Silent haemoglobin variants and determination of HbA\textsubscript{1c}
with the HPLC Bio-Rad Variant II

T Lahousen, R E Roller, R W Lipp, W J Schnedl

ORIGINAL ARTICLE

In patients with diabetes glycated haemoglobin, measured as HbA\textsubscript{1c}, is used for evaluating long term control of the disease. Glycated haemoglobin is the result of irreversible non-enzymatic glycation at one or both N-terminal valines of the haemoglobin \(\beta\) chain. The extent of glycation and the relative involvement of the \(\alpha\) and \(\beta\) chains of haemoglobin remain unclear.\(^1,2\) HbA\textsubscript{1c}, is expressed as the percentage of total haemoglobin, although the value of the total is (when all glycated sites are included) approximately 50% higher than HbA\textsubscript{1c} alone. Depending on the determination method used the concentration of HbA\textsubscript{1c} is approximately 4–6% in healthy patients without diabetes. Glycated haemoglobin most accurately reflects the previous two to three months of glycaemic control. In clinical practice, the measurement of HbA\textsubscript{1c} is required every three to six months to determine whether the patient’s metabolic control has remained continuously within the target range.\(^3\)

“All possible and all known interference caused by haemoglobin variants needs to be evaluated for each single HbA\textsubscript{1c} determination method”

Despite advances in the standardisation of methods for glycohaemoglobin determination an increasing number of haemoglobinopathies have been reported to cause false HbA\textsubscript{1c} results.\(^4\) Although several methods based on different principles (high performance liquid chromatography (HPLC), immunoagglutination, boronate affinity assays, and electrophoresis) have been developed,\(^5\) the designated DCCT comparison method is a cation exchange HPLC (Diamat; Bio-Rad, Richmond, California, USA).\(^5\) The measurement of glycated haemoglobin is interfered with by non-glucose adducts, such as carbamylation in uraemia,\(^6\) aspirin, penicillin, and metabolites occurring in alcoholism, which may attach to the haemoglobin.\(^7\) Samples with variant haemoglobins or those that contain compounds that are known to interfere with the measurement of HbA\textsubscript{1c} are specifically excluded from certification testing, and there are no specific guidelines or requirements for comparability of samples containing haemoglobin variants.\(^8\) Nevertheless, all possible and all known interference caused by haemoglobin variants needs to be evaluated for each single HbA\textsubscript{1c} determination method.\(^9\)

We describe the interference caused by Hb Graz, Hb Sherwood Forest, Hb O Padova, and Hb D in the determination of glycated haemoglobin with the automated HPLC Bio-Rad Variant II using the high resolution \(\beta\) thalassaemia programme.

MATERIALS AND METHODS

The blood samples were collected in EDTA anticoagulation bottles and sent cooled at 4°C, by fast mail to the Bio-Rad Laboratories in Munich, Germany. Determinations of HbA\textsubscript{1c} were performed within three days. The fully automated HPLC Variant II (Bio-Rad Laboratories, Munich, Germany) was used with the high resolution \(\beta\) thalassaemia programme (figs 1–3). If interference by haemoglobin variants is assumed, the Variant II dual kit allows fast switching between the routinely used 3.5 minute haemoglobin A\textsubscript{1c} programme and the extended 6.5 minute \(\beta\) thalassaemia programme without changing reagents or cartridges. As a second HPLC method the Hi-Auto A\textsubscript{1c} HA-8140 (Menarini, Florence, Italy) was used. The immunoagglutination method used was the DCA 2000 (Bayer, Vienna, Austria), which uses a specific antibody against the first six amino acid residues of the glycated N-terminal of haemoglobin. Here we describe HbA\textsubscript{1c} determinations in two patients with type 2 diabetes and the \(\beta\) chain variant Hb Graz (\(\alpha\),2(NA2) His → Leu), a patient without diabetes but with \(\beta\) chain variant Hb Sherwood Forest (\(\alpha\),104(G6) Arg → Thr), two patients (one without diabetes and one with type 1 diabetes) with \(\alpha\)-chain variant Hb O Padova (\(\beta\),30(B11) Glu → Lys), and a patient with type 2 diabetes with \(\beta\) chain variant HbD (\(\alpha\),121(GH4) Glu → Gln).\(^10\) Amino acid analysis and DNA sequence analysis were performed as described previously and the routine haematologial data of all patients were within the normal range.\(^11\) Fasting blood glucose was determined with a hexokinase/glucose-6-phosphate dehydrogenase colorimetric method (Gluco-Quant; Roche, Vienna, Austria) and fructosamine was determined with a colorimetric test using nitroblue tetrazolium in alkaline solution (Unimate FRA; Roche). All determinations were analysed blindly and the procedures were in accordance with the Declaration of Helsinki and the local ethics committee recommendations.

Abbreviations: HbA\textsubscript{1c}, glycated haemoglobin; Hb, haemoglobin; HPLC, high performance liquid chromatography

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RESULTS

In the two patients with type 2 diabetes and Hb Graz the chromatogram from the Bio-Rad Variant II using the high resolution β thalassaemia programme showed that Hb Graz migrates with fetal haemoglobin and labile HbA1c (LA1c), overlapping HbA1c, as shown in the analysis data (fig 1). No result was given for HbA1c determination in both patients with Hb Graz (fig 1). The determination of HbA1c with the HPLC Menarini described the results as “abnormal separation” and the immunoagglutination method DCA 2000 showed values

![Chromatogram](image)

**Figure 1** Chromatogram from the ion exchange high performance liquid chromatography Bio-Rad Variant II using the high resolution β thalassaemia programme in a patient with diabetes and the Hb Graz variant.

**Table 1** HbA1c results in patients with haemoglobin (Hb) variants

<table>
<thead>
<tr>
<th>Haemoglobin variant</th>
<th>HbA1c</th>
<th>Fructosamine</th>
<th>Fasting blood glucose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-diabetic reference range</td>
<td>4.7–6%</td>
<td>&lt;285 µmol/l</td>
<td>&lt;6.1 mmol/l</td>
</tr>
<tr>
<td>Hb Graz 1</td>
<td>No result</td>
<td>Abnormal sep</td>
<td>5.9</td>
</tr>
<tr>
<td>Hb Graz 2</td>
<td>No result</td>
<td>Abnormal sep</td>
<td>5.2</td>
</tr>
<tr>
<td>Hb Sherwood Forest</td>
<td>No result</td>
<td>Abnormal sep</td>
<td>4.6</td>
</tr>
<tr>
<td>Hb D</td>
<td>4.8</td>
<td>9.1 (variant Hb)</td>
<td>5.7</td>
</tr>
<tr>
<td>Hb O Padova 1</td>
<td>4.9</td>
<td>6.8 (variant Hb)</td>
<td>4.5</td>
</tr>
<tr>
<td>Hb O Padova 2</td>
<td>9.5</td>
<td>10 (variant Hb)</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Variant II, HPLC variant II (Bio-Rad); HA-8140, HPLC high-auto A1c HA-8140 (Menarini); DCA 2000, immunoagglutination DCA 2000 (Bayer); Abnormal sep, abnormal separation; variant Hb, variant haemoglobin.

HPLC, high performance liquid chromatography.

**RESULTS**

In the two patients with type 2 diabetes and Hb Graz the chromatogram from the Bio-Rad Variant II using the high resolution β thalassaemia programme showed that Hb Graz migrates with fetal haemoglobin and labile HbA1c (LA1c), overlapping HbA1c, as shown in the analysis data (fig 1). No result was given for HbA1c determination in both patients with Hb Graz (fig 1). The determination of HbA1c with the HPLC Menarini described the results as “abnormal separation” and the immunoagglutination method DCA 2000 showed values.
within the non-diabetic reference range for both patients with diabetes (table 1).

In the patient without diabetes with the Hb Sherwood Forest variant the chromatogram from the Bio-Rad Variant II using the high resolution \( \beta \) thalassaemia programme demonstrated an additional peak with HbA1c. No HbA1c result was given in the analysis data (fig 2). The result of HbA1c determination with the HPLC Menarini was “abnormal separation” and the immunoagglutination method DCA 2000 showed a value within the non-diabetic reference range for this patient without diabetes (table 1).

In the two patients (one without diabetes and one with type 1 diabetes) who had the Hb O Padova variant the chromatogram from the Bio-Rad Variant II using the high resolution \( \beta \) thalassaemia programme demonstrated an additional late (at four minutes) migrating peak (fig 3). In the patient without diabetes the result for HbA1c was within the non-diabetic reference range and compared well with values of fasting blood glucose and fructosamine (table 1). In the patient with type 1 diabetes, the result was above the non-diabetic reference range, indicating (in agreement with the fructosamine result) that blood glucose regulation was unsatisfactory. The determinations of HbA1c with the HPLC Menarini gave results as “variant haemoglobin” and the immunoagglutination method DCA 2000 showed values within the non-diabetic reference range for this patient (table 1).

### DISCUSSION

Most mutations in the globin genes of haemoglobin are a single base pair change in the DNA code, resulting in an amino acid substitution. More than 700 haemoglobin variants are known and about half of these variants are clinically silent like the ones investigated in our study. Methods to determine HbA1c include cation exchange HPLC, boronate affinity,
electrophoresis, and immunoassays. The first clinically useful cation exchange chromatographic method for HbA1c determination was published in 1978. Haemoglobin A1c was originally a term for an ion exchange chromatographic peak and is now defined as irreversibly glycated haemoglobin molecules at one or both N-terminal valines of the β chains. Here, we describe the interference of Hb Graz, Hb Sherwood Forest, Hb O Padova, and Hb D in the determination of HbA1c with an extended automated HPLC method modification, namely the Bio-Rad Variant II high resolution β thalassaemia 6.5 minute programme, which was developed to measure HbA2 in the diagnosis of β thalassaemia trait.

HPLC methods usually indicate the presence of a haemoglobin variant, but they lack the resolution necessary to differentiate between them. They may demonstrate additional peaks in the chromatograms and these may be combined with clinically low or high results (figs 1–3). The Diamat HPLC method was once used for the screening of certain haemoglobin variants, and the Hi-Auto A1c, HA-8140 HPLC method has separation conditions that seem to detect haemoglobin variants and describe the chromatogram as “abnormal” or “variant” haemoglobin. The HLC-723 GHb V A1c2.2 HPLC (Tosoh, San Francisco, California, USA) has an enhanced resolution using the 3.0 minute instead of the 2.2 minute protocol, which allows the detection of haemoglobin variants. Chromatograms from the Variant HPLC using the β thalassaemia short programme helped to establish the diagnosis of certain haemoglobinopathies. However, most HPLC systems are not able to resolve additional peaks in their chromatograms and this leads to the overestimation and underestimation of HbA1c results.

The HPLC Variant II is described as giving an acceptable analytical performance and the results compared well with an HPLC method (Variant; Bio-Rad) certified by the National Glycohaemoglobin Standardisation Programme. We found that the determination of HbA1c values in patients with early migrating haemoglobin variants, such as Hb Graz and Hb Sherwood Forest, was not possible. The HbA1c values for the late migrating Hb O Padova variant was acceptable, but the HbA1c results for the Hb D variant appeared to be too low compared with the blood glucose and fructosamine results (table 1). Using the high resolution β thalassaemia programme of the Variant II in patients with silent haemoglobin variants showed that HPLC

<table>
<thead>
<tr>
<th>Peak name</th>
<th>Calibrated area %</th>
<th>Area %</th>
<th>Retention time (min)</th>
<th>Peak area</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1a</td>
<td>–</td>
<td>0.4</td>
<td>0.165</td>
<td>12 105</td>
</tr>
<tr>
<td>A1b</td>
<td>–</td>
<td>1.1</td>
<td>0.257</td>
<td>35 579</td>
</tr>
<tr>
<td>LA1c</td>
<td>–</td>
<td>1.0</td>
<td>0.668</td>
<td>34 073</td>
</tr>
<tr>
<td>A1c</td>
<td>9.5*</td>
<td>–</td>
<td>0.805</td>
<td>184 523</td>
</tr>
<tr>
<td>P3</td>
<td>–</td>
<td>3.6</td>
<td>1.480</td>
<td>118 796</td>
</tr>
<tr>
<td>A0</td>
<td>–</td>
<td>64.6</td>
<td>1.687</td>
<td>2 143 380</td>
</tr>
<tr>
<td>A2</td>
<td>1.9</td>
<td>–</td>
<td>2.840</td>
<td>48 494</td>
</tr>
<tr>
<td>C</td>
<td>–</td>
<td>0.6</td>
<td>4.246</td>
<td>20 186</td>
</tr>
</tbody>
</table>

*Values outside of expected ranges

| HbF concentration = % | HbA1c concentration = 9.5%* | HbA2 concentration = 1.9% |

Analysis comments:

Figure 3 Chromatogram from the ion exchange high performance liquid chromatography Bio-Rad Variant II using the high resolution β thalassaemia programme in a patient with type 1 diabetes and the Hb O Padova variant.
method modifications with high resolution modes aid identification of interference caused by haemoglobin variants.

“The determination of HbA1c values in patients with early migrating haemoglobin variants, such as Hb Graz and Hb Sherwood Forest, was not possible”

However, different commercially available methods measure different fractions of glycated haemoglobin, causing different HbA1c results depending on the method used.12 13 The degree of interference of haemoglobin variants may vary with each method and even with each method modification. Several haemoglobin variants are known to interfere with measurement of HbA1c by HPLC, and an increasing number of interfering haemoglobin variants have been reported.14 Only a few haemoglobin variants are known to affect HbA1c results in immunoassays.15 Boronate affinity methods measure glycated haemoglobin regardless of the glycation site. If an erroneous result is caused by haemoglobin mutations affinity chromatography may provide a more accurate measure of glycaemic control in samples with haemoglobin variants.16 New methods are being developed, such as electrospray mass spectrometry and a method based on quenching of the fluorescence of an eosin-boronic acid solution.17 Preliminary results with these methods on samples containing haemoglobin variants (Hb S and Hb C) demonstrated no apparent bias against the comparison method used.18 19

We conclude that this modification of the HPLC method enables interference with HbA1c determination as a result of silent haemoglobin variants to be recognised more easily. However, these results emphasise the need for additional investigations into the interference caused by haemoglobin variants in all newly developed and/or modified HbA1c assays.

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