An experiment to correct magnesium deficiency in Austrian rural areas by magnesium rich foodstuff

G. Leitner, S. Porta[1, 2], D. Westmoreland[3], M. Knapp[3], K. Spencer[3], J. Merback[3], T. Leitner[2]

Zusammenfassung

15 weibliche Schüler einer ländlichen Haushaltungsschule wurden einer standardisierten Ergometerarbeit unterworfen, wobei vorher und nachher aus Blutproben aus der Fingerbeere Blutgase, Elektrolyte, Laktat und Blutglukose gemessen wurden. Während der folgenden 10 Tage wurde ein stark magnesium- und kalziumangereichertes Essen verabfolgt. Nach dieser Periode fand erneut Blutabnahme und Ergometrie wie vorher statt.
Es zeigte sich, dass eine reichliche Darbietung von Magnesium in der Nahrung gerade im Stande war, den vorher hypomagnesämischen Durchschnittswert des ionisierten Serum-Magnesiums von 0,44 ± 0,01 SEM mM/l auf 0,46 ± 0,01 SEM mM/l anzuheben. Diese Steigerung wäre vermutlich ohne gleichzeitiges Anbieten von stark magnesiumhaltigen Mineralwasser (206 mg Magnesium/Liter) nicht in diesem Maße gelungen.
Offensichtlich ist also einer der wesentlichsten Hinderungsgründe für eine genügende Magnesiumaufnahme aus der Nahrung bei Mädchen dieser Altersgruppe eine starke Tendenz zur Nahrungskarenz aufgrund falsch verstandener Schönheitsideale.
Obwohl sich keine diätbedingten Änderungen in den Mittelwerten der Blutgasparameter nach der Ergometrie zeigten, traten nach der Diätepisode individuelle Proportionalitäten zwischen Baseexzess und pH, Baseexzess und Laktat, nicht aber zwischen Laktat und Baseexzess hervor. Aus diesem Verhalten vermuten wir eine lipolysesenkende Wirkung der erhöhten Magnesiumzufuhr nur bei jenem Teil der Probanden, die ausreichend magnesiumreiche Nahrung zu sich genommen hatten. Aufgrund dieser Ergebnisse empfehlen wir eine niederkalorische Magnesiumsupplementation bei Mädchen dieses Alters.

[1] Institute of Applied Stress Research, Bad Radkersburg, Austria
[2] Institute of Pathophysiology, Karl-Franzens University, Graz, Austria
[3] Biology Department, USAF Academy, Colorado Springs, Co., USA

Summary

15 female students of a rural agricultural school have been subjected to a standardized cycle ergometry, whereby blood gases, electrolytes, lactate and blood glucose were measured before and after exercise. During the following 10 days a calcium and magnesium enriched diet was provided and afterwards the same blood sampling and ergometry exercise was carried out once more.
It turned out, that a magnesium enriched diet was just able to increase the average, hypomagnesemic ionised serum levels (from 0.44 ± 0.01 SEM mM/l to 0.46 ± 0.01 SEM mM/l). Even that would have been to no avail, unless a magnesium rich mineral water (206 mg of magnesium/l) would have been offered at the same time. Obviously, the most important prohibiting factor for a sufficient magnesium intake in the female age group of about 16 is a general avoidance of food in order to reach or keep up slenderness.
Although there were no diet induced alterations of the averages of blood gas reactions to ergometry to be seen, ensuing proportionalities of individual base excess and pH, base excess and lactate, but not lactate – pH values suggest a decreased lipolysis after increased magnesium diet in those participants with sufficient uptake [1, 2]. A low calory magnesium supplement has been recommended.

Introduction

In a former paper, a surprisingly low level of ionized serum magnesium, especially in Austrian female high school students of about 17 years of age within an urban environment has been reported [3].
Since the opportunity arose to check the same parameters of a similar collective within the more controlled circumstances of a rural boarding school, we were basically interested, whether rural environment would bring about different feeding habits. Moreover, the teaching staff agreed to provide the girls with a specially cooked magnesium rich diet, the possible effects of which upon electrolyte levels and performance parameters we could check by testing electrolytes, blood gases, lactate and blood sugar before and after the dietary intervention, both, with and without physical workload.

Materials and methods

15 female students of the Halbenrain – agricultural housekeeping – boarding school, with an average age of 16, were subjected to a standardized ergometry program (Ergo-Line, Ergo-Metrics 800S). The program was nine minutes in duration, consisting of three, three-minute intervals of controlled power output of 50 watts, 100 watts, and 150 watts, respectively. The intervals were completed in sequence and without resting between them.
Before and after ergometry, three drops of capillary blood were drawn from the fingertip for determination of lactate (Boehringer-Mannheim) (mM/L), glucose level in blood, pH, partial pressure of carbon dioxide (pCO_2) (mmHg), base excess (BE) (mM/L), hydrogen carbonate (HCO_3) (mM/L), parital pressure of oxygen (pO_2) (mmHg), and percent oxygen saturation (O_2sat) (AVL Compact 3) as well as ionized sodium (Na) (mM/L), ionized magnesium (Mg) (mM/L), and ionized calcium (Ca) (mM/L) (AVL 988-4).
During the ten days following the ergometry program, the meals fed to the subjects were prepared with a high Mg and Ca content.

Tab. 1: Magnesium uptake during ten days of magnesium enriched diet.

Calculated Mg uptake per day and person in mg	Food magnesium contents without mineral water in mg	Magnesium uptake by mineral water per day and person in mg	Percent of magnesium uptake by mineral water
468	396	72	15.83
156	86	70	44.87
238	173	56	23.52
201	125	76	37.18
212	156	56	26.41
302	208	94	31.12
256	206	50	19.53
120	84	36	30.00
205	169	36	17.56
234	140	94	40.17
226	118	108	47.87
385	299	86	22.34
323	193	130	40.25
256	184	72	28.12
278	216	62	22.30
257.33	**183.50**	**73.2**	**28.45 mean**
87.18	80.53	26.03	11.29 **SD**

As an example of the menu, we randomly choose the food arrangements of day 1 and day 7:

Day 1:
Breakfast: coarse whole meal roll, butter, jam,
2nd *breakfast:* buttermilk, rye bread, cheese, fruit.
Lunch: Liver dumpling soup, turkey-roast with "dinkel" whole grain rice, green salad, yogurt creme with fruits.
Dinner: Vegetable salad and cheese and olive dressing, rye bread, herbal tea.

Day 7:
Breakfast: Fresh home made muesli and fruits,
2nd *breakfast:* buttermilk, rye bread, cheese, fruit.
Lunch: Chicken soup, Roast chicken with full grain rice, mixed salad, rhubarb cake made from whole meal.
Dinner: Sweet "dinkel" semolina pancakes, stewed apples.

A mineral water with 206 mg magnesium per litre was available ad libitum. The subjects kept a daily log of all the food and mineral water they consumed during the course of the experiment.

Tab. 2: Means and SEM of all the parameters measured before and after workload and diet.

	pH	PCO_2	BE	HCO_3	pO_2	O_2sat	Na	Mg	Ca	Lactate	BS
1-Pre	7.417	34.97	−1.31	21.83	65.91	91.71	142.21	0.44	1.30	1.47	86.13
SEM	0.006	0.81	0.39	0.41	2.95	1.28	0.60	0.01	0.01	0.16	3.84
1-Post	7.343	29.28	−8.29	15.55	82.99	94.81	141.98	0.43	1.29	6.23	70.47
SEM	0.012	0.63	0.81	0.64	1.86	0.35	0.39	0.01	0.01	0.68	1.99
2-Pre	7.408	35.52	−1.71	21.77	69.01	92.91	141.11	0.46	1.30	2.13	88.13
SEM	0.009	1.02	0.62	0.63	2.72	0.65	0.69	0.01	0.01	0.32	3.44
2-Post	7.353	29.19	−7.79	15.83	85.20	95.37	140.37	0.43	1.28	7.04	74.20
SEM	0.012	0.96	0.80	0.70	2.12	0.22	0.37	0.01	0.01	0.68	2.78

After the 10 days nutrition regimen the subjects performed the same standardized ergometry training. The same procedure for collection and analysis of the blood was followed. All participants gave their written consent according to the Helsinki Charter, being fully aware of the nature and purpose of the experiment.

Results

1. Calculation of individual magnesium uptake by both food and mineral water:
Mg uptake per day and person was calculated according to the magnesium contents of the foodstuffs and the amount of their uptake (Tab. 1).
Although in the average little more than 300 ml of mineral water had been drunk each day, the average percentage of daily magnesium uptake by water ranged from 15 % to 47 %.

2. Measurement of blood gases, blood glucose, lactate and electrolytes:
Average values for blood gases, blood glucose, lactate and electrolytes were calculated before and after ergometry on both days. There was a statistically significant increase in basal Mg levels ($p = 0.0293$) from Day 1 to Day 2. From this higher basal level on Day 2 we also witnessed a decrease in the post-ergometry Mg (Fig. 1, $p = 0.0511$).
On Day 2, we saw a significant decrease in the post-ergometric Na as compared to Day 1 (Fig. 2, $p = 0.0011$).
Ca significantly decreased following ergometry on Day 2 only (Fig. 3, $p = 0.0329$).
The average pH decreased significantly on both days following ergometry. ($p = 0.0003$ and 0.0022 resp.). Lactate experienced increases in post-ergometry values, as should be expected. Additionally, the resting lactate on Day 2 was almost significantly higher (Fig. 4, $p = 0.0513$) than on Day 1. Blood glucose significantly decreased following ergometry on both days ($p = 0.0006$, $p = 0.0006$), and base excess

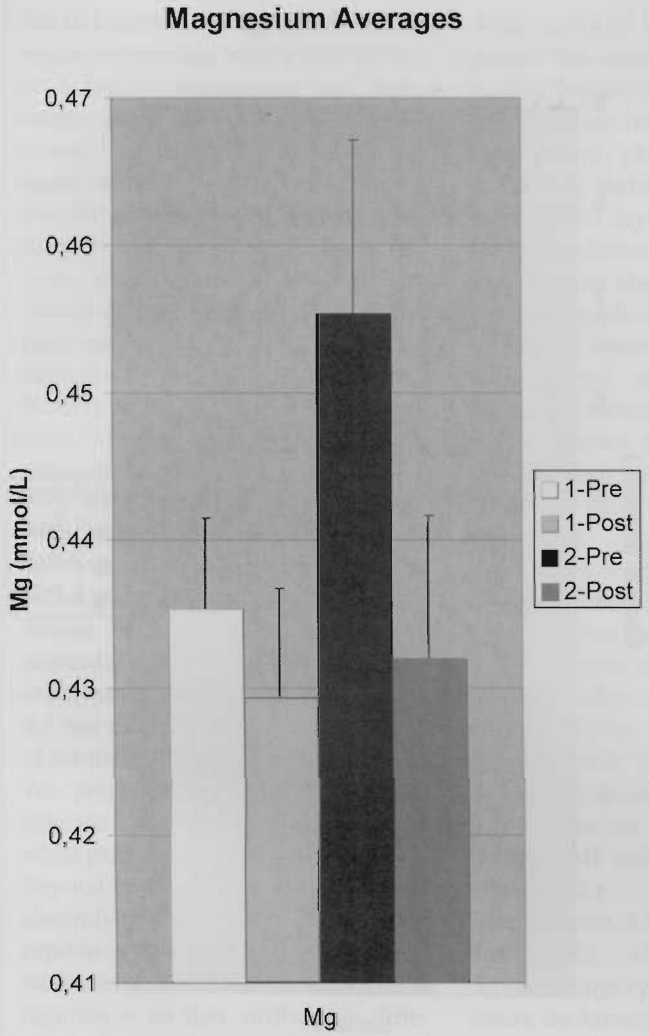

Fig. 1: Ionised magnesium before and after ergometry with and without magnesium-enriched diet.
Abszissa: 1-Pre: Before ergometry without diet
1-Post: After ergometry without diet
2-Pre: Before ergometry with diet
2-Post: After ergometry with diet
Ordinate: mmol/l magnesium

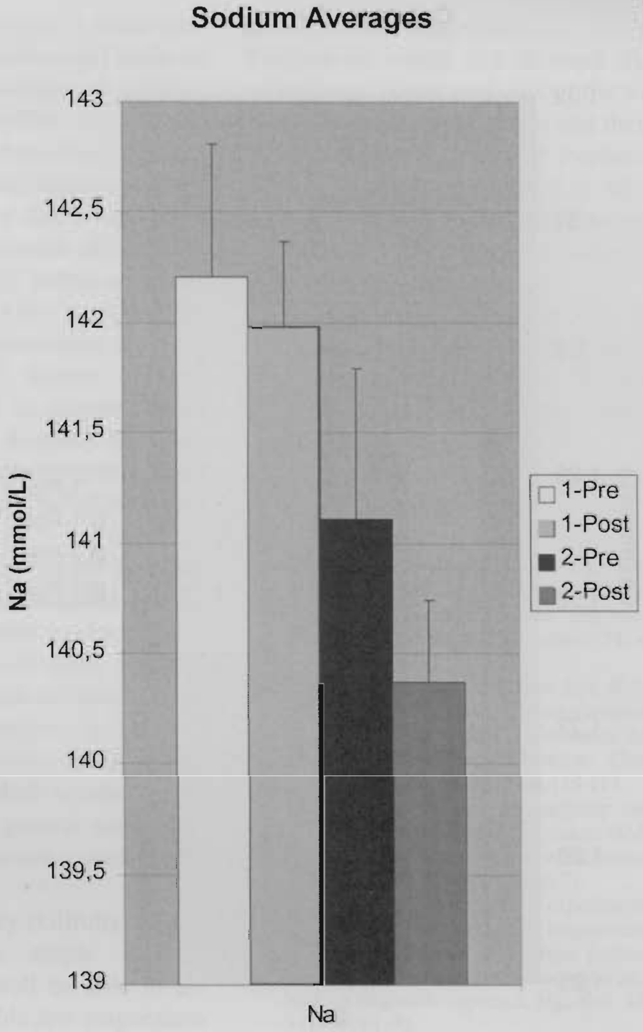

Fig. 2: Ionisod sodium before and after ergometry with and without magnesium-enriched diet.
Abszissa: 1-Pre: Before ergometry without diet
1-Post: After ergometry without diet
2-Pre: Before ergometry with diet
2-Post: After ergometry with diet
Ordinate: mmol/l sodium

significantly decreased ($p < 0.000001$, $p < 0.000001$).

Blood gas parameters, as pH, pCO_2, BE, HCO_3, pO_2 and O_2sat did not show any significant differences in their average values which could be attributed to the dietary changes (Tab. 2).

However, there was a marked difference concerning the linear relationships pH-BE-lactate between the different sampling times:

Before ergometry on day 1 no significant linear correlation between pH, BE or lactate could be seen. After ergometry a linear relationship between pH and BE evolved.

On day 2, a significant linear correlation between pH and BE was already present before ergometry. After ergometry BE values did not only correlate linearly with pH values, like on the first day, but also with lactate values. There was however no correlation between pH and lactate values at this time.

Discussion

In a former paper [3] we could show, that Austrian youngsters, especially females around the age of 16 show a remarkable lack of serum magnesium, shown by determination of ionized serum magnesium with and without ergometrical workload, thus ruling out possible hazards in determining false positive or negative basal values [3].

Shortly afterwards, we were given the opportunity of not only being able to check on the magnesium dynamics of

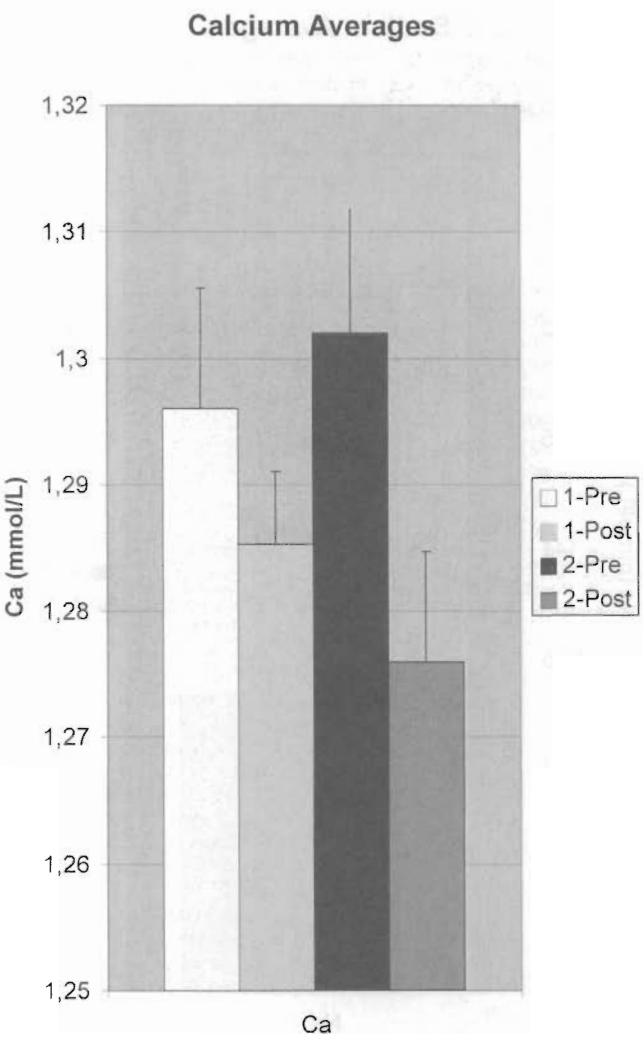

Fig. 3: Ionisod calcium before and after ergometry with and without magnesium-enriched diet.
Abszissa: 1-Pre: Before ergometry without diet
1-Post: After ergometry without diet
2-Pre: Before ergometry with diet
2-Post: After ergometry with diet
Ordinate: mmol/l calcium

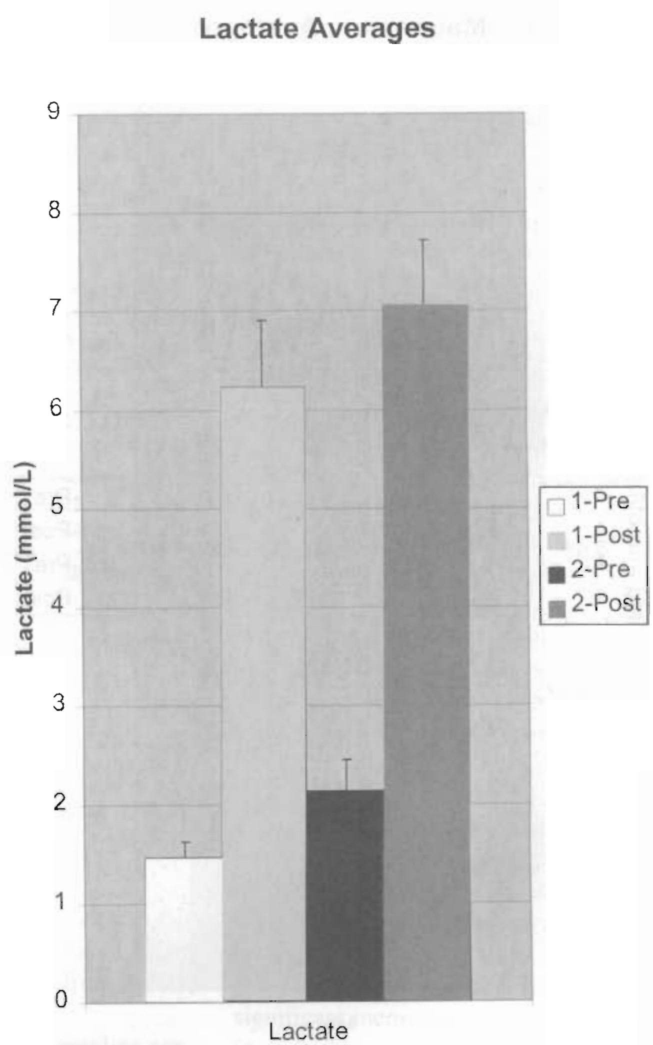

Fig. 4: Lactate before and after ergometry with and without magnesium-enriched diet.
Abszissa: 1-Pre: Before ergometry without diet
1-Post: After ergometry without diet
2-Pre: Before ergometry with diet
2-Post: After ergometry with diet
Ordinate: mmol/l lactate

a similar group of young females, but, since they were attendees of a housekeeping boarding school, we were offered by the head and staff of the school that an attempt would be made to offer to our probants during 10 days a specially cooked diet of uncommonly high magnesium and calcium content.

Although – as one can see from the menu samples in material and methods – every effort was made to cook a very palatable food, it lay in the nature of the females of about 16 that food uptake in general (with a few exceptions) was sparing. Thus, in spite of the high magnesium contents of the meals, only about 30 % of the girls ingested a total of more than 300 mg magnesium per day. Moreover, of the total average uptake of about 257 mg of magnesium, about 73 mg or about 28 % (!) was due to ingestion of a particularly magnesium rich mineral water (206 mg/l).

It does not seem highly speculative, if we estimate the normal magnesium intake in form of foodstuffs of an average 16 year old Austrian girl, without carefully selected food and without special mineral water supplement far below the average mark in this paper.

However, even a purposely magnesium enriched diet did only just increase the probants' ionized serum magnesium from clearly hypomagnesemic basal levels [6] of 0.435 mM/l to 0.46 mM/l, a level slightly above the necessary 0.45 mM/l, whereby still about half of the girls remained hypomagnesemic. Still, the regimen resulted in a significant increase of ionized serum magnesium within only 10 days of a high – magnesium diet. Ergometric workload did decrease ionized serum magnesium concentrations again, whereby we got the impression, that the girls were very hard put to go through the whole ergometry procedure, which points towards a rather poor bodily condition, possibly at least party due to the lamentable magnesium state.

Similar to the dynamics of magnesium, which showed significant differences before and after workload after only 10 days of diet, calcium levels were likewise only significantly different due to workload after, but not before the diet period.

Serum sodium levels decreased markedly from the beginning of the experiment towards its end. Since we did not calculate the sodium contents of the diet, we cannot explain this fact. We presume however, that sodium chloride was more sparingly used while preparing a "diet".

Beyond the significant differences in electrolytes, there were – with the exception of a slight but significant increase in basal lactate after the diet regimen – no diet attributable differences in the average values of blood gases and blood glucose before or after exercise, so that basal magnesium changes were most probably not due to different stress levels but to real dietary effects.

But if one looks at the proportional relations between the individual pH and base excess values at first no significant linear correlation between those two parameters under basal conditions is to be discerned [4, 5]. After workload however, a linear proportion develops between pH and base excess, probably meaning that buffer capacity does not suffice any more to keep blood pH unscathed by the developing metabolic acidosis.

After the 10 days of diet, a significant linear correlation between pH and base excess exists already before workload has been applied. After workload, an additional linear correlation between base excess and lactate ensures. However, increase in magnesium levels is known to decrease lipolysis, perhaps even via magnesium induced influence upon catecholamine turnover [1, 2].

Since there is no correlation between pH and lactate after the diet period, neither before or after workload, it is not impossible that in those 30 % of the participants, with sufficient magnesium uptake lipolysis is less expressed, while lipolysis in those with particularly poor food uptake is still high. Therefore a general proportion between pH and lactate could not be established.

In conclusion, a very skillfully cooked diet along with ample mineral supplement may well be able to increase the lamentable low magnesium levels, especially of our female youngsters, but it remains to be seen, how far an average family would be able to imitate the professionality of a housekeeping school. Even if one would succeed in doing so, the overwhelming tendency for slimming down in this age group would probably prohibit satisfactory food uptake and thus jeopardize the whole effort. Therefore any kind of magnesium supplementation, preferably in a low caloric form is suggested.

The authors would like to thank the enthusiastic young probants of the St. Martin school at Halbenrain and their highly cooperative staff of teachers. They are especially indebted to Mrs. *Leopoldine Tschiggerl*, headmaster, for the idea to this paper and fantastic food.

The help of Mrs. *B. Poncza*, Mrs. *P. Porta* and Mr. *T. Porta* is appreciated, as well as the work done by the students of the Endocrinology Seminary.

References

[1] *Gasparovic, C.; Berghmans, K.:* $Ca2^+$ and $Mg2^+$ modulated lipolysis in neonatal rat brain slices observed by one- and two-dimensional NMR. J. Neurochem. **71**, 4 (1998) 1727-1732.

[2] *de Valk, H.W.; Bianchi, R.; van Rijn, H.J.; Erkelens, D.W.:* Acute exogenous elevation of plasma free acids does not influence the plasma magnesium concentration. Clin. Chem. Lab. Med. **36**, 2 (1998) 115-117.

[3] *Porta, S.* et al.: Stress compatibility and electrolyte dynamics of sports majors (SM) and language majors (LM) at examination time. Mg.-Bull. **22**, 3 (2000) 66-71.

[4] *Porta, S.* et al.: Human field experiments about the interrelationship of magnesium, electrolyte and blood gas changes proportional to the intensity of accumulated workload – a diagnostic approach. Mg.-Bull. **21**, 3 (1999) 61-70.

[5] *Porta, S.* et al.: Typical behavior of Mg, electrolyte, blood gas and blood glucose in physically and psychically stressed individuals. Mag.-Bull. **21**, 4 (1999) 109-113.

[6] Österreichische Konsensus Konferenz: „Magnesium", 1.–3. 12. 1995 Bad Tatzmannsdorf, Session: Mg Messungen.

Correspondence to:
Sepp Porta
Institute of Applied Stress Research
Hauptplatz 2–4, A-8490 Bad Radkersburg
E-Mail: stresscenter@netway.at