Magnesium intake mediates the association between bone mineral density and lean soft tissue in elite swimmers

Catarina N. Matias¹,³, Diana A. Santos¹,³, Cristina P. Monteiro²,³, Ana M. Vasco¹, Fátima Baptista¹,³, Luís B. Sardinha¹,³, Maria J. Laires³, Analiza M. Silva¹,³

¹ Exercise and Health Laboratory, Faculty Human Kinetics, Technical University of Lisbon, Estrada da Costa, 1499-002 Cruz-Quebrada, Portugal; ² Physiology and Biochemistry Laboratory, Faculty Human Kinetics, Technical University of Lisbon, Estrada da Costa, 1499-002 Cruz-Quebrada, Portugal; ³ CIPER - Interdisciplinary Center for the Study of Human Performance, Faculty Human Kinetics, Technical University of Lisbon, Estrada da Costa, 1499-002 Cruz-Quebrada, Portugal

Correspondence: Catarina Nunes Matias. Exercise and Health Laboratory, Faculty of Human Kinetics, Technical University of Lisbon, Estrada da Costa, 1499-002 Cruz-Quebrada, Portugal. <c.matias@fmh.utl.pt>

Abstract. Magnesium (Mg) deficiency has been associated with bone disorders. Physical activity is also crucial for bone mineralization. Bone mass loss has been observed to be accelerated in subjects with low Mg intake. We aim to understand if Mg intake mediates the association between bone mineral density (BMD) and lean soft tissue (LST) in elite swimmers. Seventeen elite swimmers (eight males; nine females) were evaluated. Bone mineral content, BMD, LST, and fat mass were assessed using dual energy X-ray absorptiometry. Energy and nutrient intake were assessed during a seven-day period and analyzed with Food Processor SQL. Males presented lower values than the normative data for BMD. Mg, phosphorus (P) and vitamin D intake were significantly lower than the recommended daily allowance. A linear regression model demonstrated a significant association between LST and BMD. When Mg intake was included, we observed that this was a significant, independent predictor of BMD, with a significant increase of 24% in the $R^2$ of the initial predictive model. When adjusted for energy, vitamin D, calcium, and P intake, Mg remained a significant predictor of BMD. In conclusion, young athletes engaged in low impact sports, should pay special attention to Mg intake, given its potential role in bone mineral mass acquisition during growth.

Key words: magnesium, lean soft tissue, bone mineral density

Previous studies have documented associations between lean soft tissue (LST) and bone mineral content (BMC) and density (BMD). It has been suggested that a higher peak bone mass may be achieved by regularly performing weight-bearing exercises, particularly if associated with impacts, during growth [1]. LST increments have been suggested to be an important predictor of bone mineral during growth [1, 2]. Ferretti et al. reported that muscle mass and bone mass are closely related throughout life and LST is the strongest determinant of BMC [3]. Additionally, magnesium (Mg) has been recognized as one of the essential elements of bone, and its deficiency has been associated with disorders of bone and mineral metabolism [4, 5]. It is
estimated that there are 1300 g of calcium (Ca), 14 g of Mg and 60 g of phosphorus (P) in the bones of a 70 kg adult human [6]. This amount of Mg accounts for about 50-60% of the body’s Mg. There are several potential mechanisms that may account for decreases in bone mass acquisition in Mg deficiency [5, 7].

In young individuals, Wang et al. [8] evaluated the effect of dietary Mg on bone mass. They found that Mg intake was positively related to quantitative ultrasound properties of bone suggesting the nutritional importance of this element in skeletal growth and development. Moreover, epidemiological studies have linked dietary Mg intake to bone mass at several skeletal sites including the forearm, spine, and hip [9]. Besides nutritional habits, physical activity is also crucial for bone mineralization. There is evidence that a higher peak bone mass attained during adolescence may be achieved with more physical activity or a more active lifestyle and that the peak bone mass is probably an important determinant of bone fracture risk later in life [10-12]. In longitudinal studies, the rate of bone mass loss has been observed to be accelerated in subjects with low Mg intake [9]. Nevertheless, there is evidence that some athletes have inadequate Mg intake [13-16]. Thus, this study aims to investigate if Mg intake mediates the association between BMD and LST in elite male and female swimmers.

Material and methods

Subjects
A total of 17 elite swimmers, eight males and nine females with a mean age of 19.0 ± 1.2 and 16.6 ± 1.4 years, respectively, from swimming teams in Lisbon volunteered to participate. Inclusion criteria were:

- 1) minimum period of activity of approximately six years;
- 2) > 10 hours training per week;
- 3) negative test outcomes for performance-enhancing drugs;
- 4) not taking any medications or dietary supplements.

Females were not taking oral contraceptives. Different swimming modalities were assessed, including: six velocity swimmers, nine middle distance and three long distance swimmers. All subjects gave their written informed consent prior to participation in the study. All procedures were approved by the Ethics Committee of the Faculty of Human Kinetics, Technical University of Lisbon, and conducted in accordance to the declaration of Helsinki of the World Medical Associations for human studies [17].

Anthropometry
Subjects were weighed (BOD POD©, Life Measurement, Inc., Concord, CA, USA) and height was measured (Seca, Hamburg, Germany), according to standardized procedures [18].

Body composition and bone mineral
BMC and BMD, LST, fat mass (FM), and % fat mass (%FM) were assessed by a whole body scan using dual energy X-ray absorptiometry, fan-beam densitometer (Explorer W, Hologic, Waltham, USA, software version 12.4), according to standardized procedures [18].

Energy and nutrients intake
Energy and nutrients intake were assessed from a 24-h diet record over a seven-day period. Subjects were instructed regarding portion sizes, supplements, food preparation, and others aspects pertaining to an accurate recording of their intake. After the seven-day period, athletes were interviewed by a qualified nutritionist in order to clarify the records. Diet records were analyzed by the software package Food Processor SQL (Salem, Oregon, USA, version 10.5.0, 2009).

Statistical analysis
Data were analyzed with IBM SPSS Statistics for Windows version 19.0 (SPSS Inc, an IBM company, Chicago, USA) and presented as mean ± SD. Normality was verified using the Shapiro-Wilk test. One-sample t-tests were used to compare mean values for BMD with normative data and mean nutrient intake with recommended dietary allowances in both genders. Multiple regression analysis was performed to test the influence of gender alone and the interaction with the independent variables, LST and Mg. Because no
gender differences were observed, the analysis was performed with the whole sample. Linear regression models were performed using BMD as the dependent variable, and LST (adjusted for height) alone, as an independent variable. We also added Mg as an independent variable to the model. The coefficient of determination ($R^2$) change was analyzed to examine the separate role of Mg, and if the association was independent of energy, vitamin D, Ca, and P intake. In this context, three models were developed to understand the variables associated with BMD. The first included LST (adjusted for height), in the second Mg was added as an independent variable, and the third model included both LST and Mg and was adjusted for height, energy, vitamin D, Ca, and P intakes. During model development, homogeneity of variance and normality of residuals were tested. Statistical significance was set at $p<0.05$.

**Discussion**

Previous investigations have demonstrated an association between BMD and LST [1, 2], however, to the authors knowledge this is the first study to address this association in athletes. The primary goal of this study was to examine if Mg intake mediates the association between bone mineral density and lean soft tissue in elite male and female swimmers. It has been reported that low Mg intake affects maintenance of normal bone homeostasis, and it is a possible risk factor for low bone mass [5]. Regarding skeletal health of young people, low intakes of minerals and proteins may adversely affect the accomplishment of maximal peak bone mass and, consequently, may contribute to osteoporosis in later life [22].

Physical activity/exercise, has a positive influence on bone mineralization, particularly in pre- and early pubescent children. Additionally, as an indicator of muscle mass, LST has a major function in bone variability [2]. However, despite of the role of Mg in bone metabolism, there is not enough data to assess its impact.

**Results**

In table 1 are summarized subjects’ physical characteristics and body composition. Considering BMD, males presented lower values than the normative data [19], while in females no significant differences were observed.

Mean and standard deviation for energy and nutrient intake records are shown in table 2. Mg, P and vitamin D intakes in these athletes were significantly lower than the recommended daily allowance [20, 21].

Table 3 presents the associations between BMD and LST alone and with Mg in the models studied.

| Table 1. Physical characteristics and body composition of the athletes. |
|--------------------------|--------------------------|--------------------------|
|                          | **Male (n = 8)**         | **Female (n = 9)**       | **All subjects (n = 17)** |
| Weight (kg)              | 68.8 ± 5.5               | 60.0 ± 5.6               | 64.2 ± 7.0                |
| Height (cm)              | 180.5 ± 6.3              | 167.1 ± 6.7              | 17.4 ± 9.4                |
| BMI (kg/m²)              | 21.1 ± 1.5               | 21.5 ± 1.5               | 21.3 ± 1.5                |
| Total BMC (g)            | 2294 ± 339               | 2073 ± 319               | 2177 ± 338                |
| Total BMD (g/cm²)        | 1.077 ± 0.10*            | 1.097 ± 0.07             | 1.088 ± 0.09              |
| Total LST (kg)           | 57.3 ± 5.6               | 44.4 ± 4.7               | 50.5 ± 8.3                |
| Total FM (kg)            | 9.2 ± 1.8                | 13.6 ± 1.7               | 11.5 ± 2.8                |
| FM (%)                   | 13.4 ± 3.0               | 22.6 ± 2.4               | 18.3 ± 5.4                |

BMI: body mass index; LST: lean soft tissue; FM: fat mass; BMC: bone mineral content; BMD: bone mineral density

* Significant differences from the normative data (males: 1.206 g/cm²; females: 1.092 g/cm²).
Table 2. Energy and nutrient intake of the athletes.

<table>
<thead>
<tr>
<th></th>
<th>Male (n = 8)</th>
<th>Female (n = 9)</th>
<th>All subjects (n = 17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal/d)</td>
<td>3051 ± 883</td>
<td>1979 ± 575</td>
<td>2484 ± 900</td>
</tr>
<tr>
<td>Vitamin D (µg/d)*</td>
<td>2.72 ± 4.63</td>
<td>2.47 ± 4.33</td>
<td>2.59 ± 4.33</td>
</tr>
<tr>
<td>Ca (mg/d)</td>
<td>1309 ± 761</td>
<td>704 ± 333</td>
<td>989 ± 637</td>
</tr>
<tr>
<td>Mg (mg/d)*</td>
<td>311.7 ± 245.3</td>
<td>228.5 ± 112.2</td>
<td>267.6 ± 185.6</td>
</tr>
<tr>
<td>P (mg/d)*</td>
<td>1326 ± 339</td>
<td>1034 ± 389</td>
<td>1172 ± 386</td>
</tr>
</tbody>
</table>

*Intake significantly different from the recommended dietary allowances (Vitamin D = 15 µg; Mg = 400 mg; P = 700 mg)

Table 3. Association between bone mineral density and lean soft tissue, and the role of magnesium.

<table>
<thead>
<tr>
<th>Model</th>
<th>Dependent</th>
<th>Independent</th>
<th>β</th>
<th>p-value</th>
<th>R²</th>
<th>R² change**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BMD†</td>
<td>LST</td>
<td>0.00001</td>
<td>0.042</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>BMD†</td>
<td>LST</td>
<td>0.00001</td>
<td>0.034</td>
<td>0.50</td>
<td>0.24 (p = 0.028)</td>
</tr>
<tr>
<td>3</td>
<td>BMD†*</td>
<td>LST</td>
<td>0.00001</td>
<td>&lt;0.001</td>
<td>0.77</td>
<td>0.51 (p = 0.034)</td>
</tr>
<tr>
<td></td>
<td>Mg</td>
<td></td>
<td>0.001</td>
<td>&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BMD: bone mineral density; LST: lean soft tissue
† Model adjusted for height (cm)
* Model adjusted for energy, vitamin D, Ca, and P intake records
** R² change comparing to 1st model

The low number of participants is a potential limitation. However, the inclusion criteria of this study restricted participants to elite athletes; the Portuguese swimmer population in Lisbon is relatively small, thus limiting the number of participants available.

Future research should explore the genetic variability for bone mineralization and muscle adaptations, and also other potential mechanisms that account for bone mineralization, using a larger sample of elite athletes. On the other hand, although it was not addressed in the present study, future investigations could include other potential dietary influences on bone health, including other vitamins, trace elements, electrolytes, acid-base balance, phyto-oestrogens, vegetarianism and lactose intolerance as it has been suggested that a healthy diet containing low sodium and high potassium levels, and more fresh fruits and vegetables may also be beneficial to bone health [23].

Summarizing, young elite swimmers may benefit from an adequate Mg intake, regarding its potential role in bone mineral mass accretion during growth.
Acknowledgments

We would like to express our gratitude to the athletes for their time and efforts.

Disclosure

Financial support: this work was supported by the Portuguese Foundation for Science and Technology (PTDC/DES/098963/2008) and by the Interdisciplinary Center for the Study of Human Performance (CIPER). Conflict of interest: none.

References


20. Food and Nutrition Board, Committee to Review Dietary Reference Intakes for Vitamin D and Calcium, DRI DIETARY REFERENCE INTAKES FOR Calcium, Phosphorus, Magnesium, Vitamin D, and

