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Precision of the Magnesium Determination in Mononuclear Blood Cells and Erythrocytes

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Objective: Establishing the analytical variation and reproducibility of the intracellular magnesium (Mg) assay in mononuclear blood cells (MBC) and erythrocytes (RBC).

Design and Methods: We assessed the analytical variation of the several determination steps, and the reproducibility for the complete intracellular Mg-assay (combination of preanalytical, analytical, and biological variation). The influence of platelets was determined by comparing Mg concentrations obtained from heparinized blood and defibrinated blood.

Results: Coefficients of variation of the several determination steps used in the MBC- and RBC-assay were ≤5.4%. The overall analytical variation was 5.0–6.8%, and reproducibility of the complete Mg-assay 11.6–14.0%. Mg measurements in MBC (expressed as fmol/cell) obtained from heparinized blood showed significantly higher values than those obtained from defibrinated blood.

Conclusion: This is the first study to describe in detail reproducibility data for the individual steps in the overall procedure to measure intracellular magnesium. It is shown that results obtained in daily practice should be interpreted with care. Moreover, the removal of platelets is essential in the determination of Mg in MBC.

KEY WORDS: intracellular; reproducibility; leucocytes; monocytes; magnesium deficiency.

Introduction

Magnesium in the human body is mainly located intracellularly (Mg_{intra}), and it is after potassium the second most abundant intracellular cation. Serum magnesium contributes for <1% to the total amount in the body and its function as a marker for magnesium deficiency is doubtful (1). Therefore, an increasing interest can be noticed in the measurement of its intracellular concentration. Muscle or bone biopsies seem to be good samples but are not suited for routine measurements. Mononuclear blood cells (MBC) and erythrocytes (RBC) are more easy to obtain, but opinions about the clinical impact of these Mg parameters are not uniform. However, for a good interpretation of the relevance of determining Mg_{intra}, the precision of all elements of the assay, including the preanalytical ones, first must be established. For example, a MBC suspension obtained from heparinized blood is often contaminated with platelets (2,3). Although several studies about the diagnostic value, and relation of Mg_{intra} to other Mg parameters already have been published, until now no thorough study about the precision of the whole assay of Mg_{intra} has been described. A few authors have presented results from reproducibility measurements, but those were confusing and not always complete (2,4–7). The studies of Urdal et al. (8) and Schwinger et al. (9) provided more interesting data, but did not cover all aspects either.

Therefore, we established the analytical variation of the magnesium determination in MBC (expressed as fmol/cell and as μmol/g protein) and RBC (fmol/cell and as μmol/g dry weight), by measuring the within-day and day-to-day reproducibility of the cell count, dry weight, Mg, and protein measurements. Moreover, the within-day and day-to-day reproducibility were assessed of the complete intracellular Mg-assay (combination of preanalytical, analytical, and biological variation) in MBC and RBC obtained from heparinized blood. Since this type of sample may lead to interference from thrombocyte Mg at the measurement in MBC, we compared Mg_{intra} results obtained from heparinized blood with those from defibrinated blood as well.

Material and methods

TECHNICAL PART

Blood samples, either 10 mL heparinized blood and/or 20 mL defibrinated blood, were obtained from healthy laboratory employees between 9 and 10 AM. Volunteers had their regular breakfast but did not
use Mg supplements. Evacuated 10 mL lithium heparin tubes (15 U/mL) were obtained from Terumo (Leuven, Belgium). Tubes to prepare defibrinated blood (evacuated 10 mL tubes containing 0.8 g polystyrene granules) were obtained from Becton Dickinson (Etten Leur, The Netherlands). After defibrination both heparinized blood and defibrinated blood were treated identically.

To isolate MBC and RBC from whole blood, the blood samples were diluted with an equal amount of a phosphate buffered-saline solution (PBS; Na 160 mmol/L, H2HPO4 1.3 mmol/L, HPO4 9.2 mmol/L, Cl 140 mmol/L), and layered over four tubes each containing 4 mL density gradient separation liquid (Lymphoprep, Nycomed, Norway). The tubes were centrifuged (400 × g, 10 min) and both the MBC and RBC fractions were pooled.

MBC were washed twice with PBS, and the final pellet was resuspended in 4.5 mL PBS. Of this, 0.5 mL was used for cell count and leucocyte differentiation. The remaining 4.0 mL MBC suspension was centrifuged (600 × g, 10 min), the pellet lysed with 1.0 mL distilled water, and stored at −20 °C until magnesium and protein were determined.

Of the isolated RBC 1.0 mL was washed three times with CsCl, 155 mmol/L, pH = 7.4 (600 × g, 10 min). For cell counting 100 μL was diluted with 400 μL PBS; 200 μL was lysed with 800 μL distilled water. The lysate was stored at −20°C until Mg and dry weight were determined.

Mg measurements of the cell lysates were performed by Atomic Absorption Spectrophotometry (PE2100, Perkin Elmer, Uberlingen, Germany). The protein concentration of the MBC lysate was measured photometrically using Coomassie Brilliant Blue (Microprot, Oxford Labware, USA). Cell count was performed by a Bayer-H3-system (Bayer, Tarrytown, NY, USA), and the dry weight of the RBC lysate was measured by evaporating water (95°C, 60 min) from 100 μL lysate in preheated and weighed 1.0 mL glass tubes.

**Experimental setup**

To assess both the analytical variation and the reproducibility of the complete intracellular Mg-assay (a combination of the preanalytical, analytical, and biological variation) in MBC and RBC, the following experiments were performed.

The **within-day analytical variation** (expressed as CV_within-day) was determined by drawing 10 tubes of heparinized blood from one healthy volunteer. Isolated cells were pooled and all measurements (Mg, protein, cell count, and dry weight) were performed 10 times.

The **day-to-day analytical variation** (expressed as CV_day-to-day) was calculated by subtracting the within-day analytical variation from the overall analytical variation (CV_all) (see Equation 2). The latter was determined by drawing ten tubes of heparinized blood from two healthy volunteers each. Isolated cells were pooled per volunteer, and divided into ten aliquots, which were measured every next 10 days, with a 2-day break between day 5 and day 6. Aliquots used for cell count of RBC were stored at +4 °C, and aliquots used for Mg, protein and dry weight determinations were stored at −20 °C. Because MBC cannot be stored, the overall analytical variation of the cell count of MBC was approximated by using a commercial control sample (Parameter Control Low, Baker BV, Deventer, The Netherlands).

The within-day reproducibility of the complete Mg-assay (expressed as CV_within-day) was determined by drawing ten tubes of heparinized blood from one healthy volunteers. All ten blood samples were worked up separately.

The day-to-day reproducibility of the complete Mg-assay (expressed as CV_day-to-day) was calculated by subtracting the within-day reproducibility from the overall reproducibility (CV_all) (see Equation 2). The latter was determined by drawing 1 tube of heparinized blood from two healthy volunteers each, during 10 days, with a 2-day break between day 5 and day 6. Cells were isolated immediately and all parameters were measured on the day of sampling. Comparison between the Mg concentration in MBC obtained from heparinized blood and defibrinated blood was performed by drawing 10 mL heparinized blood and 20 mL defibrinated blood from 17 healthy volunteers. Cells were isolated, lysed, and stored until all samples were collected.

**Calculations**

Mg in MBC was expressed as fmol/cell and μmol/g protein. Mg in RBC was expressed as fmol/cell and μmol/g dry weight.

Coefficient of variation (CV) of ten measurements was calculated as the standard deviation divided by the mean value. The CV of a ratioed unit (e.g., fmol/cell) was calculated as follows (10):

\[ CV_{\text{fmol/cell}} = \sqrt{CV_{\text{MgD}}^2 + CV_{\text{CC}}^2 + CV_{\text{MgD}}^2 \cdot CV_{\text{CC}}^2} \]  

with, MgD the Mg determination in the cell lysate and CC the cell count. The day-to-day analytical variation or reproducibility of the complete Mg-assay was calculated as follows:

\[ CV_{\text{day-to-day}} = \sqrt{CV_{\text{all}}^2 - CV_{\text{within-day}}^2} \]  

In case of experiments performed in duplicate, the calculated CVs were averaged.

Statistical analysis of the difference between the Mg_intra concentration in the two different sample types was performed by a paired t-test.

All procedures followed were in accordance with the rules laid down in the Helsinki Declaration of 1975, as revised in 1983.
MAGNESIUM DETERMINATION IN MBC AND RBC

TABLE 1
Review of the Analytical Variation of the Several Determination Steps of the Intracellular Mg-Assay

<table>
<thead>
<tr>
<th>Author</th>
<th>Mg within-day (%)</th>
<th>CC within-day (%)</th>
<th>Prot within-day (%)</th>
<th>Mg day-to-day (%)</th>
<th>CC day-to-day (%)</th>
<th>Prot day-to-day (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elin</td>
<td>3.0</td>
<td>8.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Martin</td>
<td>&lt;2.0</td>
<td>5–10</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schwinger</td>
<td>1.7a</td>
<td>1.7a</td>
<td>2.4b</td>
<td>2.0b</td>
<td>0.9a</td>
<td></td>
</tr>
<tr>
<td>Urdal</td>
<td>5.3e</td>
<td></td>
<td>11.0e</td>
<td></td>
<td>1.7b</td>
<td></td>
</tr>
<tr>
<td>Reinhart</td>
<td>3.64</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>This study</td>
<td>1.6e</td>
<td>2.6</td>
<td>1.7</td>
<td>4.4</td>
<td>1.3</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Mg = magnesium measurement; CC = cell count; Prot = protein measurement; DW = dry weight determination.

~Intraassay (n = 10).
\( ^{a} \)Interassay (n = 10).
\( ^{b} \)n = 12.
\( ^{d} \)n = 10.

Results

ANALYTICAL VARIATION

Within-day reproducibility measurements of the several determination steps of the Mg-assay resulted in CVs <2.7%. CVs of the day-to-day reproducibility were all <5.0%, with the exception of the dry weight determination (duplicate) of RBC, for which calculated mean CV was 5.4% (Table 1). From all measurements one result, the Mg concentration of the RBC lysate on day 7, was rejected. This value deviated more than 20% from the mean value based on the other nine concentrations.

Calculated CVs of the ratioed units based on the CVs of the numerator (Mg concentration in cell lysates) and denominator (cell count, protein concentration, or dry weight) are presented in Table 2. The overall CV of the analytical variation of the 4 Mg parameters ranges from about 5.5% to 6.8%.

REPRODUCIBILITY OF THE COMPLETE INTRACELLULAR MG-ASSAY

Results are presented in Table 2. The CV\textsubscript{within-day} of the Mg-assay in RBC was about 4.5%, and in MBC 8.0%. The CV\textsubscript{day-to-day} ranged from 9.0–11.5%, and the CV\textsubscript{all} was for both types of cells more or less comparable, 12%, with the exception of MBC (\( \mu \text{mol/g prot} \)) which CV\textsubscript{all} was found to be 14.0%.

HEPARINIZED BLOOD VERSUS DEFIBRINATED BLOOD

In Figures 1 and 2 the differences between the Mg concentration of MBC obtained from heparinized blood, and the Mg concentration of MBC obtained from defibrinated blood are plotted against the mean intracellular Mg concentration of these two different sample types (11). The results of a paired t-test are presented in the legend of each figure. When expressed as fmol/cell, 16 of the 17 heparinized blood samples resulted in a higher intracellular Mg concentration when compared with the simultaneously drawn defibrinated blood samples. This observation was found significant (p < 0.001). When expressed as \( \mu \text{mol/g prot} \) the mean difference between the two sample types was positive (4.6 \( \mu \text{mol/g prot} \)) too, but not significant.

Discussion

Since in clinical chemistry and medicine an increasing interest in the measurement of the Mg concentration of MBC and RBC can be observed,

TABLE 2
Analytical Variation and Reproducibility Results of the Complete Mg-Assay in Mononuclear Blood Cells and Erythrocytes

<table>
<thead>
<tr>
<th></th>
<th>Analytical Variation</th>
<th>Reproducibility of the Complete Mg-Assay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CV\textsubscript{within-day} (%)</td>
<td>CV\textsubscript{day-to-day} (%)</td>
</tr>
<tr>
<td>MBC (fmol/cell)</td>
<td>3.0</td>
<td>4.7</td>
</tr>
<tr>
<td>MBC (( \mu \text{mol/g prot} ))</td>
<td>2.3</td>
<td>5.2</td>
</tr>
<tr>
<td>RBC (fmol/cell)</td>
<td>2.6</td>
<td>4.3</td>
</tr>
<tr>
<td>RBC (( \mu \text{mol/g dry weight} ))</td>
<td>2.0</td>
<td>6.5</td>
</tr>
</tbody>
</table>

Presented CVs of the analytical variation are calculated according to Equations 1 and 2, based on the CV of ten Mg determinations, and the CV of ten determinations of the protein concentration, dry weight or cell count. CV\textsubscript{within-day} and CV\textsubscript{all} (both mean of two) representing the reproducibility of the complete Mg-assay are both based on ten complete Mg determinations, and CV\textsubscript{day-to-day} was calculated according to Equation 2.
knowledge of the precision of the technique is essential. Therefore, this study about the reproducibility of the used analytical methods as well as the complete Mg-assay was performed. Although reproducibility measurements about intracellular Mg-assays are scarce, some comparison with other authors is possible.

**ANALYTICAL VARIATION**

In Table 1 the reproducibility measurements of the several determination steps of the Mg-assay in MBC are compared with those from other authors. Elin et al. (4) reported a CV within day for the Mg measurement and cell count, which was much higher than our results, but the reported CV within day values of Martin et al. (2) and Schwinger et al. (9) corresponded better.

Urdal et al. (8) measured the Mg and protein concentration in MBC lysate on 12 different days. This resulted in an analytical CV day-to-day of 5.3% and 11%, respectively. As an average we found a comparable precision of the Mg determination in MBC lysate, but our mean CV day-to-day of the protein assay was much lower, 2.6%. The CV day-to-day of the Mg determination in stored MBC lysates reported by Schwinger et al. (9) was only 2.4%. However, this low value was presented as the interassay CV without further explanation.

The contribution of the within-day analytical variation of the ratioed unit to the total analytical variation was about half that of the day-to-day analytical variation (Table 2). Obtained values were comparable with the precision established by Deuster et al. (6) (CV 2.2%), who determined the within-run precision of the Mg-assay in RBC by six replicate analyses of one sample from six individuals.

Isolated MBC deteriorates during storage, which hampers cell counting of one sample on consecutive days. To overcome this problem we used a commercial control sample for establishing the CV of the cell count. After calculating the ratioed CV of the intracellular Mg concentration (fmol/cell) with Equation 1, and subtracting CV within day (Equation 2) we found a CV day-to-day of 1.3%. We realize that this solution of using a commercial control sample is not ideal and presumably leads to an underestimated precision of the cell count, 1.3% (CV day-to-day) versus 2.6% (CV within-day). However, Schwinger et al. (9) were able to present both intra-assay and interassay CVs of the cell count of lymphocytes 1.7% and 2.0%, respectively (see Table 1). Unfortunately, no information about storage conditions was given.

For the day-to-day analytical variation of the Mg-assay in MBC, expressed as μmol/g prot, we found a value much lower than Urdal et al. (8), 5.2% versus 16%. Based on their reported values of the precision of the Mg and protein assay (Table 1), we were not able to calculate a ratioed CV of 16%. Therefore, we think this high value was obtained by calculating the final intracellular Mg concentration (μmol/g prot) daily, and using these multiple results for establishing the CV day-to-day.

**REPRODUCIBILITY OF THE COMPLETE Mg-ASSAY**

As expected the CV within day is smaller than the CV day-to-day (Table 2). However, the CV day-to-day of
Figure 2 — Difference between Mg measurements in MBC obtained from heparinized and defibrinated blood. Mg concentration expressed as μmol/g protein. Paired t-test: t = 1.45, p < 0.16.

the Mg-assay in RBC is twice the CV_within-day, while the difference between CV_day-to-day and CV_within-day in MBC is only 1–3%. A possible explanation could be a very large contribution of the MBC isolation procedure to the inaccuracy, which is comparable for both the CV_within-day and CV_day-to-day. As a result the CV_within-day will be relative high (8%) and the difference between CV_within-day and CV_day-to-day of the Mg-assay in MBC reduced. In Table 3 our reproducibility measurements of the complete assay are compared with those of others. Reinhart et al. (5) determined the within-day reproducibility of the

**Table 3**

Review of Reproducibility Results of the Complete Mg-Assay in Mononuclear Blood Cells and Erythrocytes

<table>
<thead>
<tr>
<th>Author</th>
<th>MBC</th>
<th>RBC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CV_within-day (%)</td>
<td>CV_day-to-day (%)</td>
</tr>
<tr>
<td>Reinhart</td>
<td>3.0^a</td>
<td>22.0^e</td>
</tr>
<tr>
<td>Martin</td>
<td>8.8^b</td>
<td>12.0</td>
</tr>
<tr>
<td>Gallager</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>Schwinger</td>
<td>fmol/cell</td>
<td>3.7^c</td>
</tr>
<tr>
<td>Elin</td>
<td>fmol/cell</td>
<td>12.0^g</td>
</tr>
<tr>
<td>Urdall</td>
<td>fmol/cell</td>
<td>12.0^g</td>
</tr>
<tr>
<td>Deuster</td>
<td>μg/g Hb</td>
<td></td>
</tr>
<tr>
<td>This study</td>
<td>fmol/cell</td>
<td>8.1^i</td>
</tr>
<tr>
<td></td>
<td>μmol/g prot</td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>μmol/g dry weight</td>
<td>11.5</td>
</tr>
</tbody>
</table>

^a n = 10.
^b Duplicate analysis of samples from 24 subjects.
^c Two samples with an interval of 7 days from ten subjects.
^d Duplicate analysis of 15 specimens.
^e Ten identical samples taken from five persons, from which lymphocytes were isolated.
^f n = 5.
^g n = 9, and 32% when n = 12.
^h n = 12.
^i n = 6.
^j n = 10.

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Mg-assay in MBC (expressed as fg/cell), too. They made ten cell isolates on the same day and assayed those as ten separate specimens. In our opinion, their CV (3.0%) is very low. In our study, the within-day analytical variation was already 3.0%. Martin et al. (2) determined the CV\textsubscript{within-day} of the Mg-assay in MBC by drawing a second sample from the same subject later on the day. Gallager et al. (7) assessed the precision of the entire assay by duplicate analyses of 15 specimens.

The day-to-day reproducibility of the complete Mg-assay was more or less comparable for both types of cells (Table 2). Elin et al. (4) reported lower values (<5.0% and 6.0%), but also a very high CV within-day analytical variation was already 3.0%. Martin BJ, Lyon TDB, Walker W, Fell GS. Mononuclear blood cell magnesium in older subjects: evaluation of its use in clinical practice. Ann Clin Biochem 1993; 30: 23–7.


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