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

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 β 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 β 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 immunooagglutination 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 β chain variant Hb Graz (\(\alpha_2\beta_2(NA2)\) His → Leu), a patient without diabetes but with β chain variant Hb Sherwood Forest (\(\alpha_2\beta_104(G6)\) Arg → Thr), two patients (one without diabetes and one with type 1 diabetes) with \(\alpha\)-chain variant Hb O Padova (\(\beta_4\alpha_3(111)\) Glu → Lys), and a patient with type 2 diabetes with \(\beta\) chain variant HbD (\(\alpha_2\beta_{121}(GH4)\) Glu → Gln).\textsuperscript{a} Amino acid analysis and DNA sequence analysis were performed as described previously and the routine haematological data of all patients were within the normal range.\textsuperscript{b, c} 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.

Note: This article was published in J Clin Pathol in 2002;55:699–703. It includes a detailed methodology section discussing the determination of HbA\textsubscript{1c} using the HPLC Bio-Rad Variant II method, with a focus on the interference caused by silent haemoglobin variants.
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

| 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>Variant II</td>
<td>HA-8140</td>
<td>DCA 2000</td>
</tr>
<tr>
<td>Non-diabetic reference range</td>
<td>4.7–6%</td>
<td>4.5–5.7%</td>
<td>4.5–5.7%</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.
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 β 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 β 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 determination of HbA1c with the HPLC Menarini gave results in both patients described as “variant haemoglobin” and the immunoagglutination method DCA 2000 showed values within the non-diabetic reference range for the patient without diabetes and a diabetic value for the patient with type 1 diabetes (table 1).

In the patient with type 2 diabetes and Hb D the chromatogram from the Bio-Rad Variant II using the high resolution β thalassaemia programme showed several additional “unknown” peaks, as published previously. The result for HbA1c was within the low non-diabetic reference range. Compared with the values of fructosamine and fasting blood glucose (table 1), which were in the diabetic range, the HbA1c result seemed too low. The determination of HbA1c with the HPLC Menarini gave the results as “variant haemoglobin” and the immunoagglutination method DCA 2000 showed values in the upper 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,

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**Table 1**

<table>
<thead>
<tr>
<th>Peak name</th>
<th>Calibrated area %</th>
<th>Area %</th>
<th>Retention time (min)</th>
<th>Peak area</th>
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<tbody>
<tr>
<td>Unknown</td>
<td>-</td>
<td>0.1</td>
<td>0.109</td>
<td>4033</td>
</tr>
<tr>
<td>Unknown</td>
<td>-</td>
<td>1.2</td>
<td>0.156</td>
<td>47479</td>
</tr>
<tr>
<td>A1α</td>
<td>-</td>
<td>3.9</td>
<td>0.230</td>
<td>150588</td>
</tr>
<tr>
<td>F</td>
<td>1.7</td>
<td>-</td>
<td>0.390</td>
<td>84844</td>
</tr>
<tr>
<td>LA1c</td>
<td>-</td>
<td>45.3</td>
<td>0.623</td>
<td>1770488</td>
</tr>
<tr>
<td>P3</td>
<td>-</td>
<td>2.6</td>
<td>1.492</td>
<td>101615</td>
</tr>
<tr>
<td>Ao</td>
<td>-</td>
<td>42.7</td>
<td>1.714</td>
<td>1665609</td>
</tr>
<tr>
<td>A2</td>
<td>2.8</td>
<td>-</td>
<td>2.836</td>
<td>75652</td>
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<tr>
<td>Unknown</td>
<td>-</td>
<td>0.1</td>
<td>3.256</td>
<td>4049</td>
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</table>

**Figure 2** Chromatogram from the ion exchange high performance liquid chromatography Bio-Rad Variant II using the high resolution β thalassaemia programme in a patient without diabetes but with the Hb Sherwood Forest variant.

F concentration = 1.7%
A1c concentration = %
A2 concentration = 2.8%

Total area: 3904358*

Analysis comments:
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 value 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>F3</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.

“...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.5–12 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.7–11 Only a few haemoglobin variants are known to affect HbA1c results in immunoassays.9–11 Boronate affinity methods measure glycohaemoglobin 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.12 New methods are being developed, such as electrospray mass spectrometry14 and a method based on quenching of the fluorescence of an cosin-boronic acid solution.25 Preliminary results with these methods on samples containing haemoglobin variants (Hb S and Hb C) demonstrated no apparent bias against the comparison method used.15–17

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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Thanks to Bio-Rad Laboratories (Munich, Germany) for performing the HbA1c determinations with the HPLC Variant II high resolution β thalassaemia programme.

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REFERENCES

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