Magnesium and phase angle: a prognostic tool for monitoring cellular integrity in judo athletes

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Abstract. Adequate magnesium (Mg) levels play a vital role in membrane excitability, cell contractility and metabolism, being a key nutrient for sustaining appropriate muscular contraction and performance levels in athletes. Phase angle (PhA), assessed by bioimpedance analysis (BIA), has been reported to be positively associated with most nutritional markers and is an indicator of membrane integrity and water distribution between intra- and extracellular spaces. The aim of the present study was to verify the association between Mg status and PhA as a predictor of cellular health, in a sample of judo athletes from a period of weight stability to prior to competition. Judo athletes (n = 20) from the national team were evaluated on two occasions: during a period when body weight was stable (M1), and prior to competition (M2). Changes between these occasions were calculated as M2-M1. PhA was obtained by bioelectrical impedance spectroscopy at a frequency of 50 KHz. Mg was measured in serum and red blood cells (RBC) by atomic absorption spectrophotometry, and Mg in the diet was assessed from a 24-h diet record over a seven-day period, after an assessment of body composition. Mean PhA did not differ from M1 to M2. However, individual changes in PhA were positively associated with individual changes in serum (r = 0.62, p = 0.004) and RBC Mg (r = 0.45, p = 0.048). This association was independent of weight changes between assessments, but when adjusted for Mg intake changes, only the association between PhA and serum Mg remained significant. These results highlight that in elite athletes PhA may be an indirect indicator of muscular function.

Key words: magnesium, phase angle, athletes, cellular health

Bioelectrical impedance analysis (BIA) is a rapid, safe, and non-invasive method for estimating body composition and nutritional status [1, 2]. Nevertheless, this method depends on predictive equations specific for each population [3]. Phase angle (PhA) is a measurement of interest obtained from BIA because it is independent of body height and weight, as it is calculated as the arctangent of the directly measured reactance-to-resistance ratio. PhA has been reported to be positively associated with most of the nutritional markers and an indicator of cell membrane integrity and...
water distribution between intra- and extracellular spaces [4, 5]. Recently it was found to be associated with muscle strength in hemodialysis patients [6], in cancer patients [7], and with handgrip strength and knee extension in elderly, nursing home residents [8]. It has been suggested that a lower PhA could be a useful predictor of impaired muscle function [6], and should be evaluated in routine assessment [7]. In athletes, PhA is useful for assessing function and hydration states [9]. Water pool distribution between the intra- and the extracellular compartments in athletes has been identified as an indicator of performance [10-12], accordingly PhA monitoring throughout the season might be very useful.

PhA is considered to be a useful prognostic tool as it represents either cell death or malnutrition, which are characterized by changes in cellular membrane integrity. A lower PhA appears to be consistent with cell death or a breakdown of the cell membrane, while a higher PhA is associated with large quantities of intact cell membranes and body cell mass [5]. Therefore, as magnesium (Mg) is so important for human physiology, with its concentration affecting membrane excitability, cell contractility, metabolism of energy rich compounds, and muscular contraction, and because of its key roles in the maintenance of membrane properties, adequate Mg levels are required to sustain appropriate performance levels. Stabilization of membranes by Mg is essential: in conditions of Mg deficiency, a loss of potassium, an increase in calcium and sodium in cells, as well as the release of creatine kinase and myoglobin can be observed. These observations are a consequence of increased membrane permeability. When the mitochondrial membrane is affected, the consequent disorders may induce the partial uncoupling of oxidative phosphorylation. Consequently, the production of ATP and reactive oxygen species are decreased and increased respectively. So, magnesium deficiency is likely to affect energy metabolism at muscular and extra-muscular levels. Muscle contraction stimulation, the activity of the calcium transport systems in the sarcoplasmic reticular membranes, and the allosteric regulation of troponin are also dependent on the presence of Mg [13-15]. Mg deficiency also leads to inflammation as Mg plays a key role in the immune response. Mg is a cofactor for immunoglobulin synthesis, immune cell adherence, IgM lymphocyte binding and macrophage response to lymphokines [16].

Different parameters of Mg nutritional status have been studied, and possible associations with exercise performance have been made over the years. The physiological processes involved in the impairment of physical performance by Mg deficiency have been reviewed by Lukaski and Nielsen [17]. In a review paper, Laires et al. [14] highlighted the importance of evaluating Mg status in athletes, not only because its deficit may compromise performance, but also because the practice of exercising with an Mg deficit might render the individual more susceptible to cellular damage.

Several studies involving athletes found that Mg greatly affects muscle performance, such as grip strength and muscle power [14, 15, 18, 19]. Dietary Mg deficiency impairs exercise performance and amplifies the negative consequences of strenuous exercise [20]. Matias et al. [18] observed an association between Mg status (serum, red blood cells and magnesium intake), and grip strength and muscle power. No information is available regarding the possible relationships between Mg status and PhA in athletes. Therefore, this study aimed to examine the association between Mg status and PhA, in a sample of judo athletes from a period of weight stability to prior to competition.

Methods and materials

Subjects

Twenty male judo athletes from the national Portuguese team participated in this study. The inclusion criteria for the athletes were: a) age ≥ 18 years, b) experience of a rapid weight reduction at least three times within the previous year, c) a minimum of five years of training, d) at least 15 hours of training per week, e) a minimum technical level of first degree black belt, f) negative anti-doping results, and g) currently not taking any medication or dietary supplements. All participants were informed about the possible risks of the investigation before giving their written consent. All procedures were approved by the Ethics Committee of the Faculty of Human Kinetics, University of Lisbon and were conducted in accordance with the declaration of Helsinki for human studies, of the World Medical Association [21].
Study design

All parameters were assessed at two distinct time points: during a period of weight stability (M1), and one to three days before competition (M2), with nearly one month separating M1 and M2.

Anthropometry

At each evaluation, all measurements were performed on the same day following a 12-hour fast. No alcohol or stimulant beverages were consumed, and none of the subjects had participated in any exercise within the 15 hours prior to evaluation. Subjects were weighed to the nearest 0.01 kg wearing a bathing suit, and without shoes (BOD POD©, COSMED, Rome, Italy). Height was measured (Seca, Hamburg, Germany) according to standardized procedures [22].

Body composition

To characterize the sample, % fat mass (%FM), total fat mass (FM), and fat-free mass (FFM) were determined by dual-energy X-ray absorptiometry (DXA) (Explorer W, Hologic, Waltham, USA, software version 12.4), according to standardized procedures [23].

Phase angle (PhA)

PhA was obtained using a bioelectrical impedance spectroscopy (BIS) analyzer (model 4000B, Xitron Technologies, San Diego, CA, USA). Participants adopted a supine position. Four electrodes were placed on the dorsal surfaces of the right hand and right foot, and whole body resistance and reactance were determined from a 5 kHz to 1 MHz spectrum.

BIS software is programmed to perform biophysical modeling on impedance data, which involves fitting the spectral data to the Cole-Cole model using nonlinear curve fitting [24]. This procedure generates Cole model terms (including Re - resistance associated with the ECW; Ri - resistance associated with the ICW; Cm - cell membrane capacitance; and exponent α), and additionally, by recording the voltage drop between the applied current and the two output sites, the phase shift is measured and the PhA calculated.

Magnesium

Mg was measured in red blood cells (RBC) [25] and in serum using atomic absorption spectrophotometry (GF95Z, Thermo Electron Corporation, S Series, AA Spectrometer, Massachusetts, USA). Additionally, Mg in the diet was assessed using a 24-h diet record over a seven-day period, after the assessment of body composition when subjects were also instructed regarding portion sizes, supplements, food preparation, and others aspects pertaining to an accurate recording of their intake. Diet records were analyzed by the software package Food Processor SQL (Salem, Oregon, version 10.5.0, 2009).

Statistical analysis

Descriptive statistics was applied to characterize the sample. All variables were checked for normality, using the Shapiro-Wilk test. Comparison of group means between both periods was performed using a paired sample t-test (or Wilcoxon’s test when normality was not observed). Bivariate correlations were performed to investigate the association between the PhA with the Mg parameters. Partial correlation analyses were additionally conducted to control for weight and magnesium intake changes. Data were analyzed with SPSS for Windows version 22.0 (SPSS Inc., an IBM Company, Chicago, IL, USA). For all tests, statistical significance was set at p<0.05.

Results

Participants’ characteristics, body composition, and magnesium levels during the period of weight stability and prior to competition are presented in table 1.

With the exception of RBC Mg that increased between assessments, none of the other variables changed significantly between the period of weight stability to prior to competition.

Serum Mg concentrations were within the normal range, (serum Mg 0.7-1.3 mmol/L), while mean Mg intake was lower than the Recommended Daily Allowance (400 mg/day) during the
Table 1. Athletes’ demographic characteristics, body composition and serum, RBC and diet magnesium, during a period of weight stability and prior to competition

<table>
<thead>
<tr>
<th></th>
<th>M1 - Period of weight stability</th>
<th>M2 - Prior competition</th>
<th>Differences*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>22.9 ± 2.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>73.0 ± 7.6</td>
<td>72.2 ± 7.3</td>
<td>-0.83 ± 2.17</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>174.5 ± 5.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23.9 ± 2.0</td>
<td>23.7 ± 1.9</td>
<td>-0.27 ± 0.72</td>
</tr>
<tr>
<td>Fat mass_DXa (kg)</td>
<td>8.2 ± 2.0</td>
<td>7.9 ± 1.7</td>
<td>-0.27 ± 0.93</td>
</tr>
<tr>
<td>Fat mass_DXa (%)</td>
<td>11.2 ± 2.0</td>
<td>11.0 ± 1.9</td>
<td>-0.21 ± 1.04</td>
</tr>
<tr>
<td>FFM_DXa (kg)</td>
<td>64.3 ± 6.2</td>
<td>63.7 ± 6.3</td>
<td>-0.58 ± 1.71</td>
</tr>
<tr>
<td>Phase angle (°)</td>
<td>7.78 ± 0.65</td>
<td>7.72 ± 0.52</td>
<td>-0.060 ± 0.499</td>
</tr>
<tr>
<td>Serum Mg (mmol/L)</td>
<td>0.89 ± 0.07</td>
<td>0.89 ± 0.08</td>
<td>-0.0005 ± 0.073</td>
</tr>
<tr>
<td>RBC Mg (mmol/100 g Hb)</td>
<td>1.21 ± 0.26</td>
<td>1.75 ± 0.23</td>
<td>0.534± 0.297</td>
</tr>
<tr>
<td>Diet Mg (mg/d)</td>
<td>337.0 ± 132.6</td>
<td>338.2 ± 143.3</td>
<td>1.14 ± 123.13</td>
</tr>
<tr>
<td>Energy intake (kcal/d)</td>
<td>2530.0 ± 700.5</td>
<td>2442.4 ± 830.1</td>
<td>-87.6 ± 840.0</td>
</tr>
</tbody>
</table>

Abbreviations BMI body mass index; FFM: fat-free mass; RBC: red blood cells; Hb: hemoglobin. *Differences are calculated as: prior to competition minus period of stability. #significant differences between assessments.

Discussion

A lower PhA appear to be consistent with either cell death or an increase in the fragility of the cell membranes, whereas a higher PhA is associated with large quantities of intact cell membranes and body cell mass [5]. An interpretation of the PhA as an index of membrane integrity and water pool distribution in athletes has been recently reported [9, 27]. The mean results of the PhA obtained in our study are in accordance with those reported by Koury [9] for judo athletes. Mg plays an important role in membrane excitability as well as in cell contractility and metabolism, being key to sustaining appropriate muscular contraction and performance levels, in elite athletes. The methodological approaches used to assess serum and RBC Mg may be a target of criticism, as they are not the best methodologies with which to assess Mg status in tissues, nevertheless, they are the most widely used techniques in athletes due to the non-invasive approach [20].

To our knowledge, only one investigation has demonstrated an association between PhA and Mg [28], using a peritoneal dialysis patients sample. Fein and colleagues concluded that a direct relationship exists between the two parameters, and that it may reflect the importance of maintaining a physiologically normal level of serum Mg in these patients [28]: chronic Mg deficiency is associated with multifocal cellular necrosis, accumulation of intracellular calcium, increased platelet aggregation, coronary vasoconstriction, atherogenesis, and cardiac arrhythmia. Conversely, Mg protects against the deleterious effects of reactive oxygen species and inhibits the calcium overload...
that occurs after reperfusion [29]. With this in mind, there may be a benefit to increasing Mg uptake. In order to control for Mg ingestion and its benefits in performance and health, routine PhA measurement should be encouraged, as this is a non-invasive method that works as an indicator of cellular health and integrity.

In our study, we observed a positive association between changes in PhA and changes in serum and RBC Mg levels. These results reinforce the previously reported information that PhA may be an indirect indicator of the inflammatory response and muscular function [4, 6]. The aforementioned associations between PhA and Mg status remained significant when adjusted for weight changes. This emphasizes the usefulness of PhA as a prognostic factor. However, although no differences were observed between the mean values of serum Mg, RBC Mg and PA, between athletes with adequate and inadequate Mg intakes, when adjusting for changes in Mg intake, the association with RBC Mg disappeared, suggesting that diet is a limiting factor for individual micronutrient achievement. This probably translates into an alteration of intracellular Mg status in the tissues and therefore of the general health status of the athlete. Despite the lack of evidence in the literature regarding the relationship between PhA and Mg status in athletes, it should be emphasized that our findings are consistent with growing evidence that PhA reflects a subject’s comprehensive nutritional status and quality of cellular life [4, 5]. In conclusion, within the scope of body composition assessment, our results highlight the important role of tracking PhA within an integrated evaluation of the state of health and performance of elite athletes.

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