

Correlation between the Iron, Magnesium, Potassium and Zinc Content in Adolescent Girls' Hair and Their Academic Records

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Background: The aim of this study is to investigate the correlation between school academic records and the iron, magnesium, potassium, and zinc content in adolescent girls' hair.

Methods: The iron, magnesium, potassium, and zinc content in hair samples from 148 adolescent girls was determined by atomic absorption spectrometer. Their academic records from 2 school semesters were interrelated.

Results: There was a positive correlation between magnesium ($r = 0.20$; $p = 0.016$), and zinc ($r = 0.31$; $p = 0.001$) content in the hair and academic records. Conversely, the academic records had an inverse correlation with the potassium content ($r = -0.23$; $p = 0.019$).

Conclusion: The content of magnesium, potassium, and zinc in adolescent girls' hair has a certain correlation with their learning performance. The exact effects of these three trace elements on adolescent learning performance warrants further study.

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Key words: total academic record, hair, adolescent girls, mineral, trace elements

There are many trace elements in the body that directly or indirectly participate in metabolism and play an essential role in it. More than 25% of the enzymes in the body require metals for activation and to function properly in metabolism.⁽¹⁻³⁾ Of these metals, iron, magnesium, and zinc have been identified as helping to improve cognitive functions in school children.⁽⁴⁻⁶⁾

Iron aids in the delivery of oxygen within the body through interaction with hemoglobin and myoglobin. Iron is also the main component of cytochrome C which is responsible for electron transfer within the mitochondria. Directly or indirectly, the iron status can have an effect on the ability

of a cell to execute adenosine triphosphate (ATP) production and on the oxidation of glucose and other carbohydrates.⁽⁶⁻⁸⁾ Without iron, this oxidation is hindered, which leads to the production of inactive cells. When this happens to brain cells and the nervous system, cognitive function is affected. Some authors,^(9,10) have concluded that decreased iron leads to worsening of cognitive functions, especially among schoolchildren.^(5,10) Lower iron status may directly impact verbal performance.

Magnesium helps bones grow, maintains a stable metabolism, keeps blood vessels flexible, prevents cardiovascular disease, and repairs injured cerebral cells.⁽¹¹⁻¹³⁾ A higher magnesium status may

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activate cerebral cells. Human bodies require a high level of potassium. Most potassium ions are stored in the intra-cellular fluid and participate with sodium ions in intra-cellular fluids to maintain the acid-base balance (adjusting pH values of body fluid), and normal osmotic pressure and electrolytic balance.^(7,14,15) However, only a small proportion of potassium is stored in the inter-cellular fluid where it influences potassium channel and cell activity. Abnormal levels of potassium in the inter-cellular fluid cause potassium channel dysfunction paralysis of the skeletal muscles, abnormality in nerve transmission and heart activity, and even indications of Alzheimer's disease.⁽¹⁴⁻¹⁶⁾ Zinc ions are co-factors of many liver enzymes such as fructose-1, 6-bisphosphatase, alkaline phosphatase, and ethyl alcohol dehydrogenase.⁽¹⁷⁾ A large amount of zinc has been found in the cerebellum hippocampus area and profoundly affects memory formation; zinc status could therefore influence human memory.⁽¹⁸⁻²²⁾

Hair is a good biopsy material for assessment of trace elements.⁽²³⁾ However, a strict sampling regimen must be followed, and only recently grown hair should be collected. Appropriate standard washing procedures and sensitive analytical techniques must be used to determine hair trace elements. Hair sampling is used in forensic medicine, in screening populations for heavy metal poisoning, and for monitoring environmental pollutants. In our previous studies,⁽²⁴⁻²⁷⁾ we concluded that both hair and blood can correctly reflect the status of arsenic, copper, calcium, iron, magnesium, potassium, selenium, sodium, and zinc in the human body. Blood and hair samples show accordant trends. We found no other documented reports coupling the iron, magnesium, potassium, and zinc content in hair samples from adolescent girls with their academic performance. There are reports emphasizing the influence of iron and zinc,^(5,10,18-21,28) on student performance, but the roles of magnesium and potassium have rarely been discussed. Therefore, in this study we tried to provide factors, in addition to iron and zinc, which correlate with the academic performance of adolescent girls.

METHODS

De-ionized distilled water (18 M Ω) and standard solutions (1000 ppm in H₂O) of iron, magne-

sium, potassium, zinc and reagents used for the digestion procedures were purchased from Merck (E. Merck, Darmstadt, Germany). Standard human hair samples NIES No. 5 (National Institute for Environmental Studies No. 5 human hair, Japan) were purchased and used to determine the precision and accuracy. All containers were made of inert materials such as quartz, Teflon, and polypropylene. All containers were first immersed in 8 N HNO₃ for 24 hr, rinsed with deionized distilled water, and dried at ambient temperature before use.⁽²⁷⁾

Hair sampling and cleaning

Hair samples for this study were randomly selected from students at a junior college of nursing in northern Taiwan. Their body mass indexes (BMI) and lifestyle were pre-screened to ensure that subjects were as similar as possible. Hair samples were collected from the nape section of each girl. One hundred and forty-eight adolescent girls, ranging from 15 to 17 years old, provided hair samples. Hair samples were cut near the scalp area with a thin-blade stainless steel scissors. The length of hair samples ranged from 1.0 to 3.0 cm. Hair samples were accurately weighed to 1.000 ± 0.200 g. Hair samples were then placed inside polyethylene bags and stored in an environment with controlled temperature (25°C) and humidity (65% relative humidity). The procedure for sample cleaning is described elsewhere.⁽²⁵⁻²⁷⁾

Samples were immersed in a 65 mL mixture of n-hexane, ethyl alcohol, and acetone (4:2:1; v/v) twice. Each immersion lasted 1.5 hr. Then the samples were rinsed with deionized distilled water four times and immersed in 65 mL acetone for 15 min. The samples were given a final rinse under deionized distilled water three times, filtered, dried at ambient temperature, and prepared for the digestion procedure.

Academic records were obtained for the first-year students for a period of two school semesters, from May 2004 to April 2005 (one semester before hair cutting and one semester after and the whole study was completed within six months). The subjects provided informed consent, as approved by the college medical ethics committee.

Hair digestion

Hair samples were weighed (0.200 ± 0.100 g)

and placed in a 250 mL microwave digesting vessel. Ten milliliters of nitric acid were added and heated in a microwave oven (CEM-MD2000 microwave digester, U.S.A.) using less than 30% power for 5 min. Then 10 mL deionized distilled water was added followed by heating at 40% power for 25 min and 0% power for 10 min. Finally, 2 mL hydrogen dioxide (H₂O₂) was added, followed by heating at 65% power for 5 min. After the heating procedures, vessels were taken out under normal pressure and temperature. All digested solutions were diluted to specific volumes with deionized distilled water for atomic absorption spectroscopic (AAS) determination.⁽²⁵⁻²⁷⁾

AAS analysis

With some minor variations in AAS conditions, the instrumentation and procedures (Hitachi Z-8200, Japan, Atomic Absorption Spectrophotometer coupled with a Flame Atomizer) were the same as used in our earlier study.⁽²⁷⁾ The external standard method was used for the quantitative determination of metal elements in hair. A series of standard solutions containing the following levels of iron, magnesium, potassium, and zinc ions were prepared using deionized distilled water and stock solutions (1000 ppm): 0.00, 0.10, 0.20, 0.40, 1.00 and 2.00 µg/ml. To obtain accurate quantitative data, the regression coefficient of the standard calibration curve for each element was made greater than 0.9998.

Accuracy and precision

The NIES No. 5 human hair recovery method was used to compare the accuracy of iron, magnesium, potassium, and zinc measurements. Our results showed that the overall mean recovery for these four elements was greater than 97.9%. The detailed

recoveries are shown in Table 1. The coefficients of variation (CV%) for the standard materials were used for precision comparison. According to Table 1, the CV% for these four elements was less than 7.3%. The detailed CV% is also shown in Table 1. Therefore we conclude that our method is applicable to the analysis of iron, magnesium, potassium, and zinc in hair.

Statistical analysis

The statistical graphics package (Microsoft Statistica, U.S.A.) was used to compute statistical data. If the correlation coefficient (r) of iron, magnesium, potassium and zinc content in adolescent girls hair vs. their academic record, the *p*-value, was less than 0.05 (*p* < 0.05), the correlation was considered significant. Values were expressed as means ± SD.

RESULTS

The academic records of the adolescent girls were better when they had higher iron, magnesium, and zinc content in their hair. Correlations of these trace elements with academic records are shown in Table 2. Magnesium and zinc content had positive correlations with their academic records (at least *p* < 0.05), but the correlation of iron was not significant (*p* = 0.43). Zinc (95% CI, 276.7~ 324.1 µg/g) content had a strong correlation (*p* = 0.001) with academic record (95% CI, 73.5~ 75.6). Magnesium (95% CI, 271.9~ 334.2 µg/g) content had only a weak correlation (*p* = 0.016) (95% CI, 73.5~75.6).

The academic records were worse with higher potassium content in the hair samples. The correlation of potassium content with academic records is shown in Table 2. The potassium (95% CI, 129.0~ 199.7 µg/g) content in the hair had a weak inverse

Table 1. Recoveries and Coefficient Variations of Iron, Magnesium, Potassium, and Zinc in Standard Human Hair Samples from the NIES Japan

	Certified value (µg/g)	CV %	Analyzed value (µg/g)	Recovery %	CV %
Iron	225 ± 9	4.0	224.3 ± 10.4	99.6	4.2
Magnesium	208 ± 10	4.8	203.8 ± 6.3	97.9	3.1
Potassium	34 ± 3	8.8	33.3 ± 2.46	98.2	7.3
Zinc	169 ± 10	5.9	166.9 ± 7.33	98.7	4.4

Each value is the mean ± SD of 3 runs.

Abbreviations: SD: Standard deviation; CV%: Coefficient of variation.

Table 2. Correlation of Iron, Magnesium, Potassium, and Zinc Content in the Hair of Adolescent Girls with Their Academic Records (n = 148)

Element	Academic records	<i>p</i> values	Content (µg/g) of elements with 95% confidence intervals
Iron	r = 0.07	0.434	77.9~138.6
Magnesium	r = 0.20	0.016	271.9~334.2
Potassium	r = - 0.23	0.019	129.0~199.7
Zinc	r = 0.31	0.001	276.7~324.1 73.5~75.6*

Abbreviations: r: correlation coefficient; *: One hundred and forty-eight adolescent girls two semester's mean total academic records with 95% confidence intervals.

correlation ($p = 0.019$) with academic record (95% CI, 73.5~ 75.6).

DISCUSSION

Iron showed a little or no correlation with adolescent girls' academic record in this study. But, some reports⁽⁴⁻¹⁰⁾ concluded that when iron is lacking, hemoglobin is not able to deliver the proper amount of oxygen to the brain cells and nerves. When oxygen is insufficient, brain and nerve cells may become inactive, leading to a worsening of cognitive functions.^(28,29) Furthermore, our laboratory findings agree with Bryan et al.,⁽⁹⁾ who emphasized that iron supplements in the daily diet may help the cognitive function of learning performance in children. Therefore, we suspect that a shortage of iron has a detrimental effect on adolescent girls' academic performance. We also found that the girls' academic records were better when they had a higher magnesium content in their hair. Magnesium helps stabilize metabolism which keeps the blood vessels flexible, and facilitates nutrition to brain cells and nerves. Our findings agree with Nomura's⁽³⁰⁾ conclusion that magnesium has control of higher functions of the nervous system, such as behavior, memory and learning in the humans. Magnesium plays an important role in carbohydrate metabolism by generating ATP and activating cerebral cells. It is conceivable that magnesium activates cerebral cells. Meanwhile, a higher magnesium content may enhance adolescent girls academic performance. On the other hand a shortage

of magnesium might retard adolescent girls' cognitive function and impair their academic performance. Zinc showed the highest positive correlation with academic record in this study. Therefore, we suspect that changes in zinc status may be quite effective in adolescent girls' learning performance. Our study agrees with Takeda,⁽¹⁹⁻²²⁾ who pointed out that zinc status might have an effect on memory enhancement. One possible explanation is that when the cerebrum hippocampus has enough zinc, memory is enhanced. In Table 2, we observe that adolescent girls with higher potassium content in their hair had worse academic records. Pan et al.⁽¹⁶⁾ concluded that, excess potassium causes potassium channel dysfunction and paralysis of the skeletal muscles, as well as abnormality in nerve transmission, which could lead to a worsening of cognitive functions. Therefore, we suspect that excess potassium may detrimentally effect cognitive functions and impair academic performance.

Conclusions

Our data show that adolescent girls' academic records increased with higher magnesium, and zinc content in their hair. On the contrary, we found that their academic records decreased with higher potassium content. Based on these findings, we believe that the magnesium, potassium, and zinc content in adolescent girls' hair is related to their academic performance. It is therefore suggested that adolescent girls consume diets rich in iron, magnesium, and zinc, but eat less potassium, in order to strengthen their total academic performance. Since iron, magnesium, potassium, and zinc play such important roles in academic performance, it is worth further studying the relationship of these four elements with not only school performance, but also strategies for health in adolescent girls.

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女性青少年頭髮中鐵、鎂、鉀、鋅含量 與學年成績表現關聯性研究

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背景：本研究主要目的為研究女性青少年頭髮中鐵、鎂、鉀及鋅含量與其學年總成績表現之關聯性。

方法：以原子吸收光譜法分析 148 位女性青少年頭髮中鐵、鎂、鉀、鋅含量並與其學年總成績進行關聯性分析。

結果：研究發現這 148 位女性青少年，學年總成績與她們頭髮中鎂及鋅含量有正向關係（鎂含量與學年總成績； $r = 0.20$ ； $p = 0.016$ ，鋅含量與學年總成績； $r = 0.31$ ； $p = 0.001$ ），但頭髮中鉀含量則與其學年總成績則有負向關係（鉀含量與學年總成績； $r = -0.23$ ； $p = 0.019$ ）。

結論：我們認為頭髮中鎂、鉀及鋅含量，可能會與女性青少年學習表現，產生關聯性，但此一關聯性須再進一步研究方可更明確。

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關鍵詞：學年總成績，頭髮，女性青少年，礦物質，微量元素

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