Labile glycated haemoglobin and carbamylated haemoglobin are still critical points for HbA1c measurement

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Abstract

Introduction: Haemoglobin A1c (HbA1c) is a key analyte for the monitoring of glycemic balance in diabetic patients and is used for diabetes diagnosis in many countries. The potential interference of carbamylated haemoglobin (cHb) and labile glycated haemoglobin (LA1c) on HbA1c assays must remain a matter of vigilance. Such a situation has occurred in our laboratory with a kit replacement on the Bio-Rad Variant™ II testing system, a cation-exchange high performance liquid chromatography (HPLC) system. With this method, LA1c and cHb coeluted in a same peak which may have different consequences on HbA1c values.

Materials and methods: The influence of increasing LA1c and cHb values on HbA1c results was studied with in vitro glycation and carbamylation of samples. Samples from patients with high and normal blood urea concentrations were assayed by HPLC and immunological assay.

Results: We observed that the degree of interference greatly varied depending on the nature of the interfering Hb fractions found under the so-called “LA1c peak”. Thus, we have decided to apply a decision tree using “LA1c” thresholds depending on: (i) the retention time, (ii) the shape of the peak, (iii) other analytes, like urea. If the peak recognized as “LA1c” is mainly formed by LA1c, we consider that there is no interference until 4%. If the peak is mainly formed by cHb, we consider an interference threshold equal to 2%.

Conclusions: This situation reminds that cHb and LA1c remain critical issues in chromatography-based HbA1c assays and that adapted criteria must be set up for result interpretation.

Key words: carbamylated haemoglobin; labile glycated haemoglobin; HbA1c; analytical interference

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Introduction

Since its discovery as unusual haemoglobin fraction in patients with diabetes mellitus, HbA1c, the major component of glycated haemoglobin, has proved to be a useful analyte for the monitoring of glycemic balance in diabetic patients, and for diabetes diagnosis in many countries (1–3). HbA1c is also an important predictive marker of long term complications of diabetes (4,5). HbA1c assays can be performed using different analytical principles including separative methods such as high performance liquid chromatography (HPLC) and capillary electrophoresis, but also immunological and enzymatic methods.

The quality of assay methods for HbA1c determination has greatly improved over the last decades, and most of analytical interferences have been controlled (1,6). This is the case of carbamylated haemoglobin (cHb), which results from the binding of urea-derived isocyanic acid and is increased in patients with chronic kidney disease. However, the potential interference of cHb on HbA1c assays must remain of matter of vigilance (7,8). Furthermore, interference may be caused by labile glycated haemoglobin (LA1c), a labile and reversible fraction (Schiff base) formed at early stages of glyca-
tion reaction, which directly depends on blood glucose concentration. Such a situation is reported here.

We have recently changed the kit for HbA1c determination in our laboratory, by replacing the NU Kit™ by the Dual Kit Program™ on the Bio-Rad Variant™ II testing system, based on cation-exchange HPLC. The analyser used for determination of HbA1c is the same, but the chromatography program (column, buffer gradient) and the peak integration software (column, buffer gradient) are different. The main advantage of the method with the new kit is the possibility to use the same method for HbA1c, haemoglobin A2, and haemoglobin F measurements.

Most frequent interferences encountered with such HPLC-based methods have been evaluated (9). Whereas previous evaluations of this system did not report any interference studies (10), the instruction notes of the manufacturer mention a potential interference of cHb and LA1c over 3%. Using the Dual kit program™, LA1c and cHb coeluted in a same peak called LA1c, contrary to the former program NU Kit™ which allowed the separation in two peaks. As these two minor Hb fractions coelute in a single peak before HbA1c peak, the consequences on HbA1c value may differ according to the increased fractions (cHb or LA1c). Indeed, besides reporting the differences of chromatographic separation of cHb and LA1c between the two kits, the aim of this study was to evidence that the influence of cHb or LA1c on HbA1c measurements remains a critical issue and to propose a decision tree for managing these interferences in routine practice with this method.

**Materials and methods**

**Subjects**

This study was performed from September to October 2016 in the Laboratory of Pediatric Biology and Research at the University Hospital of Reims.

Blood samples used for this study were received in the routine workload of the laboratory for HbA1c assay as part of the follow-up of 19 patients. The interference noticed with the new kit was evidenced during regularly ordered HbA1c assays. No other biological investigation than HbA1c assay was performed, and additional experiments exclusively aimed at providing an interpretable HbA1c result in patients.

Among these samples, those from patients with physiological (< 7.15 mmol/L) or increased blood urea (> 7.15 mmol/L) were assayed by two methods (HPLC and immunological assay).

**Blood samples**

Blood samples sent to the laboratory for HbA1c assays using Variant II™ analyser were collected in 5 mL ethylenediamine tetra-acetic acid dipotassium salt (K2EDTA)-containing tubes (ref. 367962, Becton Dickinson, Franklin Lakes, New Jersey, USA) and stored at + 4°C before analysis. The minimum required volume, for the primary tube, was 1 mL. For DCA Vantage® analyser, 1µL of capillary blood, obtained by finger skin puncture or venous puncture (acceptable anticoagulants being K2EDTA, heparin, fluoride/oxalate and citrate) was required. Capillary holders, which contain glass capillary, are provided by Siemens in DCA™ Systems Hemoglobin A1c Reagent Kit.

For urea measurement, blood samples were collected on lithium heparin-containing tubes (ref. 367884, Becton Dickinson, Franklin Lakes, New Jersey, USA). The minimum required volume was 1 mL for primary tubes.

**Methods**

Blood urea was assayed on Cobas® 8000 modular analyser series on c701 and c502 modules (Roche Diagnostics, Mannheim, Germany). Determination of blood urea was based on kinetic test using urease and glutamate dehydrogenase.

Variant II Hemoglobin Testing System™ (Bio-Rad, Marnes-la-Coquette, France) is a completely automated system for HbA1c measurement based on cation-exchange HPLC. Samples are automatically mixed, diluted on the station and injected into the column. Haemoglobins are separated based on their ionic interactions with the stationary phase. The mobile phase is composed of phosphate buff-
Desmons A. et al. Interference of cHb and LA1c on HbA1c measurement

er; the chromatographic station delivers a gradient of increasing ionic strength to the cartridge. The separated haemoglobins pass through the flow cell of the filter photometer, and changes in the absorbance are measured at 415 nm, and at 690 nm for background correction.

Intra-assay coefficients of variation (CVs), calculated from patient samples, were 0.4%, 0.7% and 0.4% for HbA1c values (expressed in percentages) of 5.4%, 7.3% and 12.8%, respectively. Between-assay CVs, calculated from quality control results, Bio-Rad Lyphocheck Diabetes Controls (Bio-Rad Laboratories Inc, Hercules, CA, USA), were 1.1% and 1.3% for HbA1c values of 5.7% and 9.4%, respectively. Measurement uncertainties represented 0.27% and 0.38% for HbA1c values of 5.6% and 9.4%, respectively. Bio-Rad Lyphocheck Diabetes Controls were used as quality control (QC) materials and assayed at the beginning and at the end of each assay series. Between-assay CVs were 1.8% and 2.3% for expected values at 5.6% and 9.9% of HbA1c, respectively.

In the Dual kit program™, LA1c and cHb coeluted in a same peak called LA1c, contrary to the former program NU Kit™ which allowed the separation in two peaks. This peak, which elutes just before HbA1c peak, may represent a potential interference on HbA1c quantification.

 Procedures for in vitro carbamylation and glycation

Whole blood samples were selected according the following criteria: haematocrit value in reference ranges, low LA1c value (< 1.5%), and two HbA1c levels (within reference range and over 7%). Two mL of whole blood were centrifuged (4 °C, 8 minutes, 3000g), plasma removed, and three washes (4 °C, 8 minutes, 3000 x g) of red blood cells (RBC) performed with NaCl 0.15 M (saline). 200 µL of KCNO (Sigma-Aldrich, St Louis, Missouri, USA), prepared at different concentrations: 0.125 mM, 0.250 mM, 0.375 mM, 0.500 mM, 0.750 mM, were added and incubated for 3 hours at 37 °C. A control series was performed by incubating 200 µL KCl instead of KCNO. After centrifugation (room temperature (RT), 30 seconds, 20,000 x g), supernatant was removed and 2 washes were performed (RT, 30 seconds, 20,000 x g) with saline. 200 µL of saline were added, and HbA1c assayed on Variant II™ system.

Procedure for in vitro glycation

Two mL of whole blood were centrifuged (4 °C, 8 minutes, 3000 g), plasma removed, and three washes of RBC performed with saline. 200 µL of 0.250 mM glucose (alpha-D-glucose anhydrous 96%; Sigma-Aldrich, St Louis, Missouri, USA) solution in saline were added to RBC pellet and incu-
bated for 0, 15, 17, 22, 27, 30, 45 minutes at 37 °C. After centrifugation (RT, 30 seconds, 20,000 x g), supernatant was removed and replaced by 200 µL of 5 mM glucose, and HbA1c assayed on Variant II™ system.

Statistical analysis

In vitro glycation or carbamylation experiments were analysed in triplicate. Results were expressed as means.

Relative and absolute biases were obtained with following formulas:

\[
\text{Relative bias} = \left( \frac{x - y}{y} \right) \times 100
\]

Relative bias = x – y

where \( x = \) HbA1c measured with Variant II™ analyser and \( y = \) HbA1c measured with DCA Vantage® analyser.

Uncertainty measurement (U) was calculated using the following formulas:

\[
U = 2 \times u(C)
\]

\[
u(C) = \sqrt{u^2(IQC) + u^2(EQE)}
\]

\[
u(IQC) = \frac{CV \times m}{100}
\]

\[
u(EQE) = \sqrt{\left( \frac{|\bar{E}|}{\sqrt{3}} \right)^2 + \hat{\sigma}_E^2}
\]

\[
\hat{\sigma}_E^2 = \frac{\sum (E_i - \bar{E})^2}{n - 1}
\]

\[
\bar{E} = \frac{\sum (x_{lab} - x_{ref})i}{n}
\]

\[
E_i = (x_{lab} - x_{ref})
\]

where IQC represents internal quality control, EQE external quality control, CV coefficient of variation, \( m \) represents the mean; \( x_{lab} \) laboratory result; \( x_{ref} \) reference value.

The measurement uncertainty of the Variant II™ system, calculated with the above formulas and equal to 0.3%, was used as a threshold to determine a significant difference between HbA1c results.

Results

First, we studied the influence of increasing LA1c values on HbA1c results, and showed that the increase of LA1c peak led to a decrease of HbA1c values (Table 1), the threshold of 0.3% being used as acceptance criterion to determine a significant difference between HbA1c results. Thus, a significant interference was noticed when LA1c exceeded 4%. Second, we studied the influence of chb interference and found a significant interfering effect when chb exceeded 2% (Table 2).

Thus, both LA1c and chb interfered with HbA1c determination, but it was noteworthy that the influence of the peak recognized as LA1c on chromatogram depended on the nature of the interference. When the interference was caused by chb, HbA1c decrease was more prominent than when caused by LA1c. For example, for an initial level of HbA1c equal to 5.2% (33 mmol/mol) with a LA1c peak at 1.2%, the increase of LA1c peak to 3.4 % due to glycation (LA1c increase) led to a decrease of HbA1c value to 4.9% (30 mmol/mol), whereas it was 4.4% (25 mmol/mol) when the interference was due to carbamylation (chb). Similar results were found using a sample with initial HbA1c value of 8.1% (65 mmol/mol): a decrease of HbA1c to a value at 7.7% (61 mmol/mol) was observed for a chb value of 2.2% whereas it was observed only at 4.6% of LA1c (Tables 1 and 2). The impact of chb and LA1c on the HbA1c measurements (Tables 1 and 2) was also highlighted using a graphical presentation (Figure 1).

Interestingly, we observed that chromatograms differed regarding retention time (higher for chb than for LA1c) and peak shape depending on the origin of the interference (LA1c or chb), even though the peak was only recognized as LA1c by the software (Figure 2).
Desmons A. et al. Interference of cHb and LA1c on HbA1c measurement

<table>
<thead>
<tr>
<th>Incubation time (min) with 0.25 mol/L glucose</th>
<th>0</th>
<th>15</th>
<th>17</th>
<th>22</th>
<th>27</th>
<th>30</th>
<th>45</th>
</tr>
</thead>
<tbody>
<tr>
<td>HbA1c†, mmol/mol</td>
<td>33</td>
<td>31</td>
<td>30</td>
<td>30</td>
<td>28</td>
<td>27</td>
<td>25</td>
</tr>
<tr>
<td>HbA1c†, %</td>
<td>5.2</td>
<td>5.0</td>
<td>4.9</td>
<td>4.9</td>
<td>4.7*</td>
<td>4.6*</td>
<td>4.4*</td>
</tr>
<tr>
<td>Peak recognized as «LA1c», %</td>
<td>1.2</td>
<td>3.1</td>
<td>3.4</td>
<td>4.0</td>
<td>4.0</td>
<td>4.5</td>
<td>4.8</td>
</tr>
<tr>
<td>HbA1c†, mmol/mol</td>
<td>65</td>
<td>64</td>
<td>64</td>
<td>62</td>
<td>61</td>
<td>60</td>
<td>56</td>
</tr>
<tr>
<td>HbA1c†, %</td>
<td>8.1</td>
<td>8.0</td>
<td>8.0</td>
<td>7.8</td>
<td>7.7*</td>
<td>7.6*</td>
<td>7.3*</td>
</tr>
<tr>
<td>Peak recognized as «LA1c», %</td>
<td>1.3</td>
<td>3.1</td>
<td>3.4</td>
<td>4.0</td>
<td>4.6</td>
<td>4.8</td>
<td>6.2</td>
</tr>
</tbody>
</table>

* Differences higher than 0.3% compared to initial value of HbA1c. † Mean of triplicate measurements.

Table 1. Interference of labile glycated hemoglobin (LA1c) on HbA1c measurements by Variant II equipped with Dual kit program™

<table>
<thead>
<tr>
<th>3h-incubation with KCNO (mmol/L)</th>
<th>0.000</th>
<th>0.125</th>
<th>0.250</th>
<th>0.375</th>
<th>0.500</th>
<th>0.750</th>
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<td>HbA1c†, mmol/mol</td>
<td>33</td>
<td>32</td>
<td>31</td>
<td>30</td>
<td>28</td>
<td>25</td>
</tr>
<tr>
<td>HbA1c†, %</td>
<td>5.2</td>
<td>5.1</td>
<td>5.0</td>
<td>4.9</td>
<td>4.7*</td>
<td>4.4*</td>
</tr>
<tr>
<td>Peak recognized as «LA1c», %</td>
<td>1.2</td>
<td>1.4</td>
<td>1.7</td>
<td>2.1</td>
<td>2.5</td>
<td>3.4</td>
</tr>
<tr>
<td>HbA1c†, mmol/mol</td>
<td>65</td>
<td>64</td>
<td>61</td>
<td>59</td>
<td>55</td>
<td>50</td>
</tr>
<tr>
<td>HbA1c†, %</td>
<td>8.1</td>
<td>8.0</td>
<td>7.7*</td>
<td>7.5*</td>
<td>7.2*</td>
<td>6.7*</td>
</tr>
<tr>
<td>Peak recognized as «LA1c», %</td>
<td>1.3</td>
<td>1.6</td>
<td>2.2</td>
<td>2.8</td>
<td>3.5</td>
<td>4.8</td>
</tr>
</tbody>
</table>

* Differences higher than 0.3% compared to initial value of HbA1c. † Mean of triplicate measurements.

Table 2. Interference of carbamylated hemoglobin (cHb) on HbA1c measurements by Variant II equipped with Dual kit program™

To go further into the investigation of the impact of cHb on HbA1c measurements, we performed a comparison between HbA1c values obtained with the Dual Kit Program™ (Bio-Rad) device and with the immunoassay-based DCA Vantage® (Siemens Healthcare) which is not influenced by cHb (11). Because uraemia is the main cause of increased carbamylation (12), and consequently of cHb formation, samples from 7 patients with increased blood urea (> 7.15 mmol/L) were assayed by both methods. Negative absolute and relative biases were evidenced in all samples with increased blood urea. Mean relative and absolute biases calculated were - 8.2% and - 5 mmol/L (- 0.5%), respectively (Table 3). By contrast, a similar comparison performed in samples from patients without hyperuricaemia (urea < 7.15 mmol/L) showed mean relative and absolute biases equal to + 0.9% and +1.1 mmol/mol (+ 0.1%) respectively (Table 4).

Discussion

Because HbA1c is widely used for the diagnosis of diabetes and the monitoring of diabetic patients, its quantification must be performed using robust and high quality methods (2). HPLC is commonly used for assaying HbA1c and the potential interferences, like those generated by LA1c and cHb, have generally been well described. However, these additional Hb fractions may still cause unexpected interferences (7,8,13). A previous study investigating the influence of cHb to HbA1c measurements by Bio-Rad Variant II™ analyser equipped with NU Kit™ did not evidence such an impact of cHb but recommended an interpretation with caution when cHb was increased (14).

Using the Dual kit program™, LA1c and cHb coeluted in a same peak called LA1c, contrary to the former program NU Kit™ which allowed the separation in two peaks. This peak which elutes just before HbA1c peak could represent a potential interference on HbA1c quantification.
Desmons A. et al. Interference of cHb and LA1c on HbA1c measurement.

Figure 1. Interference of LA1c (A) and cHb (B) on HbA1c measurement by Variant II equipped with Dual Kit Program™. For each interference, two samples with different levels of HbA1c (5.2% and 8.1%) have been tested. The dashed lines represent the values above which the differences have been considered significant (initial HbA1c values ± 0.3%, which corresponds to the measurement uncertainty of the method).

Figure 2. Chromatograms obtained in case of an increase of the “LA1c peak” due to A: LA1c (elution time: 0.63 min) or B: cHb (elution time: 0.71 min).
In this study, we have evidenced that although migrating under the same peak; both LA$_{1c}$ and cHb interfered differentially with HbA$_{1c}$ measurements. Indeed, the degree of interference greatly varied depending on the nature of the interfering Hb fractions found under the so-called “LA$_{1c}$ peak”. In the case of the present method, manufacturer recommendations indicated the absence of interference of the peak recognized as LA$_{1c}$ fewer than 3%. Our study evidenced that a significant interference was noticed when LA$_{1c}$ exceeded 4% and found a significant interfering effect when cHb exceeded 2%. This interference caused by cHb could lead to underestimate the value of HbA$_{1c}$ and have an impact on clinical classifications based on HbA$_{1c}$ thresholds, or even on patient management (15).

Thus, we have decided to apply different thresholds depending on the nature of the interference, according to decision tree shown in Figure 3. For differentiating the origin of the interference, we consider (i) the retention time, (ii) the shape of the peak, and (iii) other biological results, especially uraemia. If the peak recognized as “LA$_{1c}$” is mainly formed by LA$_{1c}$ we consider that there is no interference until 4% of LA$_{1c}$. When LA$_{1c}$ is increased

### Table 3. Comparison of HbA$_{1c}$ results obtained using Variant II Dual kit program and DCA Vantage in patients with hyperuraemia

<table>
<thead>
<tr>
<th>Patient</th>
<th>HbA$_{1c}$ mmol/mol (%)</th>
<th>HbA$_{1c}$ mmol/mol (%)</th>
<th>Relative bias, %</th>
<th>Absolute bias, mol/mol (%)</th>
<th>Blood urea, mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>31 (5.0)</td>
<td>40 (5.8)</td>
<td>-13.7</td>
<td>-9 (-0.8)</td>
<td>27.8</td>
</tr>
<tr>
<td>Patient 2</td>
<td>53 (7.0)</td>
<td>58 (7.5)</td>
<td>-6.6</td>
<td>-5 (-0.5)</td>
<td>25.0</td>
</tr>
<tr>
<td>Patient 3</td>
<td>38 (5.6)</td>
<td>42 (6.0)</td>
<td>-6.6</td>
<td>-4 (-0.4)</td>
<td>15.3</td>
</tr>
<tr>
<td>Patient 4</td>
<td>55 (7.2)</td>
<td>58 (7.5)</td>
<td>-4.0</td>
<td>-3 (-0.3)</td>
<td>29.0</td>
</tr>
<tr>
<td>Patient 5</td>
<td>27 (4.6)</td>
<td>33 (5.2)</td>
<td>-11.5</td>
<td>-5 (-0.6)</td>
<td>9.0</td>
</tr>
<tr>
<td>Patient 6</td>
<td>30 (4.9)</td>
<td>34 (5.3)</td>
<td>-7.6</td>
<td>-4 (-0.4)</td>
<td>30.9</td>
</tr>
<tr>
<td>Patient 7</td>
<td>44 (6.2)</td>
<td>48 (6.7)</td>
<td>-7.5</td>
<td>-4 (-0.5)</td>
<td>24.0</td>
</tr>
<tr>
<td><strong>Mean biases</strong></td>
<td></td>
<td></td>
<td>-8.2</td>
<td>-5 (-0.5)</td>
<td></td>
</tr>
</tbody>
</table>

* Determined using Variant II. † Determined using DCA Vantage.

### Table 4. Comparison of HbA$_{1c}$ results obtained using Variant II Dual kit program and DCA Vantage in non-uraemic patients

<table>
<thead>
<tr>
<th>Patient</th>
<th>HbA$_{1c}$ mmol/mol (%)</th>
<th>HbA$_{1c}$ mmol/mol (%)</th>
<th>Relative bias, %</th>
<th>Absolute bias, mol/mol (%)</th>
<th>Blood urea, mmol/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>37 (5.5)</td>
<td>37 (5.5)</td>
<td>0.0</td>
<td>0 (0.0)</td>
<td>4.2</td>
</tr>
<tr>
<td>Patient 2</td>
<td>88 (10.2)</td>
<td>79 (9.4)</td>
<td>8.5</td>
<td>9 (0.8)</td>
<td>7.0</td>
</tr>
<tr>
<td>Patient 3</td>
<td>50 (6.7)</td>
<td>46 (6.4)</td>
<td>4.7</td>
<td>4 (0.3)</td>
<td>7.0</td>
</tr>
<tr>
<td>Patient 4</td>
<td>34 (5.3)</td>
<td>34 (5.3)</td>
<td>0.0</td>
<td>0 (0.0)</td>
<td>7.0</td>
</tr>
<tr>
<td>Patient 5</td>
<td>58 (7.5)</td>
<td>57 (7.4)</td>
<td>1.4</td>
<td>1 (0.1)</td>
<td>7.0</td>
</tr>
<tr>
<td>Patient 6</td>
<td>53 (7.0)</td>
<td>53 (7.0)</td>
<td>0.0</td>
<td>0 (0.0)</td>
<td>5.4</td>
</tr>
<tr>
<td>Patient 7</td>
<td>37 (5.5)</td>
<td>39 (5.7)</td>
<td>-3.5</td>
<td>-2 (-0.2)</td>
<td>5.7</td>
</tr>
<tr>
<td>Patient 8</td>
<td>41 (5.9)</td>
<td>41 (5.9)</td>
<td>0.0</td>
<td>0 (0.0)</td>
<td>7.1</td>
</tr>
<tr>
<td>Patient 9</td>
<td>40 (5.8)</td>
<td>42 (6.0)</td>
<td>-3.3</td>
<td>-2 (-0.2)</td>
<td>7.1</td>
</tr>
<tr>
<td>Patient 10</td>
<td>62 (7.8)</td>
<td>61 (7.7)</td>
<td>1.3</td>
<td>1 (0.1)</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Mean biases</strong></td>
<td></td>
<td></td>
<td>+0.9</td>
<td>+1.1 (+0.1)</td>
<td></td>
</tr>
</tbody>
</table>

* Determined using Variant II. † Determined using DCA Vantage.
over 4%, this fraction is eliminated by incubation of red blood cells for 30 minutes at 37 °C, according to a previously described procedure (16). If the peak is mainly formed by cHb, we consider a lower interference threshold of 2%. When cHb values are higher than 2%, as cHb cannot be eliminated, we do not release values obtained by the HPLC method and perform HbA1c assay using an immunological method, such as on DCA Vantage® System, not influenced by cHb.

**Conclusion**

This article reminds that cHb remains a critical issue in chromatography-based HbA1c assays. The experimental verifications performed upon implementation of the method in our laboratory led us to change our practice, considering the coelution in a single peak of LA1c and cHb. For that reason, the use of different thresholds (2% or 4% of LA1c peak) has been established in our daily practice.

**Potential conflict of interest**

None declared.

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4. The Diabetes Control and Complications Trial Research Group. The effect of intensive treatment of diabetes on the development and progression of long-term


