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ORIGINAL RESEARCH

Relationships Between Hair Chemical Elements and Nutritional Status in Oldest-Old and Centenarian Populations

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Background: Hair chemical elements reflect physical condition over time. Collection, transporting, and storing hair is more convenient than handling blood. Hair elements show higher levels for a long time, which allows for more accurate and sensitive results than using blood. Studies explored the relationships between elements and age, without full consideration of nutritional status, in older people. This study explored the relationships between hair chemical elements and Geriatric Nutritional Risk Index (GNRI) in oldest-old and centenarian populations to provide an updated reference for nutritional evaluation of older people.

Methods: A total of 152 participants over 80 years old underwent home interviews and physical examinations. An inductively coupled plasma mass spectrometer was used to detect hair chemical elements.

Results: Women accounted for 77.0% of participants. Women had lower levels of zinc, and higher levels of selenium, manganese, lead, iron, and copper than men ($P<0.05$ for all). Ninety-two participants formed the 80–99 year group, and 60 participants formed the 100+ year group. Centenarians had lower levels of selenium, lead, iron, and copper than those aged 80–99 years ($P<0.05$ for all). Hair selenium levels were positively associated with GNRI (odds ratio: 11.55, 95% confidence interval: 3.42–19.68, $P < 0.05$) based on a multivariate linear regression analysis. Other chemical elements had no significant associations with GNRI based on a multivariate linear regression analysis.

Conclusion: Chemical elements and nutrient status were altered based on age and gender, and an association existed between hair selenium and nutritional status in older people. Chemical elements may influence and indicate nutritional status in older people.

Keywords: centenarian, oldest-old, hair chemical elements, nutritional status, selenium

Background

Hair is a proteinaceous fibre with a strong hierarchical organization of subunits consisting of α-keratin chains. Most metals have a high affinity for sulfhydryl groups of amino acids that constitute keratin, and uncharged metals combine with the hydrophobic core of the melanin polymer in hair structure, which make metals persistent in hair for a long time.[1] Therefore, a hair elemental analysis may be an effective option for revealing significant information on people's nutritional status.[2] Chemical elements in hair not only reflect chemical body pools but also reflect age-related changes in nutritional requirements and metabolic processes.[3] Children and adults had significant differences in elemental levels

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as found in a US population.[4] A study concerning a Sudanese population found different elemental levels across age groups.[5] Chemical element levels in hair were also clearly age dependent as described in a study in Pakistan.[6,7] As a non-invasive sample, hair is ideally suited for analyzing chemical elements influencing and indicating nutritional status in older people.

Bouillanne et al first proposed the Geriatric Nutritional Risk Index (GNRI) as an indicator of nutritional status, which is a combination of albumin levels and the ratio of body weight to ideal body weight.[8] The GNRI is widely used for evaluating overall nutritional status in older people.[9,10] Increases in life expectancy have led to an increase in the number of older people worldwide. However, few studies have used hair chemical elements to assess nutritional status in older people. Thus, this study explored the relationships between hair chemical elements and GNRI in Chinese oldest-old and centenarian populations to provide an updated reference for nutritional evaluation of older people.

Methods

Study Population

A total of 152 centenarians and oldest-old people over 80 years old (117 women and 35 men) in Hainan underwent home interviews and physical examinations (Table 1). Several conditions were excluded: (1) use of synthetic hair dyes, (2) vegetarian diet, (3) metal implants, (4) acute surgical disease and trauma, (5) cancer. (6) Parkinson's disease, (7) Alzheimer's disease, and (8) currently receiving chemical element preparations or hormone preparations. This study complied with the Declaration of Helsinki. It was approved by the Ethics Committee of Hainan Hospital of Chinese People's Liberation Army General Hospital (Sanya, Hainan; Number: 301HNLL-2016-01). All participants provided informed consent to take part in the study and for their data to be used.

Data Management

Height, weight, and waist and hip circumferences were measured while participants were wearing light clothing and no shoes (bare feet). We measured the height and weight of older people with a scale (Seca, Germany). Blood pressures were obtained from the right arm of the sitting participants using a calibrated desktop sphygmomanometer (Yuwell medical equipment and supply Co., Ltd., Jiangsu, China). Blood pressures were repeatedly measured, and the average of two measurements was then used when the difference between the first and second measurement was more than 5 mmHg. The GNRI was calculated from the equations shown below to evaluate nutritional status:

$$GNRI = 1.489 \times \text{albumin (g/L)} + 41.7 \times (\text{body mass}/\text{ideal body mass})$$

$$\text{Ideal body mass} = \text{height (cm)} - 100 - [(\text{height(cm)} - 150)/4]\ (\text{Male})$$

$$\text{Ideal body mass} = \text{height (cm)} - 100 - [(\text{height(cm)} - 150)/2.5]\ (\text{Female})$$

Nutritional status can be divided into four categories according to the GNRI: (1) severe malnutrition: $GNRI < 82$, (2) moderate malnutrition $82 \leq GNRI < 92$, (3) mild malnutrition: $92 \leq GNRI \leq 98$, or (4) no malnutrition: $GNRI > 98$.[8]

Hair Chemical Elements

The hair was collected from the head just above the neck using the scissors to collect the segments up to 10 mm apart from the scalp. Hair samples were stored in a clean plastic container (polytetrafluoroethylene). A 5 mg hair sample was required for chemical element analysis. The sample cleaning procedure included full immersion in deionized water and acetone for 5 min, effective cleaning with 0.5% Triton X-100 solution for 10 min, and ultrasonic washing with deionized water three times. Digestion was performed in a microwave system with 4 mL concentrated nitric acid and pre-digestion overnight at room temperature. Then, the samples were subject to a standard three-step digestion program, and the solutions were diluted to 15 mL with deionized water.[11] Finally, an inductively coupled plasma mass spectrometer ([ICP-MS] ELAN DRC II, Perkin-Elmer Norwalk, USA) was used to detect quantitative chemical elements (ng/g to µg/g levels) including selenium (Se), chromium (Cr), manganese (Mn), lead (Pb), iron (Fe), copper (Cu), and zinc (Zn). Limits of detection and quantitation (LOD and LOQ, respectively, both µL) and coefficients of variation (CV, %) of chemical elements are shown in the Table 2.

Table 1 Comparison of Characteristics Based on Gender and Age in All Particpants

	Total (n=152)	Male (n=35)	Female (n=117)	P	80≤Age<100 (n=92)	Age≥100 (n=60)	P
Age[a]	92.00 (86.00, 102.00)	100.00 (84.00, 104.00)	91.00 (86.00, 101.00)	0.173	87.00 (82.00, 91.00)	103.00 (101.00, 105.00)	
Sex[b]							
Male	35(23.0)				15(16.3)	20(33.3)	0.015
Female	117(77.0)				77(83.7)	40(66.7)	
Educational level, %[b]							
Illiteracy	138(90.8)	25(71.4)	113(96.6)	<0.001	79(85.9)	59(98.3)	0.009
Literacy	14(9.2)	10(28.6)	4(3.4)		13(14.1)	1(1.7)	
Smoking, %[b]							
No	143(94.1)	27(77.1)	116(99.1)	<0.001	87(94.6)	56(93.3)	0.753
Yes	9(5.9)	8(22.9)	1(0.9)		5(5.4)	4(6.7)	
Outgoing[b] (without wheelchair)							
No	27(17.8)	8(22.9)	19(16.2)	0.369	6(6.5)	21(35.0)	<0.001
Yes	125(82.2)	27(77.1)	98(83.8)		86(93.5)	39(65.0)	
Height[a]	145.00 (139.00, 151.00)	156.00 (151.00, 160.00)	143.00 (137.50, 148.00)	<0.001	145.00 (140.00, 151.00)	144.00 (139.00, 152.00)	0.454
Weight[a]	41.81 (36.93, 45.60)	45.30 (41.81, 49.00)	39.90 (35.85, 44.10)	<0.001	42.00 (37.60, 46.70)	41.75 (34.58, 43.85)	0.022
Waist circumference[a]	76.00 (70.00, 81.00)	75.00 (70.00, 81.00)	76.00 (70.00, 81.00)	0.897	76.00 (70.00, 84.00)	76.00 (70.00, 79.00)	0.164
Hip circumference[a]	87.00 (82.00, 92.00)	88.00 (83.00, 92.00)	87.00 (82.00, 92.00)	0.751	89.00 (84.00, 94.00)	85.50 (82.00, 90.00)	0.019
Lymphocyte count[a]	1.93(1.53, 2.25)	1.79(1.43, 2.26)	1.97(1.57, 2.24)	0.335	1.98(1.63, 2.32)	1.83(1.31, 2.17)	0.078
Serum creatinine[a]	79.00 (69.00, 96.00)	96.00 (90.00, 128.00)	76.00 (65.00, 91.00)	<0.001	80.00 (70.00, 97.00)	78.50 (68.00, 95.00)	0.922
Fasting glucose[a]	4.70(4.05, 5.66)	5.13(4.26, 5.76)	4.53(3.93, 5.52)	0.050	4.41(3.75, 5.23)	4.96(4.30, 5.74)	0.022
SBP[a]	146.00 (131.00, 163.00)	132.00 (123.50, 156.00)	148.50 (134.00, 164.50)	0.015	147.50 (132.00, 160.50)	145.00 (130.00, 165.00)	0.667
DBP[a]	78.50 (72.50, 87.00)	74.50 (68.50, 83.00)	80.00 (73.50, 87.00)	0.028	80.50 (74.50, 89.00)	75.50 (68.00, 83.00)	0.001
GNRI[a]	95.85 (89.84, 102.03)	93.00 (85.36, 96.00)	96.75 (91.17, 104.26)	0.005	98.94 (93.71, 105.58)	90.39 (80.89, 96.10)	<0.001
Selenium[a]	0.61(0.20, 0.77)	0.56(0.17, 0.63)	0.68(0.21, 0.79)	0.036	0.73(0.64, 0.85)	0.17(0.14, 0.28)	<0.001
Chromium[a]	0.29(0.21, 0.40)	0.30(0.21, 0.41)	0.28(0.21, 0.39)	0.986	0.28(0.19, 0.36)	0.31(0.23, 0.44)	0.097
Manganese[a]	1.85(0.85, 4.73)	0.91(0.39, 2.71)	2.02(1.05, 4.77)	0.001	1.62(0.81, 3.22)	2.31(0.89, 4.76)	0.148
Lead[a]	1.77(0.73, 4.19)	0.53(0.23, 1.24)	2.13(1.23, 4.83)	<0.001	1.89(0.89, 5.12)	1.39(0.52, 2.76)	0.012
Iron[a]	19.73 (12.34, 32.94)	11.16 (4.08, 17.54)	22.71 (14.77, 37.73)	<0.001	22.80 (15.29, 37.85)	14.30 (8.04, 25.34)	<0.001
Copper[a]	7.13(6.08, 9.46)	6.53(6.00, 7.21)	7.60(6.17, 9.68)	0.007	7.54(6.48, 9.54)	6.54(5.98, 8.67)	0.049
Zinc[a]	115.80 (84.42, 147.11)	139.26 (118.26, 160.71)	104.36 (78.95, 140.69)	<0.001	123.42 (89.69, 147.98)	112.78 (77.92, 143.65)	0.283

Notes: [a]Continuous variables with skewed distribution were presented with median (interquartile range) and compared using Mann–Whitney *U*-test. [b]Categorical variables were presented with number (percentage) and compared using Chi-square test.

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; GNRI, Geriatric Nutritional Risk Index.

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Table 2 Multivariate Linear Regression Analysis Between Hair Chemical Element and Geriatric Nutritional Risk Index

Variables	B	95% Confidence Interval	P	Limit of Detection	Limit of Quantitation	Coefficient of Variation
Selenium	11.55	3.42, 19.68	0.006	0.088	0.294	3.37
Chromium	6.13	−2.08, 14.34	0.142	0.011	0.038	4.93
Manganese	−0.22	−0.52, 0.08	0.144	0.018	0.060	2.72
Lead	0.00	−0.12, 0.12	0.969	0.029	0.095	0.98
Iron	0.04	−0.05, 0.12	0.410	0.055	0.182	4.46
Copper	0.19	−0.13, 0.50	0.242	0.035	0.115	2.50
Zinc	−0.01	−0.05, 0.02	0.405	0.159	0.531	3.50

Notes: Multivariate linear regression analyse was used to determine independent associations between hair chemical elements and Geriatric Nutritional Risk Index after adjusting for age, sex, educational level, smoking, outgoing (without wheelchair), height, weight, waist and hip circumferences, lymphocyte count, serum creatinine, fasting glucose, systolic and diastolic blood pressures.

Statistical Analyses

All data were documented in EpiData 3.0 software and analyzed using the Statistical Package for Social Sciences version 25.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were presented as mean and standard deviation (SD) for normally distributed variables, and median and interquartile range (IQR) for those with skewed distribution. Number and percentage were presented for categorical variables. Categorical variables were compared using chi-squared test, continuous variables with normal distribution were compared using Student's *t*-test, and continuous variables with skewed distribution were compared using Mann–Whitney *U*-tests. Multivariate linear regression analysis was used to determine independent associations between hair chemical elements and GNRI after adjusting for age, sex, educational level, smoking, outgoing (without wheelchair), height, weight, waist and hip circumferences, lymphocyte count, serum creatinine, fasting glucose, systolic and diastolic blood pressures (SBP and DBP, respectively). $P < 0.05$ indicated statistical significance.

Results

One-hundred fifty-two participants, including 117 women and 35 men, were enrolled in this study. Characteristics based on gender and age are compared in Table 1. Women accounted for 77.0% of participants, and the majority of these participants were illiterate and non-smoking. Women had lower levels of height, weight, serum creatinine, and zinc, and higher levels of SBP, DBP, GNRI, selenium, manganese, lead, iron, and copper than men (P<0.05 for all). Ninety-two participants formed the 80–99 year group, and 60 participants formed the 100+ year group. Centenarians had lower levels of weight, hip circumference, DBP, GNRI, selenium, lead, iron, and copper, and higher levels of fasting glucose than those aged 80–99 years (P<0.05 for all). As shown in the Table 2, hair selenium levels were positively associated with GNRI (odds ratio: 11.55, 95% confidence interval: 3.42–19.68, $P < 0.05$) based on a multivariate linear regression analysis. Other hair chemical elements had no significant associations with GNRI based on a multivariate linear regression analysis.

Discussion

The resulting data demonstrate that hair chemical elements and nutrient status were altered based on age and gender after analysing their relationships. Moreover, altered hair chemical elements, such as selenium, had significant and positive relationships with nutritional status in Chinese oldest-old and centenarian populations.

Selenium exerts beneficial effects through the antioxidant capacities of selenocysteine-containing enzymes, which are an important selenoprotein through which selenium contributes to different pathways, including enzyme activation (glutathione peroxidase and thioredoxin reductase) and antioxidant defense.[12,13] Animal experiments demonstrated that low selenium levels lead to an increase in local oxidative stress levels, which in turn affects nitric oxide-mediated vascular responses.[14] Data from the Women's Health and Aging Studies (WHAS) in the United States revealed that low selenium levels were associated with an increased risk of death in older women.[15–17] Furthermore, selenium were inversely associated with weight, possibly due to the role of selenium and adipose tissue-resident selenoproteins in

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adipocyte physiology, when both increased and decreased selenoprotein expression may lead to adipocyte dysfunction.[18,19] Schweizer et al observed that brain selenium are largely independent of plasma selenium and proposed the existence of a selenoprotein cycle in the brain in which selenoprotein P may act as a local selenium storage and recycling protein that directly maintains brain selenium levels.[20] We found that women had higher selenium levels than men over 80 years old, and hair selenium levels decreased in centenarians and were significantly correlated with GNRI. This finding indicates that maintaining proper selenium levels and nutritional status through nutritional intervention and element supplement may be of importance and mutually reinforcing in older people.

Lead is ubiquitous in the environment and used in industrial processes. Human exposure to lead comes from many sources, including air, soil, water, and food.[21] Smoking status of family members was found to have a correlation with the levels of toxic elements in hair, with lead being more significant.[22] Özden et al reported that children exposed to smoking and traffic on highways had elevated lead levels in their hair.[23] Strumylaite et al found that lead levels in hair positively correlated with age.[24] Our results showed that women's hair lead levels were much higher than those of men, and lead levels of centenarians were lower than those aged 80–99 years. Previous studies have shown that cheese, fish, and lettuce resulted in an increase in lead levels in hair. Conversely, tea, coffee, and lemon caused a decrease in lead levels in hair. Additional sources of exposure to lead could be smoking, distance from heavily trafficked roads, painted walls, and amalgam fillers.[23,25,26]

Iron is a major component of cytochrome c, which is responsible for electron transport within mitochondria and supports oxygen transport through interactions with myoglobin and hemoglobin.[27] Hair iron was reported to have a positive correlation with transferrin saturation.[28] Bisse et al suggested that hair iron may be helpful to evaluate the iron status of the body.[29] Meanwhile, copper participates in and is essential for the activities of antioxidant enzymes and cytochrome oxidase at the electron transport chain terminus.[30] Plasma copper, immunoreactive ceruloplasmin, and cytochrome c oxidase in platelets and monocytes increased with age in healthy adults.[31] Copper levels were positively associated with age in people from Ireland, while zinc levels only showed a slight upward trend with age.[32] In our study, centenarians had lower levels of iron and copper than those aged 80–99 years, and, iron and copper levels in women's hair were higher than those in men, while zinc levels were lower than that in men. Zinc is necessary for DNA synthesis, neurosensory function, and cell-mediated immunity.[33] Generally, it is suggested to pay attention to providing timely supplementation of zinc in older people.

Manganese is involved in the regulation of carbohydrate and lipid metabolism, acting as a constituent or activator of many enzymes, such as the activation of digestive enzymes and lipid breakdown and utilization of vitamins C, E, and choline.[34] Moreover, it participates in the synthesis and secretion of insulin.[35,36] However, neurotoxicity is known to be caused by exposure to high manganese levels. Manganese neurotoxicity shares neuropathology with several clinical disorders, especially Parkinson's disease.[37–39] Our data indicate that manganese levels in women's hair were much higher than those of men and those of centenarians were higher than those aged 80–99 years.

As one of the most important essential elements, chromium is involved in carbohydrate metabolism and cholesterol synthesis. A study reported that age-related chromium levels in hair were reduced in 51,665 people in England, and reduced chromium levels led to an increase in the risk of impaired glucose and lipid metabolism.[40] In our data, no differences in hair chromium levels were found based on gender and age.

It should be emphasized that nutritional status declined with age in Chinese oldest-old and centenarian populations. Traditional nutritional assessment methods are inconvenient and inappropriate for these older people. In this regard, our research has shown that hair samples can conveniently and non-invasively be used to evaluate chemical element levels and may help to improve the overall nutritional status of older people. It has been reported that hair chemical elements can promote nutritional status assessment and provide useful prediagnostic information for older people aged ≥ 60 years.[41]

This study has some limitations that must be discussed. It is worth noting that potential limitations of using hair for nutritional assessment were present considering practical issues involved in the preparation of hair samples for analysis and quantitation difficulty of chemical elements in hair.

Conclusions

Our findings analyzed epidemiological relationships between hair chemical elements and nutritional status and revealed a marked association between hair selenium and nutritional status in Chinese older people. Chemical elements may influence and indicate nutritional status in older people; however, these finding should be validated with future large prospective studies.

Data Sharing Statement

In attempt to preserve the privacy of individuals, clinical data will not be shared; the data can be available from authors upon request.

Ethics Approval and Consent to Participate

This study complied with the Declaration of Helsinki. It was approved by the Ethics Committee of Hainan Hospital of Chinese People's Liberation Army General Hospital (Sanya, Hainan; Number: 301HNLL-2016-01). All participants gave informed consent to take part in the study and for their data to be used.

Author Contributions

Qiao Zhu, Qingkai Zhao, Ping Ping, Qian Zhang are co-first authors. All authors made a significant contribution to the work reported in the conception, study design, execution, acquisition of data, analysis and interpretation; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors have no competing interests.

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