

Changes in Serum Magnesium Concentration after Strenuous Exercise

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Serum magnesium concentration (S-Mg) was measured in 20 highly trained young men (mean age 19.5, \pm 0.5, range 18–20.5) before, and at 1 hour, 24 hours, 72 hours, and 3 months after a 120 km hike. As found in previous studies, S-Mg was significantly decreased at the end of the hike ($p < 0.001$; Student's t-test). In this group S-Mg had risen significantly after 24 hours in relation to the value at 1 hour (but not to starting value); yet, at 72 hours and 3 months later, it was once more significantly lower than the starting value ($p < 0.001$ and $p < 0.05$, respectively, Student's t-test). A marked elevation in serum creatine kinase activity (CK) suggests that the rise in S-Mg observed at 24 hours is the result of either exertional rhabdomyolysis or loss of membrane integrity, as a result of the strenuous exertion, since the CK had fallen sharply by 72 hours after the hike. The biphasic, statistically significant, lowering of S-Mg which persisted after 3 months suggests that strenuous exertion induces magnesium deficiency.

INTRODUCTION

There is a transient fall in serum magnesium concentration (S-Mg) after marathon running, cross country skiing, or treadmill exercise under controlled conditions [1–4]. All of these measurements were made before and after exercise and, in one instance [4] measurements were also made during the exercise. However, to our knowledge, no one has measured S-Mg for longer periods after exercise to determine whether there is a sustained fall.

MATERIALS AND METHODS

Twenty highly trained apparently healthy male volunteers whose mean age was 19.5 \pm 0.5 years (range 18–20.5) underwent a 6-month period of graded exercise, consisting of daily short hikes which increased in length a month prior to a brisk 120-km hike. As a safeguard, a free supply of fluid was offered, and all activity was supervised by a specially trained physician who was always in attendance. The probands were not subject to more mental stress than the population at large. Informed consent was obtained from all volunteers.

The 120-km hike took 22 hours, the temperature ranged from 20 to 26°C, and the relative humidity was between 50 and 60%. The estimated magnesium intake during the march averaged 340 mg from food and 367 mg from water (the tap water contained 28.2 mg Mg/L) [5], yielding a total of 707 mg. In addition to measure-

ments of S-Mg, serum calcium (S-Ca), and creatine kinase activity (CK), a standard battery of clinical laboratory tests was obtained, and weight and VO_2 ml/min/kg (VO_2 max), measured according to Astrand (1960)[6]. Measurements were made prior to the 120-km hike, and at 1 hour, 24 hours, and 72 hours after the hike. In addition S-Mg and S-Ca were also measured 3 months after the hike.

Blood samples were collected using a brief stasis. Magnesium was measured using a Perkin-Elmer 305A Atomic Absorption Spectrophotometer at the National Physical Laboratory of The Hebrew University. An "Intensitron" hollow cathode lamp (15 mA), air acetylene flame, and a 4-in. single slot burner were used. Measurements were made at 285.2 nm with spectral band width of 0.2 nm (2 Å). The diluent was 0.25% $SrCl_2$ [7]. Other measurements were carried out using standard methods at the Clinical Chemistry Laboratory, Ichilov Hospital. The mean value of S-Mg of 40 apparently healthy Israeli males, nontrainees, matched for sex (mean age 29.9 \pm 5.6, range 21–45), which served as a control was 0.814 mmol/L \pm 0.058, range 0.73–0.95 mmol/L [5]. The data were evaluated using paired Student's t-test linear regressions and the χ square test.

RESULTS

The S-Mg before the hike, and at 1 hour, 24 hours, 72 hours, and 3 months after the hike are shown in Table 1 and Figure 1. The starting mean S-Mg did not differ

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TABLE 1. Serum Magnesium Concentration (mmol/L) before and after a 120-km Hike

S-Mg (mmol/L)	Before	1 hr after	24 hrs after	72 hrs after	3 months after	$\bar{x} \pm SD$ and normal range of S-Mg of Israeli non-trainees matched for sex
$\bar{x} \pm SD$	0.830 \pm 0.140	0.717 \pm 0.095**	0.769 \pm 0.059	0.668 \pm 0.045**	0.755 \pm 0.064*	0.814 \pm 0.058 0.73 \pm 0.95
n	n = 20	n = 19	n = 20	n = 19	n = 18	n = 40

* = $p < 0.05$; ** = $p < 0.001$ (in relation to the measurements made before the hike).

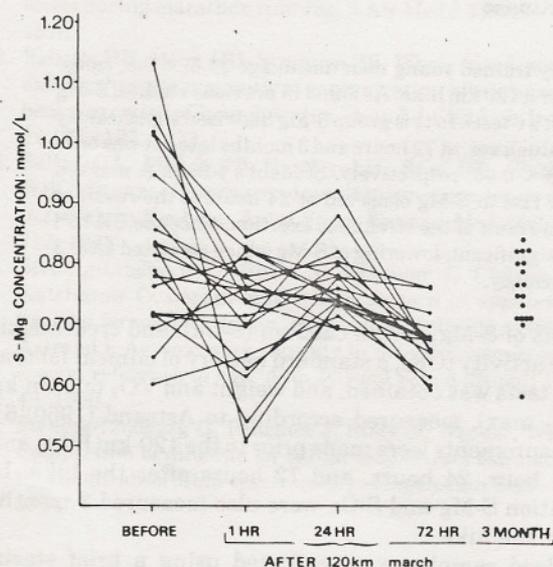


Fig. 1. S-Mg before and after the 120-km hike.

significantly from that of 40 apparently healthy Israeli nontrainees, matched for sex, who served as a control. The mean S-Mg was significantly lower 1 hour after the hike. However, 24 hours later there was a transient rise in S-Mg in relation to the value at 1 hour, but not to the starting value. The mean was again significantly decreased 72 hours after the hike. Three months later the mean was still significantly lower than the starting value. In 42% (8/19) of the probands, S-Mg had fallen below < 0.73 mmol/L by 1 hour after the hike; by 24 hours the incidence of hypomagnesemia was 15% (3/20) only, while at 72 hours after the hike 89% (17/19) of the probands were hypomagnesemic. At 1 hour, 72 hours, and 3 months later S-Mg was below the starting mean and that of 40 apparently healthy Israeli males not engaged in strenuous effort ($p < 0.001$, $p < 0.001$, and $p < 0.05$, respectively; Student's t-test). Also the incidence of hypomagnesemia in the probands differed significantly from the 8% found in the nontrainee controls, at 1 hour ($\chi^2 = 4.8$, $df = 1$, $p < 0.05$) and at 72 hours ($\chi^2 =$

14.7, $df = 1$, $p < 0.001$); it no longer differed 3 months later ($\chi^2 = 2.9$, $df = 1$, $p > 0.05$).

The concurrent changes in other laboratory constituents are shown in Table 2 and Figures 2-5, and VO_2 max and weight in Table 3.

The only statistically significant correlation we found between S-Mg and other variables measured was the negative correlation of S-Mg and S-Ca before the march ($\tau = -499$, $n = 20$, $p < 0.05$). The mean S-Ca which was initially below the normal range (Table 2, Fig. 2) was raised at 1 hour and at 24 hours but no longer differed at 72 hours. However, on renewed measurements 3 months later, S-Ca was again significantly raised compared with the starting mean ($x = 2.488$ mmol/L, $SD 0.206$, $n = 18$, $p < 0.001$, Student's t-test).

There was a uniform increase in CK 1 hour after the end of the hike followed by a gradual fall (Table II, Fig. 3). At 72 hours, although still significantly raised, the S-CK was below 405 IU (i.e., the upper limit of the range) in all probands. A similar pattern was shown by Aspartate Amino Transferase (S-AST) (Table 2, Fig. 4) which peaked at 1 hour and gradually fell, whereas Alanine Amino Transferase (S-ALT) (Table 2, Fig. 5) showed peak values first at 24 hours, but no longer differed at 72 hours.

Blood sugar, raised at 1 hour and 24 hours also normalized at 72 hours, while S-creatinine, S-total protein, S-albumen, and S-globulin remained significantly raised at 72 hours (Table 2).

Coinciding with the second fall of S-Mg at 72 hours (Table 1), S-cholesterol was significantly lowered. At the same time, a significant rise of S-triglycerides took place (Table 2).

The weight and VO_2 max were significantly lowered at 1 hour and 24 hours, but no longer differed at 72 hours (Table 3).

DISCUSSION

As reported in previous studies, the S-Mg falls during strenuous exercise when measurements are made shortly after completion of exercise [1-4]. However, in none of the previous studies were measurements carried out beyond the time immediately following the exercise.

TABLE 2. Laboratory Constituents before and after the 120 km March

	Before			1 hr after			24 hrs after			72 hrs after			Normal range
	\bar{x}	SD	n	\bar{x}	SD	n	\bar{x}	SD	n	\bar{x}	SD	n	
S-calcium (mmol/L)	2.038 ±	0.215	(20)	2.410 ±	0.426	(20)**	2.324 ±	0.170	(20)***	2.144 ±	0.214	(19)	2.20 - 2.60
S-creatinine (mmol/L)	80.4 ±	11.5	(20)	122.4 ±	11.1	(20)***	98.1 ±	12.4	(20)***	91.9 ±	12.4	(19)**	44 - 141
S-total protein (g/L)	64.9 ±	6.4	(20)	83.6 ±	7.6	(20)***	80.9 ±	6.0	(19)***	75.8 ±	4.6	(19)***	60 - 82
S-albumen (g/L)	35.9 ±	1.8	(20)	40.9 ±	1.6	(20)***	40.2 ±	1.4	(19)***	37.5 ±	1.4	(19)**	35 - 50
S-globulin (g/L)	29.1 ±	4.9	(20)	42.7 ±	6.3	(20)***	40.7 ±	5.1	(19)***	38.2 ±	4.1	(19)***	15 - 30
B-haemoglobin	153.2 ±	0.8	(18)	155.5 ±	1.3	(10)	155.2 ±	1.0	(18)**	150.9 ±	1.2	(18)	103 - 176
B-haematocrit (vol %)	45.6 ±	2.6	(18)	46.1 ±	2.6	(9)	46.3 ±	2.9	(18)	45.2 ±	3.0	(18)	42 - 50
B-sugar (mmol/L)	4.61 ±	0.34	(20)	6.83 ±	1.13	(20)***	5.22 ±	0.79	(20)	4.54 ±	0.79	(18)	3.3 - 5.7
S-triglycerides (mmol/L)	6.10 ±	2.13	(20)	5.30 ±	1.08	(20)	5.97 ±	1.32	(20)	8.70 ±	1.53	(20)***	< 1.70
S-cholesterol (mmol/L)	4.19 ±	0.24	(20)	4.11 ±	0.70	(20)	4.01 ±	0.65	(20)	3.80 ±	0.46	(20)**	3.9 - 7.7
S-AST (IU/L)	13.1 ±	2.3	(20)	100.4 ±	40.9	(20)***	87.5 ±	34.7	(20)***	24.2 ±	20.5	(19)*	< 40
S-ALT (IU/L)	7.9 ±	1.9	(16)	10.1 ±	2.9	(20)*	13.4 ±	3.8	(19)***	9.9 ±	3.9	(19)	< 35
S-CK (IU/L)	97.7 ±	46.6	(20)	1555.1 ±	1353.2	(19)***	782.5 ±	335.3	(19)***	173.4 ±	97.3	(19)**	0 - 100

* = $p > 0.05$; ** = $p > 0.01$; *** = $p > 0.001$ (in relation to the start value).

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TABLE 3. VO_2 max and Weight before and after 120-km March

	Before			1 hr after			24 hrs after			72 hrs after		
	\bar{x}	SD	n	\bar{x}	SD	n	\bar{x}	SD	n	\bar{x}	SD	n
VO_2 max	44.5	6.2	20	38.3	4.9	8*	39.3	6.0	18*	45.8	4.6	19
Weight (kg)	74.9	6.6	20	68.5	4.8	10**	69.8	6.3	19**	72.6	5.8	19

* = $p < 0.05$; ** = $p < 0.01$ (compared with the value before the march).

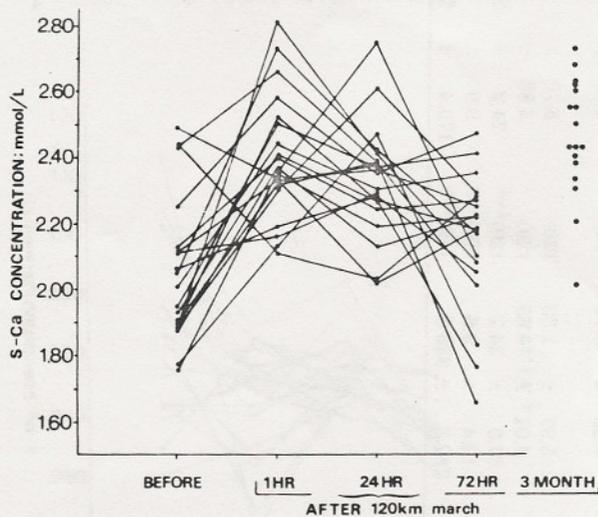


Fig. 2. S-Ca before and after the 120-km hike.

In this study S-Mg was measured at 1 hour, 24 hours, 72 hours, and 3 months after the strenuous exertion. At the end of the hike there was a significant (14%) decrease in S-Mg which was accompanied by a striking rise in CK. After 24 hours, while the CK was still significantly elevated, the magnesium concentration was also increased. Since magnesium is primarily an intracellular cation [8], it may well be that the rise of S-Mg, which was subsequently shown to be transient, was the result of leakage of intracellular magnesium into the extracellular pool due to exertional rhabdomyolysis, a view supported by the increased CK.

When S-Mg was measured 72 hours later, it was once again significantly decreased (20%) and, in fact, the mean S-Mg was still significantly decreased (9%) when measured 3 months later. During these 3 months the subjects continued routine training but did not engage in any long hikes.

Many studies strongly suggest that strenuous exercise, particularly in hot climates, results in hypomagnesemia, probably through a depletion of body stores of magnesium. Some, but not all, of the decrease in S-Mg has been shown by Bellar et al to be due to loss of magnesium in sweat [4]. As pointed out by Conolazio [9], reduction in sweat magnesium does not accompany adaptation to heat. Therefore, sweat loss probably does not

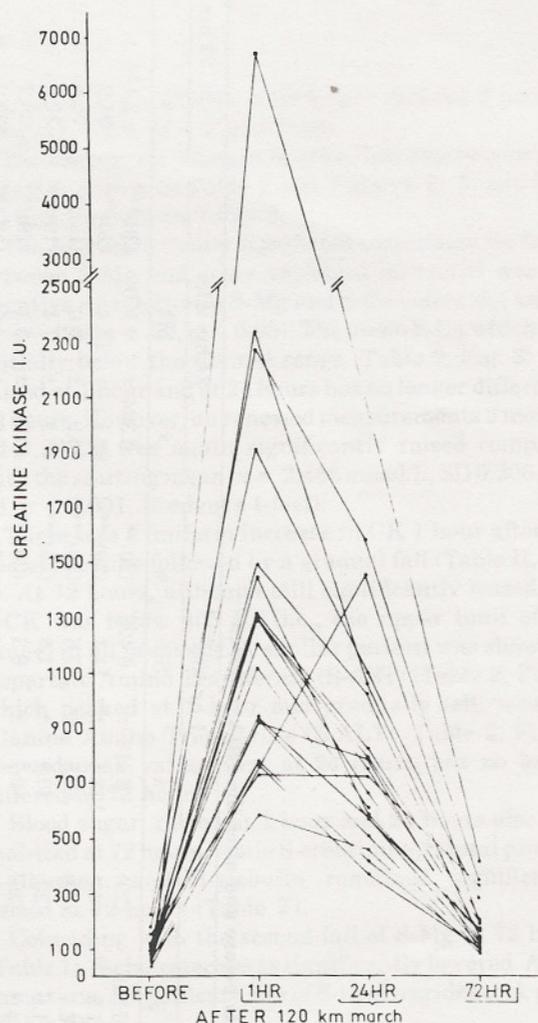


Fig. 3. Serum creatine kinase activity; IU before and after the 120-km hike.

account entirely for the reduction in S-Mg even though these subjects lost an average of 5.5 kg.

Exercise of this degree undoubtedly leads to increased glycolysis as suggested by the significant rise of blood sugar seen in our, as well as other, studies [10]. In the kidney, increased glucose uptake and glycolysis may block divalent cation reabsorption, giving rise to mag-

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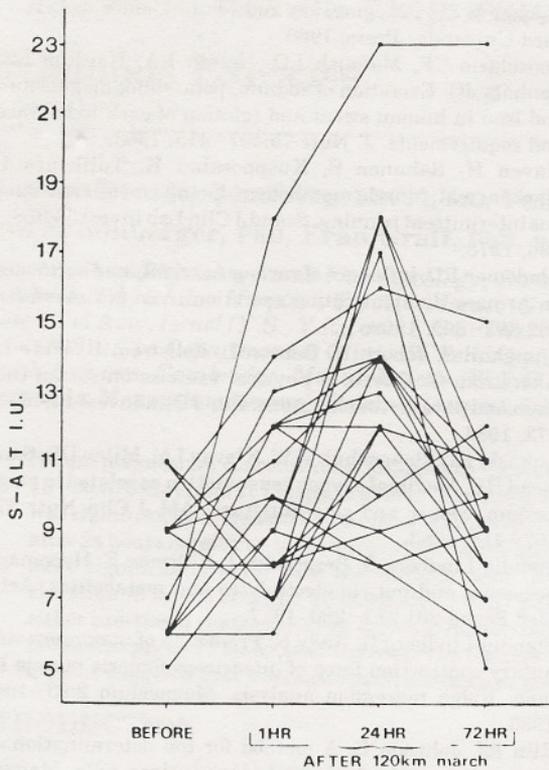


Fig. 4. S-ALT activity; IU, before and after the 120-km hike.

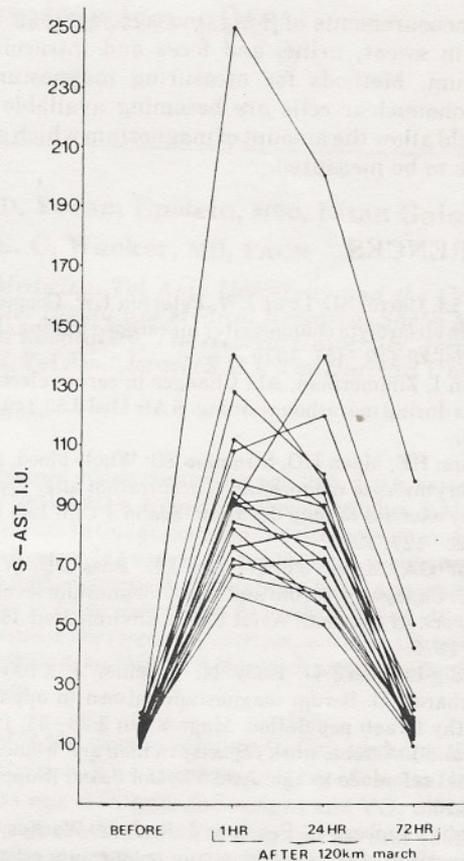


Fig. 5. S-AST activity; IU, before and after the 120-km hike.

nesium diuresis [11]. An intracellular shift is suggested by the studies of Refsum [3]. This could be due to increased oxidative phosphorylation and increased breakdown of creatine phosphate and gluconeogenesis, all of which, as well as glycolysis, are magnesium-dependent processes [8]. Finally, it is likely that the magnesium released from cells, as a result of exertional rhabdomyolysis (as suggested by its rise at 24 hours, following the peak increase in CK) or released due to loss of membrane integrity [8], was also excreted, leading to the observed decrease in S-Mg at 72 hours. Further, such a loss of total body magnesium probably contributed to the significant lowering of S-Mg observed 3 months after the hike.

The rise of S-CK, as well as the other changes of laboratory constituents found by us have been previously extensively reported, following exercise, whereas the rise of S-Ca following exercise has been studied only more recently [12]. However, what was not, to our knowledge, reported before, is the late rise of S-triglycerides, coinciding with the second fall of S-Mg. This interesting finding requires further study.

Lukaski et al [13] reported a correlation between plasma magnesium and VO_2 max. As regards S-Mg in our own study, following the significant lowering of VO_2 max at 1 hour and 24 hours, the VO_2 max was found to be slightly, although not statistically significantly, higher at 72 hours than its starting value, in spite of the significant concomitant second lowering of S-Mg.

Since magnesium is required in a host of intra- and extracellular biological processes [8] and chronic hypomagnesemia was found to be accompanied by intracellular magnesium deficiency [14], the persistent hypomagnesemia which occurs after strenuous exercise, particularly in a hot climate, suggests that such exertion induces magnesium deficiency. Such a deficit could not be replenished, even over a period of 3 months, due to the inadequate food magnesium intake [5]. Consequently, serial measurements of S-Mg and the addition of supplemental magnesium to the diet of athletes and other persons undergoing repeated strenuous exertion, especially in the heat, are probably indicated and may well lead to an improvement in physical performance [15].

The extension of these studies should include, in addi-

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tion to measurements of S-Mg, measurements of magnesium in sweat, urine, and feces and intracellular magnesium. Methods for measuring magnesium in blood mononuclear cells are becoming available [16] and should allow the amount of magnesium which shifts into cells to be measured.

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