0163-4984/93/3702-3–0107 $03.00

The Action of Excessive, Inorganic Silicon (Si) on the Mineral Metabolism of Calcium (Ca) and Magnesium (Mg)

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Received June 8, 1992; Accepted September 19, 1992

ABSTRACT

The influence of silicon treatment on the levels of calcium and magnesium in blood serum and tissues was studied in rats. The concentrations of both elements were estimated in samples of sera and tissues of rats receiving per os a soluble, inorganic silicon compound—sodium metasilicate nonahydrate ($Na_2SiO_3 \cdot 9H_2O$ (REACHIM, USSR)), dissolved in the animals' drinking water. A decrease of magnesium concentration in serum was observed with accompanying elevation of registered calcemia. Moreover, a reduction of tissue calcium levels was found with a simultaneous increase of magnesium tissue pool.

The results provide evidence for silicon involvement in mineral metabolism. It could result in a modification of pathological processes concerning bone tissue.

Index Entries: silicon, calcium, magnesium, mineral metabolism.

INTRODUCTION

Within the last decade, silicon (Si) has been recognized as an essential trace element participating in the normal metabolism of higher ani-

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mals. The concept that silicon plays a considerable role in bone was introduced by Charnot, who investigated the relationship between silicon and fluoride in areas of North Africa, where fluoridosis is prevalent (*1*). She also postulated the existence of a silicase enzyme that liberates silicon from its bound form. This enzyme was discovered later in the pancreas, stomach, and kidneys (*1,2*). It appears that liberated silicon tends to increase calcium absorption from the gastrointestinal tract (*3*). Organic compounds of this element increase bone retention of calcium and magnesium following a modification of bone turnover (*2,4*). A series of studies by Carlisle suggested a physiological role for silicon in the early stages of bone calcification (*3,5–8*). Silicon's primary effect in bone and cartilage is on the matrix, where formation of the organic matrix appears to be affected by silicon deficiency more so than the mineralization process (*5,6,9*). This chemical element is a major ion of osteogenic cells and is present in especially high concentrations in the metabolically active state of the cell, reaching maximum levels in their mitochondria (*3,8*).

From the body of recent works, it is obvious that silicon performs a specific and important function in mineral metabolism. However, possible interrelations of systemic hypersilicemia with calcium and magnesium metabolism have not been clarified so far. In this study, we have investigated the influence of oral administration of excess, inorganic silicon on the tissue and blood serum pools of calcium and magnesium in the rat.

MATERIALS AND METHODS

Animals and Procedures

One hundred male Wistar rats, aged 2 mo and weighing approx 180 ± 20 g, were used in this experiment. Rats were housed individually in hanging stainless cages with wire-mesh floors, in a room maintained at 23–25° C. A normal, 12-h light-to-dark cycle was maintained. They were fed with a standard diet, at normal rates. Forty of the animals served as controls. Silica solutions, containing 0.05% Si, 0.1% Si, and 0.2% Si in water, were prepared, and in succession constituted the tested animals' drinking water for the whole period of 18 wk. For the preparation of these solutions, reagent-grade sodium metasilicate nonahydrate ($Na_2SiO_3 \cdot 9H_2O$ (REACHIM, USSR)) was used, which contains 10.11% silicon. The average daily dose of silicon for the first 6 wk of the experiment was 0.1 mg/g body wt (0.05% soln), for the next 6 wk 0.2 mg/g body wt (0.1% soln), and for the last 6 wk 0.4 mg/g body wt (0.2% soln). The rats were weighed weekly during the 18-wk experiment. In the course of the investigation, one-third of the animals from each group was sacrificed after 6, 12, and 18 wk from the beginning of silica administration. Blood samples were obtained at termination by cardiac puncture following

anesthetization with chloroform (POCH, Gliwice, Poland). Blood was placed in heparinized tubes. After centrifugation, plasma was separated and stored at −25° C until analyzed. While continuing under anesthetization, the rats were killed by decapitation, and their livers, kidneys, lungs, and a sample of aorta were removed, weighed, and stored at −25° C until analyzed. The aorta sample represented approx 3 cm of the descending thoracic aorta beginning immediately below the aortic arch.

Calcium and Magnesium Determination

The obtained samples of serum, liver, kidneys, lungs, and aorta were dried at a temperature of 105° C for 2 h. Subsequently, they were placed in a muffle furnace and ashed at a temperature of 600° C for 2 h. After cooling the mineral remnant was dissolved in 5 mL of HNO_3 solution (1:1, v/v/) in the case of serum and 10 mL of the same HNO_3 solution (1:1 v/v/) for the tissue samples. After filtration, the supernatant was used for the trace element determination.

Concentrations of calcium and magnesium were determined in serum and in nitric digests of liver, kidneys, lungs, and aortic walls by atomic absorption spectrophotometry (AAS). The device used was a Varian-Techtron spectrophotometer model AA-6, Australia 1981. The technical parameters of the determination are shown in Table 1. The results obtained were statistically analyzed using the test for two mean values from small groups and Students's *t*-test.

RESULTS

The data obtained are shown in Figs. 1–4. The concentration of calcium in serum increases in the experimental group, as compared to the controls, with statistical significance at the 18th wk of the experiment. In the case of magnesemia, its levels in the experimental group were lower, with statistical significance in the last series of determinations. Analyzing the results obtained for the tissue samples, we have observed contradictory changes, in comparison to the calcemia and magnesemia modifications. The concentrations of calcium were lower in the majority of samples from the animals belonging to the tested group. The modifications were statistically confirmed for liver samples in all series of determinations, for kidneys after 12 and 18 wk of Si administration, and for the lung tissue in the 18 wk of the study.

The magnesium tissue levels were higher for the experimental group, showing statistical significance in the case of aorta in the 12th and 18th wk of the experiment, and for the pulmonary tissue in the last series of determinations. All the differences between both groups of animals increased with time during the experiment and the dose of administered silicon compound.

Table 1
The Technical Parameters of Calcium and Magnesium Determination by AAS

Element	Heater current (mA)	Wavelength (nm)	Interstice width (nm)
Calcium (Ca)	3.5	422.7	0.5
Magnesium (Mg)	3.5	285.2	0.5

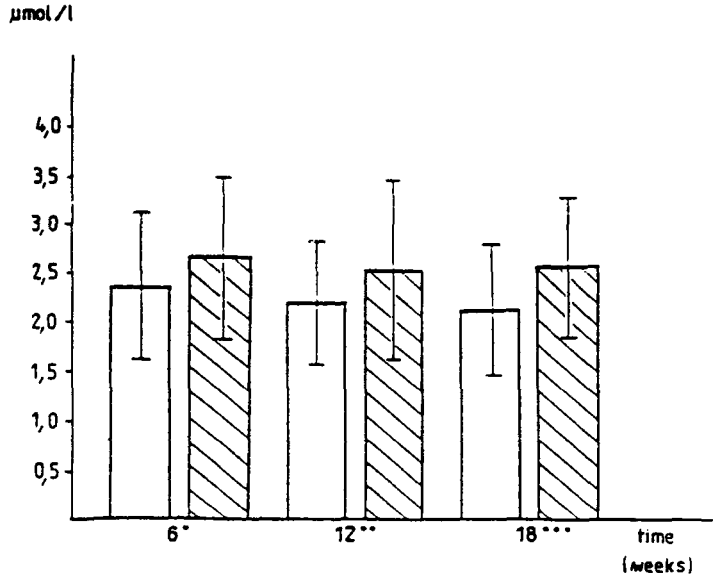

Fig. 1. The concentrations of calcium in blood serum of the animals from the control and experimental group. □ Control group · ns ▨ Experimental group •• ns ••• $p < 0.02$.

DISCUSSION

The potential effects of systemic hypersilicemia have been only minimally investigated. Much better analyzed was the opposite situation (*5–7,9*). In the conditions of experimental silicon deficiency, skeletal development is affected, resulting in depressed growth and skull deformations (*5,10*). All the observed effects are reversible after dietary silicon supplementation.

There is a positive relationship between dietary silicon level and percent bone ash (*11*). It was also proved that this chemical element is involved in an organic phase of bone formation prior to calcification of the bone tissue. The silicon content of the osteoid tissue differs greatly during the mineralization process, depending on the calcium-to-phosphorus ratio (*8,11*). From comparatively high levels in the beginning of the mineralization, it falls considerably when calcium content ap-

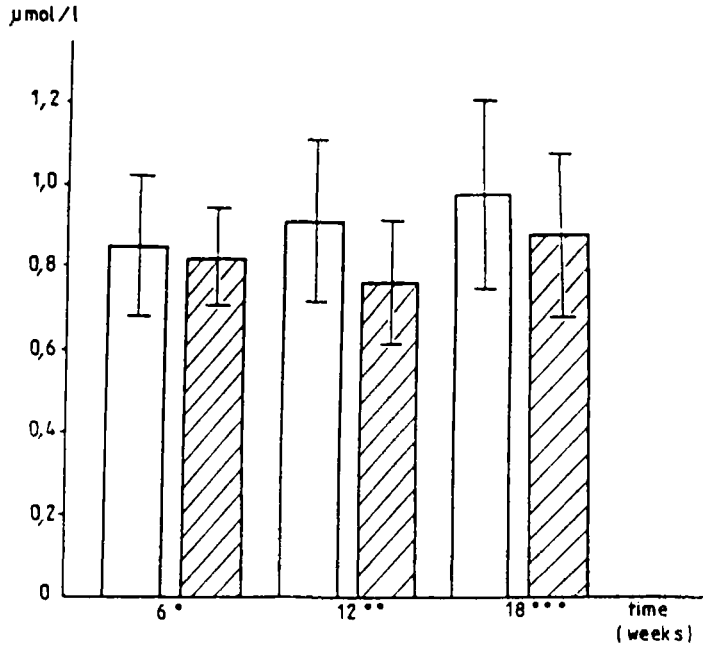

Fig. 2. The concentrations of magnesium in blood serum of the animals from the control and experimental group. ☐ Control group · ns ▨ Experimental group ·· ns ··· $p < 0.05$.

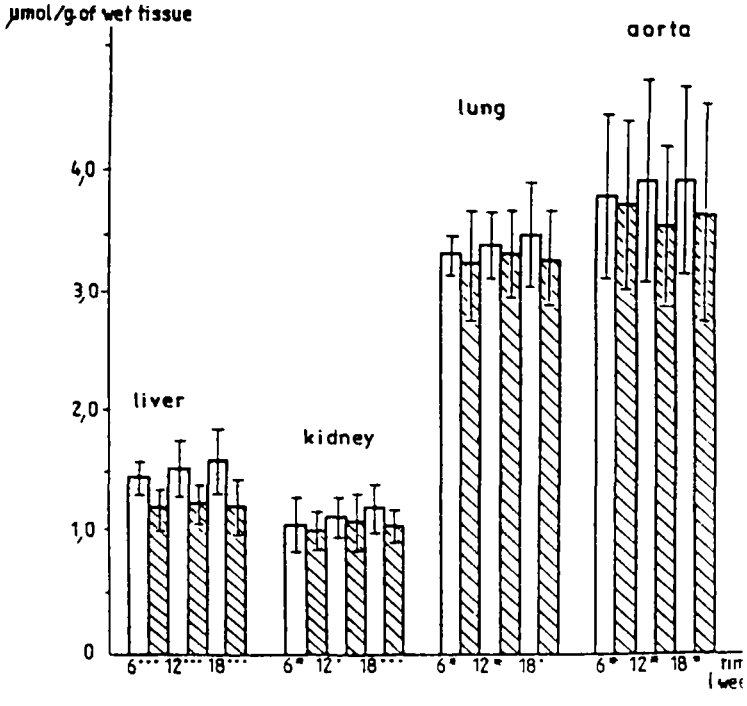

Fig. 3. The concentrations of calcium in the tissues samples of animals from the control and experimental group. * ns · $p < 0.05$ ·· $p < 0.02$ ··· $p < 0.01$ ···· $P < 0.001$ ☐ Control group ▨ Experimental group

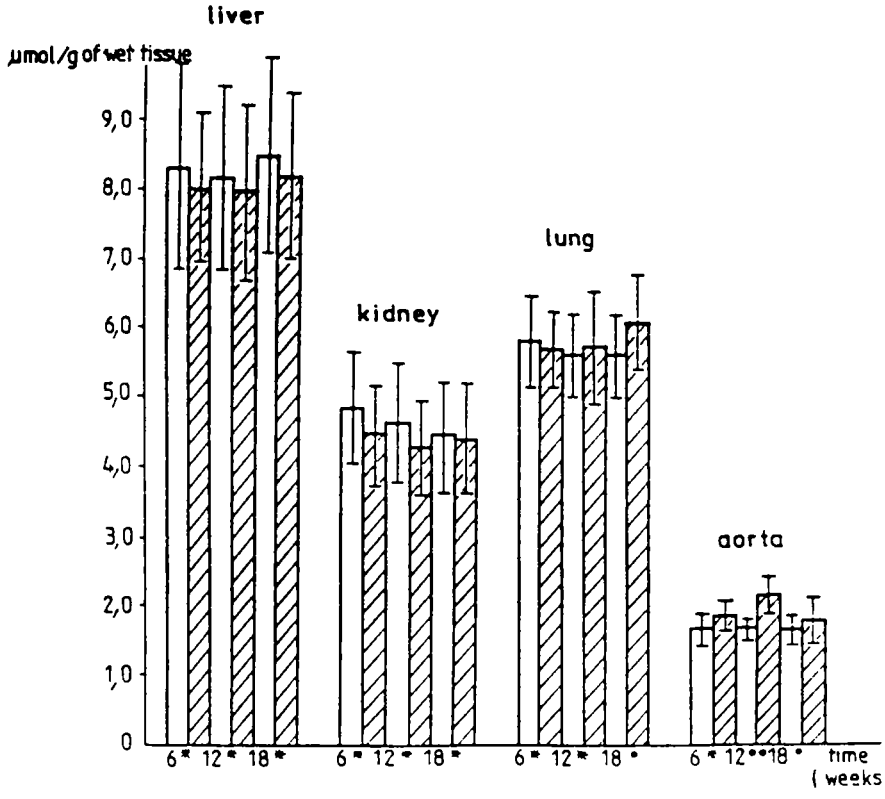

Fig. 4. The concentration of magnesium in the tissues samples of the animals from the control and experimental group. * ns · $p < 0.05$ ·· $p < 0.02$ ··· $p < 0.01$ ···· $p < 0.001$ □ Control group ▨ Experimental group

proaches the levels typical for the mature bone (*7*). In previous studies, it was found that organic silicon compounds, unlike their inorganic species, enhanced the uptake of calcium ions by the cells of osteoid tissue that had been earlier replaced by potassium ions (*2*).

It thus appears that the elevation of silicon tissue content is usually accompanied by an increase of calcium in bone, with a simultaneous reduction of magnesium and phosphorus concentrations in the same compartment (*2,12*). However, the direction of the observed modifications often depend on the type of silicon compound used in a given study. According to Charnot, organic silicon derivatives are much more active in the modification of calcium and magnesium metabolism (*12*). An increased ingestion of silicon in its organic form tends to decrease calcemia and elevation of magnesium concentration in serum (*2*). The changes observed are contrary to the modification of blood serum ionogram during the synthetic gestagens administration. Organic silicon compounds are also capable of restoring a normal, systemic calcium and

magnesium metabolism, altered by the process of senescence, or experimental ovariectomy (*2*).

In our investigation, we have observed changes in the metabolism of both elements which in many aspects are contrary to the data presented above. In the course of excessive oral inorganic silicon administration, a reduction of magnesemia was registered with an accompanying elevation of calcium concentration in serum. The tissue levels of both elements presented also contradicts trends in the modifications observed in studies with organic silicon derivatives. Essentially all observations made in our study appear to be incompatible with the findings of Charnot (*2*).

In the case of calcium metabolism, observed reduction of tissue concentrations was probably a consequence of a transfer of this ion to serum, where levels regularly increased during silicon administration. The possibility that this was because of a reduction of calcium absorption in the gastrointestinal tract appears to be much less probable. There was a positive correlation between silicon intake and calcium ingestion in previous works (*4*). Kidneys have also been earlier excluded as the site of intense calcium elimination in conditions of systemic hypersilicemia (*13*). Magnesium cation, with excretion in urine, is undoubtedly positively correlated with the range of orthosilicic anion elimination by kidneys (*14*). In the case of magnesium, observed modifications of its metabolism are contrary to the results presented above for calcium. In the condition of systemic hypersilicemia a transfer of this ion from serum to tissue pool is observed.

The mechanism of silicon action remains unclear. The paucity of knowledge on silicon and its participation in mineral metabolism is a result of the technical difficulties in its determination and the lack of general data about silicon metabolic pathways. Noteworthy is the contrast between some metabolic effects exerted by organic and inorganic silicon compounds (*2*). The reason for this phenomenon is probably because of variations in bioavailability of the silicon derivatives used in different experiments. In contrast to simple, inorganic soluble silicates, organic compounds of this element require silicase to liberate Si from their structure. On the other hand, organic silicon derivatives show enhanced biological activity, being effective at much lower doses levels in silicon supplementation in Si-deficient animals, when compared to silicates (*1,2*). From the body of previous works, organic silicon compounds have been reported to show antiosteoporotic activity assisting in the transfer of calcium ions to bone tissue (*1*).

In conclusion, silicon plays an important, although only partially clear role in calcium and magnesium metabolism. It is an essential trace element for bones in the early stage of its development, greatly influencing mineral metabolism. However, there is also a possibility of silicon influencing mature bone tissue metabolism in the conditions of systemic hypersilicemia, often observed in patients with chronic renal failure, although this finding appears still somewhat underestimated (*14*).

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