ORIGINAL ARTICLE

Magnesium loss in magnesium deficient subjects with and without physical exercise during prolonged hypokinesia

Costas B. Tsiamis¹

Kostas K. Kakuris²

Viktor A. Deogenov²

Kosmas B. Yerullis²

¹Medicine Department, School of Medicine, Athens, Greece and

²European Foundation of Environmental Sciences, Athens, Greece

Manuscript submitted 3rd November, 2007

Manuscript accepted 18th December, 2007

Clin Invest Med 2008; 31 (1): E16-E23.

Abstract

Objective: To show the effect of hypokinesia (HK; diminished movement) on magnesium (Mg^{2+}) loss in Mg^{2+} deficient subjects and the effect of physical exercise and on Mg^{2+} deficiency with and without physical exercise: Mg^{2+} balance, serum Mg^{2+} concentration and Mg^{2+} loss were measured.

Methods: Studies were conducted on 30 healthy male volunteers during a pre-experimental period of 30 days and an experimental period of 364 days. They were divided equally into three-groups: unrestricted active control subjects (UACS), continuous hypokinetic subjects (CHKS) and periodic hypokinetic subjects (PHKS). The UACS group ran average distances of 9.3 ± 1.2 km.day⁻¹; the CHKS group walked average distances of 0.9 ± 0.2 km.day⁻¹; and the PHKS group walked and ran average distances of 0.9 ± 0.2 km and 9.3 ± 1.2 km.day⁻¹ for 5-and 2-days per week, respectively.

Results: Mg^{2+} deficiency, serum Mg^{2+} level, fecal and urine Mg^{2+} loss increased ($P < 0.05$), in the PHKS and CHKS groups compared with their pre-experimental values and the values in the UACS group. However, serum Mg^{2+} concentration, urine and fecal Mg^{2+} loss and Mg^{2+} deficiency increased more ($P < 0.05$) in the PHKS group than in the CHKS group.

Conclusions: Mg^{2+} deficiency is more evident with than without physical exercise and Mg^{2+} loss is exacerbated more with higher than lower Mg^{2+} deficiency. This indi-

cates that Mg^{2+} deficiency with and without physical exercise and Mg^{2+} loss with higher and lower Mg^{2+} deficiency is due to inability of the body to use Mg^{2+} and more so when physically healthy subjects are submitted to prolonged periodic than continuous hypokinesia.

Abbreviations

Diminished movement (Hypokinesia)

Hypokinesia (HK)

Periodic hypokinesia (PHK)

Continuous hypokinesia (CHK)

Unrestricted active control subjects (UACS)

Continuous hypokinetic subjects (CHKS)

Periodic hypokinetic subjects (PHKS).

Magnesium (Mg^{2+})

Hypokinesia (HK; diminished movement) is a factor of catabolism induction^{1, 2} which results in reduction of energy production, blood volume and cell mass. Among the many types of HK, periodic hypokinesia (PHK) and continuous hypokinesia (CHK) have been of the greatest interest because of their effect on electrolyte deposition.³⁻⁷ This is largely because HK has

been increasingly recognized as an important determinant of lower electrolyte deposition and higher plasma electrolyte level and electrolyte loss with electrolyte deficiency.

CHK is characterized by continuous and steady restriction of muscular activity without fluctuation and/or interruption in the magnitude of muscular activity to which hypokinetic subjects are submitted at that time. CHK promotes electrolyte shifting in plasma that potentially leads to higher electrolyte loss.⁸⁻¹² Escalated plasma electrolyte level and electrolyte loss occur with electrolyte deficiency.⁸⁻¹² There is a correlation between electrolyte deficiency and plasma electrolyte level and electrolyte loss.⁸⁻¹² Studies into the role of CHK on electrolyte deposition¹³⁻¹⁵ have shown that CHK may be the interfering mechanism by which electrolyte deposition results in the higher plasma electrolyte level and electrolyte loss with electrolyte deficiency. The higher plasma electrolyte level and electrolyte loss with electrolyte deficiency is attributable to decreased electrolyte deposition because of many factors, primarily due to muscle cell injury.^{16, 17} Because plasma electrolyte level and electrolyte loss are escalated more during PHK than CHK³⁻⁷, studying the ability of the body to use electrolytes during PHK and CHK is important in understanding the mechanisms of higher plasma electrolyte level and electrolyte loss with electrolyte deficiency.

PHK is an alternating restriction of muscular activity, i.e. a condition characterized by periodic restriction of muscular activity with regular and/or irregular muscular activity. Individuals may be subjected to PHK when they periodically increase their muscular activity while living and working under sedentary conditions as occurs with the present work-rest cycle, i.e., 5-days work, 2-days rest and recreation. The frequency with which the urban population is subjected to sedentary living and working conditions has increased sharply, making exposure to sedentary living and working conditions one of the most pressing problems of hypokinetic physiology.^{1, 2} It is remarkable that no studies have been conducted on the

effect of the present work-rest cycle on electrolyte metabolism. Most studies on electrolyte homeostasis have been performed under conditions which did not include hypokinesia while the electrolyte metabolism during PHK has been studied very little.³⁻⁷ There are no reports on the effect of the present work-rest cycle on magnesium (Mg^{2+}) homeostasis and few studies have been published³⁻⁷ on the effect of PHK on electrolyte metabolism. Thus, to determine the potential of decreased Mg^{2+} deposition and Mg^{2+} loss with Mg^{2+} deficiency, it is important to establish the effect of PHK and CHK on Mg^{2+} homeostasis.

The objective of this study was to determine the effect of prolonged HK on total body Mg^{2+} loss in Mg^{2+} deficient subjects and the effect of exercises on Mg^{2+} deficiency which aimed at showing the ability of the body to use Mg^{2+} . Measurements of Mg^{2+} balance, serum Mg^{2+} concentration and urine and fecal Mg^{2+} loss in physically healthy subjects were carried out during prolonged hypokinesia with and without physical exercises.

Materials and methods

Thirty physically healthy male subjects 22.2 ± 2.4 yr gave informed consent to take part in the study after verbal and written explanations of the procedures and risks involved were given. There were no medical problems among the volunteers and none was receiving any drug therapy that could have interfered with magnesium metabolism. All procedures were previously reviewed and approved by the Committee for the Protection of Human Subjects. Financial incentives were used to encourage compliance with the protocol of the study. Subjects were students and ran average distances of 9.3 ± 1.2 km.day⁻¹ at a speed of 9.7 ± 1.2 km.h⁻¹ for three to five years. Subjects had a body weight of 73.1 ± 7.4 kg and peak oxygen uptake of 48.8 ± 6.0 mL.kg⁻¹.min⁻¹. During the pre-experimental period of 30 days, subjects ran average distances of 9.3 ± 1.2 km.day⁻¹ at a speed of 9.7 ± 1.2 km.h⁻¹.

Random Assignment of subjects:

Group one: Ten healthy subjects ran average distances of 9.3 ± 1.2 km.day⁻¹ for 364-days. They were assigned to the unrestricted active control subjects (UACS) group.

Group two: Ten healthy subjects walked average distances of 0.9 ± 0.2 km.day⁻¹ for 364 days. They were assigned to the continuous hypokinetic subjects (CHKS) group.

Group three: Ten healthy subjects walked average distances of 0.9 ± 0.2 km.day⁻¹ and ran average distances of 9.3 ± 1.2 km.day⁻¹ for 5-days and 2-days/week, respectively, for 364-days. They were assigned to the periodic hypokinetic subjects (PHKS) group.

Protocol

The study consisted of a 30-day pre-experimental phase and a 364-day HK phase. Diets were served as a 4-day menu rotation. Meals were prepared under standard conditions in a research kitchen. The mean daily energy value of diet was 3230 ± 322 , 2735 ± 250 and 2930 ± 242 Kcal, and the mean daily magnesium (Mg²⁺) consumption was 181.1 ± 10.2 , 181.2 ± 11.3 and 181.3 ± 12.0 mmol for the UACS, CHKS and PHKS groups, respectively.

Simulation of continuous and periodic hypokinesia

During CHK, the number of km walking per day was restricted to an average of 0.9 ± 0.2 and was monitored daily by an accelerometer. Activities allowed were those that approximated routines of sedentary individuals. During PHK, and at the initial five days of the week, the conditions for subjects were the same as the conditions during CHK: i.e. from Monday to Friday subjects were walking average distances of 0.9 ± 0.2 km.day⁻¹, while for the other two days of the week the conditions for PHKS were the same as those with UACS; i.e., from Saturday to Sunday subjects were allowed to resume their routine daily activities and run

average distances of 9.3 ± 1.2 km.day⁻¹. Subjects were allowed to walk to dining tables and laboratories where the tests were given. Climbing stairs and other activities that required greater efforts were not allowed. Subjects were mobile and were not allowed outside hospital ground.

Magnesium balance measurements

The balance of Mg²⁺ was determined under strict surveillance and under a controlled environment so that the precise estimation of the Mg²⁺ amounts consumed with diet and excreted in urine and feces could be calculated. It was directly assessed magnesium content in the diet by keeping an exact duplicate of the food consumed of each subject, and the total Mg²⁺ loss in 24 hr urine and fecal samples was measured. Because of individual differences in bowel patterns, collection periods for Mg²⁺ balance calculation used multiple days, i.e., 18-days, to ascertain representative Mg²⁺ balance. The magnesium balance was calculated as the difference between Mg²⁺ consumed and Mg²⁺ loss in urine and feces, i.e., magnesium balance is equal to the total Mg²⁺ amount consumed minus the total Mg²⁺ loss in urine and feces.

Blood, urine and fecal sample collection

To accommodate inter-individual differences in bowel habit, urine and feces were collected daily and were pooled to form 6-days composites, while blood samples were taken every 6-days during pre-experimental and experimental period. The 6-day (consecutive days) pooled samples were collected. Blood samples were collected with disposable polypropylene syringes. Following overnight fasting for about 6-7 hr, venous blood samples were taken at rest and before any meals. Blood samples were drawn under the same conditions between 8.00 and 9.00 a.m., without venous stasis and after subjects had been sitting for about 30 min. The sample volume was 7 to 9 mL. To obtain serum, blood was clotted for 60 min at room temperature and, after rimming, was centrifuged at

3000 x g for 10 min. Aliquots for serum Mg^{2+} measurements were stored at $-20^{\circ}C$. Twenty four hour urine samples were stored at $-4^{\circ}C$ until needed for Mg^{2+} analysis. Creatinine loss was measured using a colorimetric method to ensure 24 hr urine collections. Feces were collected in plastic bags, weighed and stored at $-20^{\circ}C$ for Mg^{2+} analysis. Fecal samples were dried-ashed in a muffle furnace at $600^{\circ}C$ overnight. Ashed samples were dissolved in 5% nitric acid. To ensure complete feces recovery polyethylene glycol was used.

Magnesium measurements

Samples were analyzed in duplicate, and appropriate standards were used for the measurements: The plasma, urine and fecal Mg^{2+} levels were measured by an atomic absorption spectrophotometer Perkin-Elmer 330, Perkin-Elmer Corp., Norwalk, CT. The urine and fecal samples were diluted as necessary with deionized distilled water and aspirated directly into an atomic absorption spectrophotometer. The Mg^{2+} was determined by the atomic absorption spectrophotometer after diluting the specimen 1:50 with a solution of lanthanum-HCl to eliminate interference from anions including phosphate and protein and metal oxides.

Data analyses

The Mg^{2+} balance and Mg^{2+} level in serum, urine and feces were subjected to 3-way analysis of variance (ANOVA) to measure the effect of HK on Mg^{2+} homeostasis; the three way interaction (pre-experimental/experimental values, time, periodic/continuous, unrestricted hypokinetic/ control groups). The Tukey-Kramer post-hoc tests were used to establish which means were significantly different from each other. ANOVAS for each time point measurements were used. The predetermined level of significance was set at $P<0.05$. Results were reported as mean $\pm$ SD.

Results

During the pre-experimental period, Mg^{2+} homeostasis, serum Mg^{2+} concentration, and urine and fecal Mg^{2+} loss did not differ between the active control and hypokinetic groups of subjects and between the PHKS and CHKS groups (Table 1).

During the experimental period, Mg^{2+} homeostasis, serum Mg^{2+} level, urine and faecal Mg^{2+} loss did not change in the UACS group compared with baseline values (Table 1). The Mg^{2+} deficiency, serum Mg^{2+} level, and urine and fecal Mg^{2+} loss increased ($P<0.05$) in the PHKS and CHKS groups compared with their pre-experimental values and the values in their respective active control group (UACS) (Table 1). However, the Mg^{2+} deficiency, serum Mg^{2+} level, and urine and fecal Mg^{2+} loss increased more ($P<0.05$) in the PHKS group than in the CHKS (Table 1).

Discussion

During the pre-experimental period, no changes in Mg^{2+} homeostasis, serum Mg^{2+} level or Mg^{2+} loss occurred among the periodic or continuous hypokinetic, or control groups of subjects. This was consistent with previous reports⁸⁻¹² where, in the pre-experimental period, the electrolyte homeostasis was relatively stable regardless of the magnitude of physical activity. This suggests that, in the pre experimental period, the consumed Mg^{2+} may have been taken up for deposition and consumed by the body that in turn protected the net Mg^{2+} homeostasis without showing any gross differences in the hypokinetic and control groups of subjects⁸⁻¹².

During the experimental period, the differences among the hypokinetic and the control groups of subjects, as were seen with Mg^{2+} deficiency and higher serum Mg^{2+} level and Mg^{2+} loss, shows that Mg^{2+} deposition decreases more in the hypokinetic group than in the control group. If the hypokinetic group had not experienced decreased Mg^{2+} deposition, serum Mg^{2+} level and Mg^{2+} loss could not have increased

TABLE 1. Urinary and fecal magnesium loss, serum magnesium concentration and magnesium balance measured in physically healthy subjects at pre-experimental period and during ambulation and periodic and continuous hypokinetic period.

Days	Urinary Mg ²⁺ mmol/days	Fecal Mg ²⁺ mmol/days	Serum Mg ²⁺ mmol/L	Mg ²⁺ Balance mmol/Mg ²⁺ /days
Unrestricted Ambulatory Control Subjects (UACS), n=10				
Pre-experimental	4.45 ± 0.2	13.07 ± 1.3	0.77 ± 0.03	+0.01 ± 0.02
60th	4.43 ± 0.3	12.76 ± 1.2	0.76 ± 0.02	+0.03 ± 0.03
120th	4.40 ± 0.4	12.85 ± 1.5	0.75 ± 0.04	+0.02 ± 0.02
180th	4.43 ± 0.2	12.64 ± 1.6	0.76 ± 0.03	+0.01 ± 0.03
240th	4.40 ± 0.3	12.73 ± 1.4	0.75 ± 0.02	+0.03 ± 0.02
300th	4.43 ± 0.2	12.57 ± 1.5	0.76 ± 0.05	+0.01 ± 0.02
364th	4.41 ± 0.4	12.73 ± 1.6	0.75 ± 0.04	+0.02 ± 0.03
Continuous Hypokinetic Subjects (CHKS), n=10				
Pre-experimental	4.44 ± 0.5	12.80 ± 1.4	0.78 ± 0.03	+0.02 ± 0.03
60th	5.95 ± 0.4*	18.67 ± 1.5*	0.86 ± 0.02*	-3.87 ± 0.04*
120th	5.80 ± 0.3*	16.05 ± 1.4*	0.85 ± 0.05*	-3.50 ± 0.05*
180th	6.55 ± 0.5*	21.81 ± 1.6*	0.88 ± 0.03*	-3.97 ± 0.03*
240th	6.07 ± 0.4*	18.54 ± 1.5*	0.86 ± 0.05*	-3.63 ± 0.04*
300th	7.04 ± 0.5*	23.75 ± 1.7*	0.89 ± 0.03*	-4.12 ± 0.05*
364th	6.85 ± 0.3*	20.35 ± 1.4*	0.87 ± 0.04*	-3.71 ± 0.04*
Periodic Hypokinetic Subjects (PHKS), n=10				
Pre-experimental	4.42 ± 0.3	12.61 ± 1.7	0.77 ± 0.05	+0.01 ± 0.02
60th	7.95 ± 0.6**	24.77 ± 1.5**	0.94 ± 0.04**	-4.85 ± 0.06**
120th	7.51 ± 0.4**	21.11 ± 1.8**	0.93 ± 0.05**	-4.41 ± 0.05**
180th	8.59 ± 0.5**	28.42 ± 1.7**	0.96 ± 0.03**	-5.15 ± 0.04**
240th	8.20 ± 0.6**	24.28 ± 1.6**	0.94 ± 0.04**	-4.67 ± 0.06**
300th	9.43 ± 0.5**	31.56 ± 1.5**	0.97 ± 0.03**	-5.51 ± 0.07**
364th	8.87 ± 0.6**	27.22 ± 1.6**	0.95 ± 0.05**	-5.02 ± 0.05**

All values were expressed as mean ± SD.

*p<0.05 significant differences between the unrestricted ambulatory control and the hypokinetic groups of subjects. Each of the hypokinetic groups of subjects was compared with their respective unrestricted ambulatory controls (UACS vs CHKS and PHKS, and CHKS vs PHKS).

**p<0.05 significant differences between the periodic and continuous hypokinetic groups of subjects.

with Mg²⁺ deficiency.⁸⁻¹² This shows that with Mg²⁺ deficiency the higher serum Mg²⁺ level and Mg²⁺ loss is attributable to reduced Mg²⁺ deposition because plasma electrolyte level and electrolyte loss cannot increase with electrolyte deficiency unless electrolyte deposition decreases.⁸⁻¹² With Mg²⁺ deficiency, the higher serum Mg²⁺ level and Mg²⁺ loss is related to lower Mg²⁺ deposition capability, because the lower electrolyte deposition, the higher plasma electrolyte level and electrolyte loss and the greater electrolyte deficiency followed.⁸⁻¹² Decreased electrolyte deposition promotes electrolyte shifting in plasma leading to higher plasma electrolyte level and electrolyte loss with electrolyte deficiency.⁸⁻¹² The higher serum Mg²⁺

level and Mg²⁺ loss with Mg²⁺ deficiency during HK shows different mechanisms from those involved in the lowered serum Mg²⁺ level and Mg²⁺ loss with Mg²⁺ deficiency during normal muscular activity. Some research has shown that plasma electrolyte level and electrolyte loss increases more with higher than lower electrolyte depletion⁸⁻¹² and electrolyte deficiency reduces more in muscle and bone with less weight-bearing supporting function and morphology.¹⁸⁻²⁰ This is attributable to many factors and primarily to the differences in electrolyte uptake by the body which could have been decreased more with than without physical exercise.²¹⁻²³ With electrolyte deficiency the higher serum electrolyte level and

the higher electrolyte loss is ensured by the decreased electrolyte deposition because of many factors inherently to prolonged hypokinesia.^{13, 14}

Decreased protein synthesis can induce Mg^{2+} deficiency²⁴ and Mg^{2+} deficiency can affect Mg^{2+} deposition and/or serum Mg^{2+} concentration and Mg^{2+} loss with Mg^{2+} deficiency.⁸⁻¹² Mg^{2+} is one of the elements necessary for protein synthesis²⁴; but an Mg^{2+} deficiency and a decrease of protein synthesis are demonstrable during prolonged HK. Mg^{2+} deficiency can reduce protein synthesis and the shortage of protein can diminish Mg^{2+} deposition and decreased Mg^{2+} deposition can affect serum Mg^{2+} level and Mg^{2+} loss with Mg^{2+} deficiency. However, probably, skeletal muscle cell injury as a result of higher intracellular calcium (Ca^{2+}) level, because of Mg^{2+} deficiency, is the main mechanism of even lower Mg^{2+} deposition and higher serum Mg^{2+} concentration and Mg^{2+} loss with Mg^{2+} deficiency. With skeletal muscle cell injury, on one hand, and decreased protein synthesis on the other, the reaction develops like a vicious cycle, in which there is even higher serum Mg^{2+} level, higher Mg^{2+} loss and Mg^{2+} deficiency. The failure to normalize Mg^{2+} deficiency in healthy subjects with Mg^{2+} supplementation during prolonged HK may be used as confirmation of this hypothesis.¹⁰⁻¹²

Differences in Mg^{2+} deposition, as with the greater Mg^{2+} deficiency and the higher serum Mg^{2+} level and Mg^{2+} loss, was observed more in the PHKS group than in the UHKS group. The greater Mg^{2+} deficiency, higher serum Mg^{2+} level and greater Mg^{2+} loss in the PHKS than in the CHKS group, shows that the PHKS group experienced lower Mg^{2+} deposition than the CHKS group. Because of the lower Mg^{2+} deposition, the PHKS group with greater Mg^{2+} deficiency show higher serum Mg^{2+} level and Mg^{2+} loss than the CHKS group. The PHKS group shows lower electrolyte deposition than the CHKS group because greater electrolyte deficiency, lower electrolyte deposition and higher serum electrolyte level and electrolyte loss followed.³⁻⁷ Because the PHKS group, with greater Mg^{2+} deficiency, shows lower Mg^{2+} deposition and

higher serum Mg^{2+} level and Mg^{2+} loss than the CHKS group, this indicates that serum Mg^{2+} level and Mg^{2+} loss increase more with higher than lower Mg^{2+} deficiency. Thus, the PHKS group reacted with greater Mg^{2+} deficiency, and lower Mg^{2+} deposition and higher serum Mg^{2+} level and Mg^{2+} loss than the CHKS group. The mechanism by which the PHKS group with greater Mg^{2+} deficiency shows lower Mg^{2+} deposition and higher serum Mg^{2+} level and Mg^{2+} loss than the CHKS group is unclear. Some research had shown greater electrolyte deficiency, lower electrolyte deposition, higher serum electrolyte concentration and higher electrolyte loss in the PHKS than in the CHKS group.³⁻⁷

The most striking abnormality found among PHKS and CHKS groups is the lack of correlation between Mg^{2+} homeostasis and muscular activity. If physical exercise had played any part in Mg^{2+} homeostasis, the PHKS group, who was exercised vigorously for at least two days per week, would have shown better Mg^{2+} homeostasis than the CHKS group. However, with physical exercise, Mg^{2+} homeostasis deteriorated more in the PHKS group than in the CHKS group. This shows that physical activity may not be important for Mg^{2+} homeostasis while other mechanisms that could have affected Mg^{2+} homeostasis should not be excluded. This may be related to many factors and, in particular, to the type of muscular activity to which the volunteers were subjected. With physical activity, the greater Mg^{2+} deficiency in the PHKS than in the CHKS group shows that the more often the steady state changes, the less likely is it to normalize Mg^{2+} deficiency.³⁻⁷ This resembles positive feedback, i.e., the more active hypokinetic subjects have the greater Mg^{2+} deficiency. The mechanism by which, with physical exercise, Mg^{2+} deficiency increases more in the PHKS group than in the CHKS group is unclear. Hypokinetic subjects may experience a more labile and less responsive control Mg^{2+} homeostasis when they are engaged in physical exercises.

Thus, physical exercise affects more Mg^{2+} deposition and any condition which alters the steady condi-

tion of the muscular activity may be a factor of stress rather than a stimulus for Mg^{2+} deposition. Periodic physical exercise may act more as a stressor than as a stimulus for electrolyte deposition²⁵; a fact that must be taken into consideration when muscular activity is used for improving electrolyte deposition. By alternating muscular activity, hypokinetic subjects were submitted to PHK which may lead to lower electrolyte deposition.³⁻⁷ Using physical training and recreation programs after a week of long sedentary working and living conditions, i.e., five days work plus two days rest and recreation programs, the sedentary population is subjected to PHK. With this work-rest cycle and recreation programs carried out to facilitate the electrolyte deposition, the sedentary population was exposed to lower electrolyte deposition. This adds an important contribution to the lifestyle effect on electrolyte homeostasis as many people may practice regular physical training, with and/or without electrolyte supplementation. The results revealed a common belief, that muscular activity is beneficial, that may be erroneous when other lifestyle factors as HK-factors are involved. Physical exercise by sedentary people while they are living and working under sedentary conditions may be more of a stressor than a stimulus for electrolyte deposition; or be more of a detriment than people being completely sedentary.

Conclusion

The greater Mg^{2+} deficiency with than without physical exercise shows that Mg^{2+} deficiency is inversely related to the magnitude of physical activity. The higher total bodily Mg^{2+} loss with higher than lower Mg^{2+} deficiency in turn shows that total bodily Mg^{2+} loss is inversely related to the severity of Mg^{2+} deficiency. Dissociation between physical exercise and Mg^{2+} deficiency and Mg^{2+} loss shows that the decreased Mg^{2+} deposition is the main mechanism of Mg^{2+} deficiency and Mg^{2+} loss because Mg^{2+} deficiency and Mg^{2+} loss cannot occur with physical exercise unless the Mg^{2+} deposition decreases. Thus, Mg^{2+}

deficiency and total bodily Mg^{2+} loss would increase during periodic and continuous HK unless factors leading to the decreased Mg^{2+} deposition are reversed. It is concluded that Mg^{2+} deficiency is more evident with than without physical activity and that total bodily Mg^{2+} loss is exacerbated more with higher than lower Mg^{2+} deficiency. In all, during periodic and continuous HK, Mg^{2+} deficiency and total bodily Mg^{2+} loss is due to the inability of the body to use Mg^{2+} and more so when subjects are engaged to physical exercises.

References

1. Fedorov IV, Chernyy AV, Fedorov AI, Synthesis and catabolism of tissue proteins in animals during hypodynamia and resumption of muscular activity. *Fiziol Zh SSSR* 1977; 63:1128-33.
2. Fedorov IV, Metabolism under Hypokinetic Conditions, Izdatelstvo Nauka Press, Moscow, 1982.
3. Zorbas YG, Charapakhin KP, Afonin VB, Yarullin VL, Kakurin VJ, Deogenov SD, Serum, urinary and fecal magnesium changes of endurance trained athletes during periodic and continuous hypokinesia. *Magnesium Bulletin* 1999; 21:1-8.
4. Zorbas YG, Kakurin VJ, Afonin VB, Charapakhin KP, Yarullin VL, Deogenov VA. Plasma, urinary and faecal potassium changes in endurance trained athletes during ambulatory, periodic and continuous hypokinetic conditions. *Clin Biochem* 2000; 33: 37-46.
5. Zorbas YG, Charapakhin KP, Afonin VB, Yarullin VL, Kakurin VJ, Denogradov SD. Serum, urinary and faecal phosphate changes in athletes during periodic and continuous restriction of muscular activity. *Nutrition Research* 2000; 20: 461-77.
6. Zorbas YG, Kakurin VJ, Denogradov SD, Yarullin VL. Urinary and serum electrolyte changes in athletes during periodic and continuous hypokinetic and ambulatory conditions. *Biol Trace Elem Res.* 2001; 80:167-86.
7. Zorbas YG, Kakuris KK, Deogenov VA, Yerullis KB. Phosphate homeostasis in healthy subjects during prolonged periodic and continuous hypokinesia, *Clin Biochem* 2007; 40:460-6.
8. Zorbas YG, Federenko YF, Saito ChN. Endogenous parathyroid hormone and renal excretion of magnesium in endurance trained volunteers during pro-

- longed restriction of muscular activity. *Magnesium-Bulletin* 1994;16:104-12.
9. Zorbas YG, Kakurin VJ, Afonin VB, Charapakhin KP. Serum, urinary and faecal magnesium changes in trained and untrained subjects during prolonged hypokinesia. *Magnesium Bulletin* 1999;21:80-8.
 10. Zorbas YG, Kakurin AK, Kuznetsov NK, Federov MA, Yaroshenko YY, Yarullin VL. Magnesium loading effect on magnesium deficiency in endurance trained subjects during prolonged restriction of muscular activity *Biol Trace Elem Res* 1998;61:222-33.
 11. Zorbas YG, Kakurin VJ, Afonin VB, Charapakhin KP. Magnesium supplements effect on magnesium balance in athletes during prolonged restriction of muscular activity. *Kidney and Blood Pressure Research*. 1999; 22:146-53.
 12. Zorbas YG, Kakurin VJ, Yarullin VL, Andreyev ID. Magnesium determination during and after hypokinesia in disclosing magnesium deposition during hypokinesia and magnesium supplementation in normal subjects. *Trace Elements and Electrolytes* 2003; 20:81-96.
 13. Krotov VP. Kinetics and regulation of fluid-electrolyte metabolism in animals and man during hypokinesia. PhD thesis, Interkosmos Council, Academy of Sciences USSR and Directorate of Kosmic Biology and Medicine, Ministry of Health USSR, Moscow, Russia, 1982.
 14. Volozhin AV. Pathogenesis of disturbances of mineral metabolism in mineralized tissues during long-term hypokinesia. PhD thesis, Interkosmos Council, Academy of Sciences USSR and Directorate of Kosmic Biology and Medicine, Ministry of Health USSR, Moscow, Russia, 1987.
 15. Deogenes KG, Tsiamis CB, Kakuris KK, Deogenov VA, Yerullis KB. Sodium loss with muscle sodium deficiency in sodium supplemented and unsupplemented subjects during hypokinesia, *Clin Chem Lab Med* 2007; 46:145-51.
 16. Zorbas YG, Ivanov AL, Immura YK. Changes in total body potassium, haemoglobin and bromine space after hypokinesia and physical exercise. *Mater Med Pol* 1990; 22:300-33.
 17. Portugalov VV, Rhoklenko KD. Changes in striated muscle fibers of mice under hypokinetic conditions. *Kosmicheskaya Biol i Aviokosmicheskaya Med* 1969;3:45-52.
 18. Zorbas YG, Charapakhin KP, Kakurin VJ, Deogenov VA. Electrolyte content in femur of rats during prolonged restriction of motor activity. *Acta Astronautica* 2000; 47:781-8.
 19. Mikhaleva N P, Yefimenko GD, Bobrovnitskiy IP. Electrolyte content of the myocardium, skeletal muscles and blood of rats during prolonged hypokinesia and readaptation. *Kosmicheskaya Biol i Aviokosmicheskaya Med*.1978;12:80-1.
 20. Zorbas YG, Kakuris KK, Neofitos EA, Afoninos NI. Water-electrolyte changes in skeletal and cardiac muscles during prolonged hypokinesia in rats. *Physiol Chem Phys Med NMR* 2005;37:127-40.
 21. Zorbas YG, Andreyev VG, Verentsov GE. Ion regulating functions of rat kidney after hypokinesia and physical exercise. *Urol Int* 1987; 36:465-76.
 22. Zorbas YG, Andreyev VG, Popescu LB. Fluid-electrolyte metabolism and renal function in men under hypokinesia and physical exercise *Inter. Urol. Nephrol*, 1988; 20, 215-223.
 23. Zorbas YG, Abratov NI, Stoikolescu CB, Renal excretion of potassium in men under hypokinesia and physical exercise with chronic hyperhydration. *Urologia* 1988;36, 229-38.
 24. Mirskiy NP, Osava S. *Functional Morphology of Cell*, Izdatel'stvo Nauka Press, Moscow, 1963; p. 368.
 25. Zorbas YG, Alekseyev NB. Effect of periodic hypokinesia on man. *Int J Rehab Res*1987; 10:431-4.

Correspondence to:

Dr. Kostas K. Kakuris
European Foundation of
Environmental Sciences
GR-162 32 Athens, Greece
email: kkakuris@in.gr