Comparison of Methods for Measurement of Na\(^+\)/Li\(^+\) Countertransport Across the Erythrocyte Membrane

To the Editor:

About 30% of patients with insulin-dependent diabetes mellitus develop diabetic nephropathy. Since diabetic nephropathy contributes to a large extent to the high mortality of these patients, a risk marker for the development of this condition is desirable. Increase in Na\(^+\)/Li\(^+\) countertransport across the red cell membrane has been suggested as such an early marker [1-4], although this was not uniformly confirmed [5-7]. In this study, the three main methods to load erythrocytes with Li\(^+\) were compared and tested for their measuring error and intra-subject variation of \(V_{\text{max}}\) and \(K_{0.5}\) for Na\(^+\).

The "classic" LiCl loading [8, 9] is the most "physiological" and non-invasive method. However, the loading procedure takes 3 h, which precludes the use of this method as a standard procedure. The Li\(_2\)CO\(_3\) loading as described by Elving et al. [6] has the advantage that it takes only 30 min to load the cells with Li\(^+\). The Li\(^+\) enters the cell via the HCO\(_3^-\)/Cl\(^-\) exchanger as a LiCO\(_3^-\) ion in exchange for a Cl\(^-\) ion, which explains the fast Li\(^+\) loading. This method has been reported to give the fast Li\(^+\) loading. This method has been reported to give plots to which Michaelis-Menten kinetics apply [10]. The nystatin method was developed by Canessa et al. [11] because at 150 mmol/L Na\(^+\) (the highest concentration that can be used at an osmolality of 300 mosmol/L), the extracellular binding site for Na\(^+\) is often not saturated. With nystatin, an antifungal drug that penetrates the plasma membrane, the intra- and extracellular osmolality can be raised to 600 mosmol/L, so extracellular concentrations of Na\(^+\) up to 300 mmol/L can be used. Because of this, \(K_{0.5}\) values can in principle be measured more accurately than with the other methods. We found, however, that even at this high Na\(^+\) concentrations the \(V_{\text{max}}\) of diabetic patients is often hardly reached.

Participants in this study were four male patients with insulin-dependent diabetes with diabetic nephropathy and four male healthy volunteers. The subjects had fasted overnight before a blood sample was taken.

The efflux media for the erythrocytes loaded with Li\(^+\) by using the LiCl or Li\(_2\)CO\(_3\) methods contained 0-150 mmol/L NaCl, 150-0 mmol/L choline chloride, 1 mmol/L MgCl\(_2\), 10 mmol/L Tris-3-(N-morpholino)propanesulfonic acid (MOPS) buffer pH 7.4, 10 mmol/L glucose, and 0.1 mmol/L ouabain. Na\(^+\) concentrations were 0, 10, 20, 40, 60, 80, 100, 120, and 150 mmol/L. The sum of the concentrations of Na\(^+\) and choline was always 150 mmol/L. The efflux media for the erythrocytes loaded with Li\(^+\) by using the nystatin method contained 0-300 mmol/L NaCl and 300-0 mmol/L choline chloride; the rest of the medium was the same. Used Na\(^+\) concentrations were 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 220, 240, 260, 280, and 300 mmol/L.

Here the sum of the concentration of Na\(^+\) and choline was always 300 mmol/L. Li\(^+\) concentrations were measured by atomic absorption spectrometry (Model 4100; Perkin-Elmer, Norwalk, CT). The \(V_{\text{max}}\) and \(K_{0.5}\) values were determined or extrapolated with the computer program Graphpad Inplot version 4.0 (Graphpad software, San Diego, CA). A rectangular hyperbola (binding isotherm) was fitted through the data. The following equation was used: \(V = A[Na^+] / (B+[Na^+])\); A = \(V_{\text{max}}\) B = \(K_{0.5}\).

From each subject a blood sample was taken twice, with a time interval of 1 month. The data were analyzed and the \(V_{\text{max}}\) and the \(K_{0.5}\) for Na\(^+\) were determined. \(R^2\) (coefficient of determination), a marker for the fit of the curve to Michaelis-Menten kinetics, was calculated. When the LiCl method was used, 25% of the \(R^2\) values were <0.7, which indicates a poor fit to Michaelis-Menten kinetics. There were no curves including Hill plots that fitted better. The nystatin method generated only one \(R^2\) value <0.7, and with the Li\(_2\)CO\(_3\) method all \(R^2\) values were >0.7. It is clear that the data obtained with the Li\(_2\)CO\(_3\) or nystatin method fit better to Michaelis-Menten kinetics than the data obtained with the LiCl method. This was a reason for us to continue with the methods involving Li\(_2\)CO\(_3\) and nystatin.

Next, the CV of the measuring error of the data obtained with the Li\(_2\)CO\(_3\) or nystatin Li\(^+\) loading methods was analyzed (with a paired t-test). At one day the same sample of blood was analyzed twice (Table 1). It was assumed that the difference was negligible between the "month-to-month variation within one sample" and the measuring error. It was further assumed that differences between two methods were statistically independent from each other, both between subjects and between months. For both methods the CV of the measuring error of the \(K_{0.5}\) for Na\(^+\) did not significantly differ from the measuring error of the \(V_{\text{max}}\) (nystatin \(P = 0.21\); Li\(_2\)CO\(_3\) \(P = 0.29\)). When the two methods are compared, there seems to be no important difference in the CV of the measuring error of the values for \(V_{\text{max}}\) or \(K_{0.5}\). For both methods the \(V_{\text{max}}\) difference between the values obtained with the nystatin and Li\(_2\)CO\(_3\) method was 0.6% (SD = 6.3, \(P = 0.79\)) and for the \(K_{0.5}\) for Na\(^+\) the difference was -5.3% (SD = 13.1, \(P = 0.29\)).

In addition, the intra-subject variation was examined (Table 1). A blood sample was taken three times, with intervals of 1 month. The samples were analyzed with both the Li\(_2\)CO\(_3\) and nystatin Li\(^+\) loading methods. For both methods the intra-subject variation for the \(K_{0.5}\) for Na\(^+\) was large. Table 1 shows that for all methods the \(V_{\text{max}}\) is more constant than the \(K_{0.5}\). For the nystatin, method comparison of the values for the CVs of \(V_{\text{max}}\) and \(K_{0.5}\) for Na\(^+\) gives a difference of 22.7% (SD = 19.9, \(P = 0.015\)) and for the Li\(_2\)CO\(_3\) method the difference was 12.6% (SD = 15.0, \(P = 0.05\)). From Table 1 it seems as if the variation of the \(V_{\text{max}}\) values obtained from one individual is smaller when the nystatin method is used, although this trend could not be supported statistically (\(P = 0.09\)).

Until recently the Na\(^+\)/Li\(^+\) countertransport activity was measured...
as the Li+ efflux rate in medium containing 150 mmol/L Na+ after subtraction of the efflux rate in Na+-free medium. LiCl was used to load erythrocytes. As a discriminatory value, 400 μmol Li+/L (μL/L red blood cells) (RBC)) was used. Subjects with a countertransport above this value were described as at risk. The values found for the mean Na+/Li+ countertransport at 150 mmol/L Na+ for the healthy individuals, when measured with the LiCl loading [mean 225 μmol Li+/(L/L RBC)] are below this cut-off value. The values obtained with the Li2CO3 method or the nystatin method are higher, although <400 μmol Li+/L (μL/L RBC) [260 and 312 μmol Li+/(μL/L RBC)]. For the whole group (diabetic and nondiabetic patients) the values for V150 are significantly different when two of the three methods are compared. The V150, however, has been criticized as a marker because it was reported that at 150 mmol/L Na+ the Vmax was often not reached. Our results confirm this. Measurement of Vmax and K0.5 for Na+ could give more reliable values. Moreover, as Rutherford et al. [22] already mentioned, any differences in V150 observed can be due to differences in either Vmax or K0.5.

In addition, changes in both the K0.5 and the Vmax have been reported [13,14]. If Vmax and K0.5 are to be used as risk markers, new cutoff values for abnormal Na+/Li+ counter-transport activity have to be established.

Both the Li2CO3 and nystatin loading methods result in higher values for K0.5 and Vmax than those obtained with the LiCl method (P <0.001). The reason for this is unknown. One possible explanation could be that loading with Cl means exchange of HCO3 for Cl− via the band 3 anion transporter. This could lead to pH changes in the erythrocyte, which could influence Na+/Li+ counter-transport. Elving et al., however, reported that after the washing cycles the intracellular HCO3 and Cl concentrations were identical in cells loaded with either Li2CO3 or LiCl [16]. Another possibility is that the optimal internal Li+ concentration is not reached in all experiments by this method.

Bisch et al. [15] already compared the LiCl method with the Li2CO3 method. In contrast to the present study, they found no difference in values for Vmax or K0.5. But they concluded that the Li2CO3 method was to be preferred because this method takes considerably less time. Zerbini et al. [16] compared the LiCl method with the nystatin method and they concluded that at 150 mmol/L NaCl the maximum activity is not always reached, and that therefore the nystatin loading method is to be preferred. But none of these studies compared all three methods or studied the measuring error and inasubject variation of the values obtained.

Hardman and Lant [17] and Wierzbicki [18] raised the question whether nystatin will be removed by washing. The fact that the mean values of our results obtained with both the nystatin and Li2CO3 method do not differ significantly from those obtained with the nystatin method (P = 0.21 and 0.08).

The values for Vmax and K0.5 for Na+ obtained with the LiCl method differed significantly from both the nystatin and Li2CO3 method; P <0.001 for the Vmax and P = 0.016 for K0.5 for Na+ when nystatin and LiCl are compared, P <0.001 for both the Vmax and the K0.5 when Li2CO3 and LiCl are compared.

Table 1. Measuring error and Intrasubject variation of K0.5 and Vmax when the nystatin loading or Li2CO3 loading method is used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Value</th>
<th>Mean (Median)</th>
<th>SD (95% confidence Interval)</th>
<th>Measuring error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vmax</td>
<td>540</td>
<td>68</td>
<td>8.1 (3.4-12.8)</td>
<td>7.7 (3.9-11.5)</td>
</tr>
<tr>
<td></td>
<td>(457)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K0.5</td>
<td>74</td>
<td>24</td>
<td>30.8 (15.1-45.1)</td>
<td>9.1 (4.0-14.2)</td>
</tr>
<tr>
<td></td>
<td>(76)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V150</td>
<td>378</td>
<td>70</td>
<td>16.6 (8.5-23.4)</td>
<td>7.1 (2.3-11.9)</td>
</tr>
<tr>
<td></td>
<td>(324)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vmax</td>
<td>533</td>
<td>127</td>
<td>18.4 (7.6-29.2)</td>
<td>7.1 (3.7-10.5)</td>
</tr>
<tr>
<td></td>
<td>(455)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K0.5</td>
<td>89</td>
<td>32</td>
<td>31.0 (19.4-42.6)</td>
<td>14.3 (6.8-21.8)</td>
</tr>
<tr>
<td></td>
<td>(76)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Li2CO3 V150</td>
<td>339</td>
<td>43</td>
<td>11.7 (4.9-18.5)</td>
<td>16 (1.6-7.2)</td>
</tr>
<tr>
<td></td>
<td>(292)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The P-values for the differences between the CI's were: " vs " P = 0.015; " vs " P = 0.21; " vs " P = 0.049; " vs " P = 0.09; " vs " P = 0.78; " vs " P = 0.58; " vs " P = 0.29. The mean values for Vmax, K0.5 for Na+, and V150 were 392, 43, and 311 respectively, when the LiCl method was used. The Vmax values and the values for K0.5 for Na+ obtained with the Li2CO3 method did not differ significantly from those obtained with the nystatin method (P = 0.21 and 0.08). The values for Vmax and K0.5 for Na+ obtained with the LiCl method differed significantly from both the nystatin and Li2CO3 method; P <0.001 for the Vmax and P = 0.016 for K0.5 for Na+ when nystatin and LiCl are compared, P <0.001 for both the Vmax and the K0.5 when Li2CO3 and LiCl are compared.
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References


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