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The influence of oral administration of silicon on chromium concentrations in blood and chosen tissues of rats

Wpływ doustnego podawania krzemu na stężenie chromu we krwi i wybranych tkankach szczurów

INTRODUCTION

Silicon, after iron and zinc, is the third most abundant trace element in human body. It is present in all healthy tissues of the human organism. The highest concentrations of silicon are found in connective tissues, especially aorta, trachea, tendon, bone and skin [9]. Lower levels of silicon were measured in liver, heart, muscles, kidneys and lung, and free orthosilicic acid, not bonded to proteins, was found in blood. Total body content of silicon for a subject with body weight of 70 kg is within the range from 140 to 700 mg. The amount of silicon in human tissues decreases with age and development of some diseases, e.g. atherosclerosis [3].

The average daily dietary silicon intake, determined in cross-sectional, population-based studies separately for adult men and women in the original Framingham and the Framingham Offspring cohorts, is about 20–50 mg/person/day, with higher intakes for men than women [8]. Main food sources of silicon are: grains and grains products, beer, root vegetables as carrots, beetroot and raddish, fruits, especially bananas, as well as dried fruits (raisins) and nuts. Silicon is highly available from drinking water and its concentration depends upon the surrounding geology of the water, because it is derived from the weathering of rocks and soil minerals [16].

Orthosilicic acid is bioavailable form of silicon for animals and human. Dietary silicates undergo hydrolysis to orthosilicic acid, which is readily absorbed in the gastrointestinal tract. The average daily absorption of silicon is 12.1–13.5 mg/day in men and 9.9–10.2 mg/day in women. Increased silicon concentration in blood serum is observed about 60–84 minutes after orthosilicic acid ingestion. The study on silicon excretion has found that it is rapidly cleared from serum (within 4h), with quite high renal clearance rate (70–80%). Organ retention has been also observed, being greatest for kidney, liver and lung [13].

Silicon plays important role in formation and maintenance of connective tissue. Its involvement in bone metabolism has already been well documented [9]. It has been found to be essential in processes of tissues regeneration and immune functions potentiating of the organism. It exerts anticancerous, antiatherosclerotic and antidiabetic actions as well as beneficial effects on several human disorders, e.g.: osteoporosis, ageing of skin, hair and nails, atherosclerosis, heart diseases and wound healing [3,7,11,15].

Chromium occurs in many oxidation degrees, but its most common forms are on two oxidation degrees: +III and +VI. In natural conditions it always occurs in trivalent form Cr (III), however hexavalent Cr (VI) is formed as a result of human operation [2]. Hexavalent chromium is considered toxic and mutagenic [10]. It can pass though cell membrane, where in cytoplasm its reduction, and metabolic products (such as Cr (V), Cr (IV), Cr (III), free radicals) interact with DNA [2]. DNA injury causes genotoxicity and may induce cancer formation [2,6]. However, trivalent chromium compounds have been recognized as essential for proper tissue metabolism function in human. They play the main role in carbohydrate and lipid metabolism so that they are popular as diet supplements for patients with diabetes and with parallel disturbance of lipid metabolism. Chromium (III) has the ability to increase muscle mass and reduce body fat in obese individuals therefore it is often used as a supplement in slimmer's diet [17].

Total quantity of chromium in human organism is about 6 mg. The main chromium storage is liver, but it occurs also in lungs and kidneys. Its concentration in tissues is 10 to 100 times higher than in plasma (0.14 ng/ml to 0.16 ng/ml). Chromium concentration is also very high in hair [10].

The recommended daily chromium intake for adults is between 25–45 μg/d. The best absorbed chromium form is chromium picolinate. The highest amounts of bioavailable chromium are found in brewers yeast, liver, meat, cheese, cereals, broccoli, green beans, fresh fruits, black pepper, chicken breast, fish, seafood and some kinds of beer and wine. The demand for chromium raises with physical effort and hyperglycaemic diet because of its higher excretion with urine [1].

Chromium is provided to organism with food, and it is absorbed mainly in small intestine. Its absorption depends on chemical form in which it occurs. Organic chromium is better absorbed than its inorganic forms. There are two forms which are the most frequently used in supplementation: chromium picolinate and chromium nicotinate [2]. However, last reports have shown that chromium picolinate can have harmful effects on DNA by production of oxygen radicals. Potential harmful effects of chromium picolinate on human organism could occur after long-term consumption of its very big dose: 600–1000 mg daily (10 times more than daily demand for that element) for 5 years [2,9]. Chromium is excreted mainly with urine (about 10 μg/day), in small amounts with sweats, bile and by hair. Chromium concentration decreases with age, with the exception of lungs where amount of chromium increases [1].

Deficiency of Cr (III) may result from its lack in food, long term starving and disturbances in its absorption as well as in patients on parenteral nutrition. Basic symptoms of the deficiency are: growth inhibition, appetite increase, overweight. Increased level of cholesterol and triglycerides in blood, fertility disturbances and OUN injuries were also observed. Chromium deficiency may lead to increase of circulating insulin concentration, decrease in amount of insulin receptors, and depressed ability of insulin receptor binding. Symptoms intensity depends on the degree of chromium (III) deficiency in the organism [5].

The aim of our study was to investigate possible interactions between oral silicon administration and chromium metabolism and storage within rats' organisms.

MATERIALS AND METHODS

The experiment was carried out on five groups of adolescent male Wistar rats (ten animals each). Control group was given distilled water to drink. Rats of group 0 were given solution of sodium hydroxide at concentration of 0.001 mol/L, whereas animals of groups 1, 2 and 3 received solutions of orthosilicic acid (H_4SiO_4) as the only drinking fluids. As a source of orthosilicic acid the preparation "Compendium krzemowe" [silicon compendium] was used. Group 1 received 0.05% solution of the preparation in the solution of NaOH (0.001 mol/L), group 2–0.5% solution of the preparation in 0.001 mol/L NaOH and the group 3 was given 1% solution of the preparation in 0.001 mol/L NaOH. The weights of animals at the beginning of the experiment were within the range of 180–230 g. Rats had free access to standard feed LSM and drinking solutions. Half of the experiment animals from each group were sacrificed under pentothal narcosis after 4 weeks and the rest of animals after 8 weeks of the experiment. Every time blood and the tissues of kidney, brain and liver were collected. The prepared material was stored at temperature - 20^{o}C until analysis. The determination of chromium in blood and the tissues was performed using inductively coupled plasma emission spectrometry (ICP-AES, Liberty II AX, Varian) with set-up and conditions according to the method accredited by local Voivodship Inspectorate of Environment Protection.

Comparisons between control and tested groups as well as between silicon supplemented groups were made using the c-Cochran-Cox test. Values were considered significant with $p<0.05$.

The study was performed according to statutory bioethical standards and approved by I Local Ethical Commission of Medical University of Lublin, acceptance no. 550/AM/2005.

RESULTS

Results of chromium concentration in blood and chosen tissues of rats receiving various doses of silicon are presented in Table 1.

Decrease of chromium concentration was observed in blood of animals of all examined groups in comparison to control group after 4 weeks of the experiment. The biggest differences (statistically important) were noted in case of groups receiving two the lowest doses of silicon (groups 1 and 2). Statistically significant increase in chromium concentration was found in blood of animals receiving water solution of sodium hydroxide to drink (group 0) for 8 weeks versus control group. Values of Cr concentrations in blood of rats drinking various solutions of silicon were similar to the level of the element in blood of animals from control group. Statistically significant decrease of blood chromium concentration was noted in control group after 8 weeks of the experiment with silicon in comparison to the value obtained after 4 weeks. The period of silicon administration also influenced the increase of chromium concentration in blood of animals receiving the lowest silicon dose (group 1).

Table 1. The influence of silicon administration on chromium concentration in blood (μmol/L) and chosen tissues (μmol/kg) of rats

Tissue	Dose of Si	The period of Si administration					
		4 weeks			8 weeks		
		Mean_Value $\bar{x}$	Standard deviation (SD)	Statistical analysis	Mean_Value $\bar{x}$	Standard deviation (SD)	Statistical analysis
Blood	K	0.956	0.098	-	0.766	0.049	↓
	0	0.735	0.059	ns	0.829	0.028	*
	1	0.698	0.071	*	0.786	0.067	↑
	2	0.688	0.043	*	0.706	0.046	ns
	3	0.829	0.086	ns	0.793	0.070	ns
Kidney	K	1.139	0.132	-	1.274	0.327	ns
	0	1.075	0.251	ns	1.277	0.145	ns
	1	1.226	0.214	ns	1.326	0.228	ns
	2	1.420	0.341	ns	1.640	0.331	ns
	3	1.152	0.171	ns	1.708	0.281	ns
Brain	K	1.677	0.333	-	1.532	0.266	ns
	0	1.540	0.384	ns	1.353	0.310	↓
	1	1.561	0.431	ns	1.448	0.412	ns
	2	1.653	0.377	ns	1.471	0.348	↓
	3	1.535	0.126	ns	1.640	0.241	ns
Liver	K	1.461	0.147	-	1.251	0.173	↓
	0	1.630	0.126	ns	1.502	0.148	*↓
	1	1.383	0.312	ns	1.488	0.125	*
	2	1.567	0.153	ns	1.451	0.138	ns
	3	1.412	0.221	ns	1.579	0.114	*

* - statistically significant differences vs. control at $p \leq 0.05$

↑↓ - statistically significant differences vs. values obtained after 4 weeks of the experiment, $p \leq 0.05$

ns – lack of statistical significance

Increase of chromium concentrations in kidney tissue of animals from groups 1 and 2 as well as decrease of Cr concentrations in group 0 were noted after 4 weeks of silicon administration. All the changes were statistically insignificant. Values of chromium level in kidneys of rats from group 0 and 1 were similar to the level of the element in control group. Slight increase of chromium concentrations was noted in kidneys in case of two the highest doses of silicon (groups 2 and 3) in comparison to control group. Duration of the experiment did not influence chromium concentrations in kidneys of examined animals.

Insignificant decrease of chromium concentration in brain was observed in all examined groups versus control group after 4 weeks of the experiment and in groups 0, 1 and 2 after 8 weeks of silicon administration. Chromium level in brain of animals receiving the highest silicon dose for 8 weeks was slightly higher than the value obtained for the animals of control group. Significant influence of the period of silicon intoxication on chromium concentration in brain was noted in case of groups 0 and 2 (decrease of chromium concentration in brain after 8 weeks in comparison to the value obtained after 4 weeks of the experiment).

Insignificant changes of hepatic chromium concentrations in all experimental groups in comparison to control group were stated after 4 weeks of silicon administration. After 8 weeks of Si intoxication, increase in chromium level in liver of all examined groups of animals versus control group was noted. Statistically significant differences were observed in case of groups 0, 1 and 3. The period of the experiment duration resulted in significant decrease of chromium concentration in liver of animals from control group and these given water solution of sodium hydroxide to drink (group 0).

No significant changes in chromium concentration were found between silicon supplemented groups regardless of examined tissues as well as the duration of intoxication period.

DISCUSSION

There are no reports on direct interactions of silicon and chromium in living organisms. A few studies concerning influence of oral administration of different forms of silicon on mineral content in blood, blood serum and some tissues of animals can be found in the literature [4, 12]. Data obtained from these experimental studies have stated correlations between silicon and Zn, Al, Ca, P and Mg. Such a broad range of silicon interactions with other elements may suggest that mechanism of its influence on chromium involves action of other elements. Our study revealed significant dose-depended increase of hepatic chromium concentration during longer exposure period (8 weeks): the higher Si dose the bigger increase of Cr level in liver of examined rats. Metabolic pathways of most mineral elements are placed in liver. Silicon has been shown to accumulate in liver and therefore its prolonged administration can affect hepatic concentrations of some elements including chromium.

Our studies also revealed decrease of chromium level in blood of animals receiving all three doses of orhtosilicic acid for 4 weeks. In case of blood silicon and chromium seem to have one thing in common, as, they were both found to lower cholesterol concentration in blood serum. Chromium (III) chloride administration caused reduction of coronary and aortic lipid deposits and serum cholesterol concentration in rabbits [14]. Intake of silicon-rich diatomaceous earth was associated with a significant reduction of serum cholesterol, low-density lipoprotein cholesterol and triglycerides levels in healthy people [18]. Four weeks after diatomaceous earth administration serum cholesterol, low-density lipoprotein cholesterol and triglycerides still remained low and level of high-density lipoprotein cholesterol increased significantly. However, detailed mechanism of silicon – chromium interaction in blood need to be investigated to confirm these hypothesis.

CONCLUSIONS

Oral silicon administration seems not to exert any direct effects on chromium metabolism and storage within rats' organism. Mechanisms of these interactions might involve other elements or biologically important molecules. However, metabolic interactions between both elements remain unknown and require further investigations.

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SUMMARY

Silicon is an essential nutrient. It has been found to take part in many life processes of animals related to tissue regeneration and maintaining healthy connective tissue and bones. It causes anticancerous, antiatherosclerotic and antidiabetic actions and beneficial effects on several human disorders, as for example osteoporosis, ageing of skin, hair and nails, atherosclerosis, wound healing and immune functions. Trivalent chromium compounds are recognized as essential for proper tissue functions in human. It actively participates in carbohydrate and lipid metabolism and this is the reason why it is popular as a supplement in diet for patients with diabetes and with parallel disturbance of lipid metabolism. Is has ability to increase muscle mass and reduce body fat in obese individuals. Chromium may also inhibit key enzymes in the synthesis of cholesterol, thus improving the lipid profile of individuals with dyslipidaemia. Results of our studies confirmed influence of orally administered silicon on concentrations of chromium in liver and blood of experimental animals, while no interactions between administered silicon and chromium concentrations in brain and kidneys were found.

Metabolism of silicon in human beings remains unknown and that is the reason for further studies concerning its utilization and its interactions with other elements and nutrients are needed.

Keywords: chromium, silicon, rats

STRESZCZENIE

Krzem jest składnikiem mineralnym niezbędnym w wielu procesach życiowych związanych z regeneracją tkanek oraz prawidłowym funkcjonowaniem tkanki łącznej i kostnej. Wiele badań wykazało jego działanie przeciwnowotworowe, przeciwmiażdżycowe i przeciwcukrzycowe oraz pozytywny wpływ w przypadku licznych schorzeń takich jak osteoporoza, miażdżyca naczyń krwionośnych oraz procesów starzenia się skóry, włosów i paznokci, gojenia ran i funkcjonowania układu immunologicznego. Związki chromu trójwartościowego są niezbędne dla prawidłowego funkcjonowania organizmu człowieka. Aktywnie uczestniczą w przemianach węglowodanów i tłuszczy i z tego powodu są powszechnymi suplementami diety pacjentów z cukrzycą i z analogicznymi zaburzeniami metabolizmu lipidów. Chrom posiada zdolność zwiększania masy mięśniowej i redukcji tkanki tłuszczowej u otyłych osób. Może również wpływać hamująco na działanie kluczowych enzymów syntezy cholesterolu, poprawiając w ten sposób profil lipidowy pacjentów z dyslipidemią. Wyniki badań własnych potwierdzają wpływ doustnego podawania krzemu na stężenie chromu w wątrobie i krwi zwierząt doświadczalnych, natomiast nie stwierdzono żadnych interakcji pomiędzy podawaniem krzemu a stężeniem chromu w tkance mózgu i nerki. Metabolizm krzemu w organizmie ludzkim nie jest jeszcze do końca poznany, dlatego niezbędne są dalsze badania dotyczące jego zastosowania oraz interakcji z innymi pierwiastkami i składnikami odżywczymi.

Słowa kluczowe: chrom, krzem, szczury