining verbal consent was also approved by the authorities of University of Szczecin. All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

Results

Table 1 presents the main anthropometric data, data on the hair levels of Ca, Mg, Cu, Fe, Zn, K, Na as well as the results of the comparative analysis of the underweight group (n = 14) vs. normal range BMI group (n = 74).

Table 1. Anthropometric data and mineral content in the hair of Tanzanians, and differences between the groups under analysis

Measurements/ elements	BMI ≤ 18.49 kg/m^2 (n = 14)		BMI = 18.50 – 24.99 kg/m^2 (n = 74)		p-value
	mean value ± SD	range (min–max)	mean value ± SD	range (min–max)	
calendar age	15.15 ± 1.37	12.83–17.55	16.85 ± 1.89	13.30–21.32	0.0019
body height (B-v) (cm)	158.54 ± 13.30	133.00–176.30	163.74 ± 7.56	135.30–184.20	0.0425
body weight (kg)	44.39 ± 7.68	30.20–54.00	56.84 ± 6.24	41.80–69.30	0.0000
BMI	17.53 ± 0.70	15.90–18.47	21.18 ± 1.66	18.62–24.98	0.0000
Ca (μg/g)	886.46 ± 120.49	680.20–1120.40	1121.48 ± 204.95	785.30–2089.70	0.0001
Zn (μg/g)	125.48 ± 37.92	44.20–158.80	85.56 ± 36.68	33.50–189.10	0.0004
Mg (μg/g)	8.21 ± 1.88	5.30–11.30	6.64 ± 1.98	4.10–10.90	0.0071
Fe (μg/g)	15.76 ± 2.48	10.30–18.50	10.36 ± 3.28	4.10–18.30	0.0000
Cu (μg/g)	8.69 ± 2.86	4.30–12.60	7.23 ± 2.86	2.30–12.80	0.0821
K (μg/g)	308.19 ± 49.92	231.11–410.21	208.26 ± 68.63	101.30–433.50	0.0000
Na (μg/g)	413.02 ± 60.74	334.19–521.78	310.58 ± 78.18	200.10–466.40	0.0000
Ca/Mg	112.86 ± 28.74	66.77–177.96	183.09 ± 58.59	90.58–366.00	0.0000
Zn/Cu	16.73 ± 8.48	3.51–36.81	13.29 ± 6.48	2.99–32.51	0.0873

BMI – body mass index; SD – standard deviation.

Out of all the chemical elements included in the analysis, only copper levels did not show a statistically significant difference between underweight and normal-weight participants. In the normal-weight category, the analysed minerals occurred in higher concentrations, with the exception of calcium.

Table 2. Correlation coefficients between the variables under investigation. Low body weight group, BMI ≤ 18.49 kg/m² (n = 14)

Measurements/ elements	body height (B-v)	body weight	BMI	Ca	Zn	Mg	Fe	Cu	K	Na
calendar age	0.64*	0.71**	0.52	0.01	–0.22	–0.31	0.18	–0.02	–0.31	0.30
body height (B-v) (cm)		0.97***	0.14	–0.45	–0.23	–0.63*	0.08	–0.16	–0.33	0.12
body weight (kg)			0.36	–0.29	–0.20	–0.66*	0.10	–0.10	–0.29	0.19
BMI				0.56*	0.07	–0.19	0.10	0.17	0.07	0.26
Ca (μg/g)					0.24	0.25	0.09	0.36	0.25	0.09
Zn (μg/g)						0.17	–0.13	–0.38	–0.28	0.14
Mg (μg/g)							0.39	0.14	0.17	–0.38
Fe (μg/g)								0.37	–0.16	–0.23
Cu (μg/g)									0.65*	0.31
K (μg/g)										0.34

BMI – Body Mass Index; *p < 0.05; **p < 0.01.

Table 3. Correlation coefficients between the variables under investigation. Normal body weight group, BMI = 18.50 – 24.99 kg/m² (n = 74)

Measurements/ elements	body height (B-v)	body weight	BMI	Ca	Zn	Mg	Fe	Cu	K	Na
calendar age	0.48***	0.57***	0.25*	–0.05	0.15	0.05	–0.14	0.16	–0.20	–0.21
body height (B-v) (cm)		0.71***	–0.16	–0.01	–0.05	–0.05	–0.10	0.09	–0.03	–0.06
body weight (kg)			0.58***	–0.18	0.11	–0.06	–0.26*	0.30**	–0.07	–0.31**
BMI				–0.24*	0.20	–0.04	–0.24*	0.31**	–0.04	–0.37**
Ca (μg/g)					0.04	0.12	0.17	–0.23*	0.02	0.13
Zn (μg/g)						0.15	0.11	0.27*	0.22	0.09
Mg (μg/g)							0.19	–0.01	0.08	0.01
Fe (μg/g)								0.37**	0.39***	–0.05
Cu (μg/g)									0.18	–0.19
K (μg/g)										0.30

BMI – Body Mass Index; ** p < 0.05; ** p < 0.01; *** p < 0.001.

Correlation analysis (Tab. 2 and 3) revealed a weak negative relationship of Ca vs. BMI (r = –0.24) in the group of participants with normal body weight. In the underweight group, the Ca vs. BMI correlation was a strong positive relationship (r = 0.56). Among the underweight students, a strong negative correlation was found for Mg vs. body height and body weight (respectively: r = –0.63 and r = –0.66). No significant relationships were found between Mg and any of the analysed variables in the group with normal weight. In the group with normal body weight, iron vs. body weight and BMI demonstrated a weak statistically significant negative relationship, r = –0.26 and r = –0.24 respectively. In the same group, a statistically significant relationship of moderate intensity was also found between Cu vs. body weight, BMI, Ca, Zn, Fe (respectively: r = 0.30, r = 0.31, r = –0.23, r = 0.27, r = 0.37). In the underweight group, a strong positive correlation was found in K vs. Cu (r = 0.65). The same element showed a statistically significant relationship of moderate intensity vs. Fe in the group with normal body weight (r = 0.39). Statistically significant relationships, also of moderate intensity, but of negative value, were found in the normal-weight group for Na vs. body weight and BMI (respectively: r = –0.31, r = –0.37).

Table 4. Results of the backward stepwise multiple regression analysis for the dependent variable BMI (BMI ≤ 18.49 kg/m², n = 14)

stepwise	Cu	K	Ca/Mg	Mg	Fe	Zn/Cu	Zn	Na	Ca	F	adjusted R^2
0	–0.05	0.031	–0.29	–0.56	0.325	0.509	–0.42	0.308	1.00	0.521	–0.50
1		0.011	–0.27	–0.53	0.312	0.567	–0.45	0.314	1.00	0.732	–0.20
2			–0.28	–0.53	0.307	0.562	–0.45	0.318	1.01	1.004	0.002
3				–0.26	0.319	0.578	–0.48	0.324	0.862	1.349	0.14
4					0.277	0.760	–0.68	0.473	0.892*	1.587	0.18
5						0.533	–0.53	0.354	0.820*	1.774	0.19
6							–0.10	0.222	0.562	1.917	0.18
7								0.211	0.539*	3.048	0.24
8									0.559*	5.458	0.26

BMI- Body Mass Index; * $p < 0.05$.

Table 5. Results of the backward stepwise multiple regression analysis for the dependent variable BMI (BMI = 18.50 - 24.99 kg/m², n = 74).

stepwise	Ca	Ca/ Mg	Mg	Zn	K	Zn/Cu	Na	Fe	Cu	F	adjusted R^2
0	–0.26	0.453	0.454	–0.30	0.199	0.570	–0.42*	–0.49*	0.752	5.454	0.36
1		0.059	0.093	–0.26	0.169	0.534	–0.42*	–0.49*	0.759	5.902	0.35
2			0.041	–0.24	0.162	0.518	–0.41*	–0.47*	0.739	6.823	0.36
3				–0.23	0.152	0.513	–0.41*	–0.46*	0.729	8.030	0.37
4					0.147	0.270	–0.40*	–0.46*	0.531*	9.440	0.37
5						0.292	–0.36*	–0.41*	0.559*	11.218	0.36
6							–0.31	–0.41*	0.400*	11.958	0.31
7								–0.42*	0.464*	11.487	0.22

BMI- Body Mass Index; * $p < 0.001$.

Backward stepwise multiple regression analysis according to BMI categories (Tab. 4 and 5) revealed that copper and calcium played completely different roles in the equation. In the underweight group, all the variables included in the backward stepwise regression analysis accounted for 26% of BMI variance (Tab. 4). The most pronounced change of the above figure was noted after eliminating copper from the model, which was the first element to be eliminated. Solution of the problem pointed to the crucial role of calcium in explaining BMI variance. Calcium retained a positive value and after eliminating Mg became statistically significant. In the group with normal body weight (Tab. 5), Cu remained statistically significant throughout the analysis, alongside Fe. All the variables included in the equation accounted for 22% of BMI variance in well-nourished participants. In this group, the adjusted R^2 did not demonstrate considerable changes in successive steps prior to eliminating Na out of the equation. It brought about a 9% decrease in explaining the variance of BMI. The role of Ca in the group with normal body weight was quite different (Tab. 5). In the equation Ca assumed a negative value and was eliminated in step one. This may indicate that calcium acts in different ways in the two BMI-based groups under analysis.

Discussion

Any deficiency or excess of minerals in the human body may lead to a number of metabolic disorders and, consequently, health problems. The recommended range for some of these elements is very narrow and requires careful attention. That is why periodic supplementation, while sometimes reasonable, should be well considered. In milder cases, the negative impact of nutritional deficiencies should be mitigated by appropriate dietary measures.

Studies devoted to proper nutrition, as well as overweight and obesity problems have long focused on adequate energy supply in the diet. Recently, however, the issue of excess accumulation of minerals in the body has increasingly been raised. The accumulated excess may lead to metabolic disorders and, consequently, induce overweight and obesity (Hong et al. 2009; Park et al. 2009; García et al. 2012). In studies involving the obese and those with diagnosed diabetes it was demonstrated that where excess energy was supplied coupled with nutritional imbalance, the recommended levels of minerals were not reached. Instead, health complications emerged, probably as a result of nutrient deficiencies (Skalnaya, Demidov 2007). Studies show that there is a correlation between BMI and increased hair concentrations of: Na, K, Cr, and Cd. The findings of the 2007 study by Skalnaya and Demidov (2007) indicate that mineral concentrations demonstrate a strong relationship with the BMI range and increase in proportion to the index. Studies by Bae and Cho (2008) revealed a significant correlation of BMI with the levels of Mg, Na, K, Fe and Zn. The researchers noted especially the highly significant correlation between Na, K and BMI. In my own studies, K demonstrated a high statistically significant correlation vs. Cu in the group with abnormal body weight. In the well-nourished group, K demonstrated a positive statistically significant dependence vs. Fe ($r = 0.39$) of moderate intensity. Notably, sodium played a different role depending on BMI rating. In the underweight group, it did not reveal a statistically significant relationship with any of the variables included in the analysis. In the group with normal BMI rating, a statistically significant correlation was found vs. body weight and BMI. For the group within the normal BMI range, regression analysis showed that Na had a high statistical significance ($p < 0.001$), and after eliminating Na out of the equation, the explanation of BMI variance was considerably (by ~9%) reduced (R^2 dropped from 0.31 to 0.22). This confirms the findings by Bae and Cho (2008) regarding the significant impact of K and Na on body weight fluctuations.

A similar mechanism was demonstrated by Chin-Thin Wang et al. (2005) who investigated the levels of Ca, Cu, Fe, Mg, Zn in the hair of young women from Taiwan with varied BMI scores. Heaney et al. (2002) concluded that the calcium content within a body is directly related to the de-composition of the fatty acid within the brown fat cells in the subcutaneous tissues. Teegarden (2003) demonstrated in his research that higher calcium concentration in the body will suppress the formation of the new fat and catalyze the decomposition of the existing fat. Clouet et al. (1986) pointed out that, like iron, copper may also have an indirect impact on fatty acid oxidation and ATP production in the mitochondria so that the body's metabolism is able to break down fatty acids and reduce fat.

Research studies have shown (Linder et al. 1996; Bae, Cho 2008; Kretsch et al. 1998) that adolescent girls with abnormal iron levels in the body (permanent or temporary) tended to have higher BMI scores and lower cognitive performance.

The analysis of the present findings reveals a close relationship between BMI and hair mineral concentrations in the studied population.

For the group with low body weight, correlation analysis revealed a strong relationship of Ca vs. BMI. This confirms the claims that calcium plays a key role in metabolic processes responsible for maintaining normal body weight. It is also corroborated by the regression analysis. Calcium was the only element to demonstrate statistical significance in explaining the BMI variance in participants with lower than normal weight (Tab. 4). In correlation analysis for the normal BMI group, calcium showed weak dependence. In turn, in the regression analysis it was the first element to be eliminated out of the equation and was not statistically significant (Tab. 5). This may suggest that calcium affects the participants' body weight and also that it may impact on other minerals involved in stabilising metabolic processes.

To accompany the drop in calcium concentrations in the group with low body weight, abnormal Ca:Mg ratios were also noted. Research has shown that imbalanced cellular Ca:Mg ratios caused by abnormal Ca levels altered overall ion regulation in the metabolic syndrome responsible for arterial hypertension, insulin resistance, left ventricular hypertrophy, and arteriosclerosis (Resnick 1992).

In the group with low body weight, Cu concentrations were higher than in the group with normal BMI. The differences were not statistically significant.

In the group within the normal BMI range, Ca demonstrated statistical significance vs. body weight, BMI, Zn and Fe. Regression analysis also revealed the different roles played by copper in explaining BMI variance. In the underweight group, Cu was eliminated in step one and it had an impact on R^2 as a sign of strong synergistic relationships with other elements involved in metabolic processes responsible for normal body weight. In the group with normal body weight, Cu demonstrated high statistical significance ($p < 0.001$) in regression analysis. The final R^2 is unambiguously explained by this element together with Fe. It is hard to determine precisely why in the two groups included in the analysis copper played such disparate roles in explaining BMI variance.

Members of the study population had been staying at the boarding school (providing room and board) for no less than a year. It may not be claimed that the differences found in the BMI and elemental concentrations in hair resulted from dissimilar diets. Concentration levels of individual minerals in hair may have been affected by personal idiosyncrasies as to absorbing nutrients, as well as synergy-based disorders. The same factors may also explain the differences in the levels of analysed minerals in the two groups in the study. The participants did not belong to the poorest strata of Tanzanian society. Their families paid modest tuition and boarding fees. Among the participants, many came from impoverished backgrounds where lack of regular meals was not unheard of. In a study conducted by Rębacz (2006) it was demonstrated that young Kenyans during intensive growth quickly gained weight once the quality and quantity of their meals improved. The present study explores a very similar social group. One may presume that individuals with normal BMI had arrived at the boarding school in a slightly better condition than members of the underweight group.

Varied BMI scores among the participants may have been caused by over-nutrition in terms of food quantity, buying extra sweets and soft drinks, or individual differences in nutrient absorption.

Adolescents require special attention with regard to a balanced diet, both in terms of food quantity and quality. The participants were still in the growth period and any elemental deficiencies might have permanent consequences for their health. Incorrect ratios of minerals in an imbalanced diet may contribute to excessive accumulation of adipose tissue. The present findings may be useful in periodic health checkups, population studies and health promoting campaigns.

Conclusions

Hair mineral analysis is a non-invasive test that may help uncover nutrient deficiencies, and also prevent the adverse consequences of unhealthy eating habits across populations. It also needs to be remembered that poor eating habits can be reinforced by the culture. It may be particularly true of isolated or remote communities, inhabiting poorly urbanised regions of the world. Moreover, obtaining hair for analysis is relatively easy and non-invasive, and the professional laboratory analysis is performed far from the investigated population. The relationship between mineral deficiencies and normal body weight has not been fully appreciated to date, but the exploration of these correlations is helpful in the recognition of factors contributing to excess adiposity. Once applied, this knowledge may help prevent the global weight gain, which a multi-faceted and seemingly unstoppable phenomenon these days.

The present study and those of others indicate that adequate levels of minerals in the body may be helpful in reducing body weight.

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