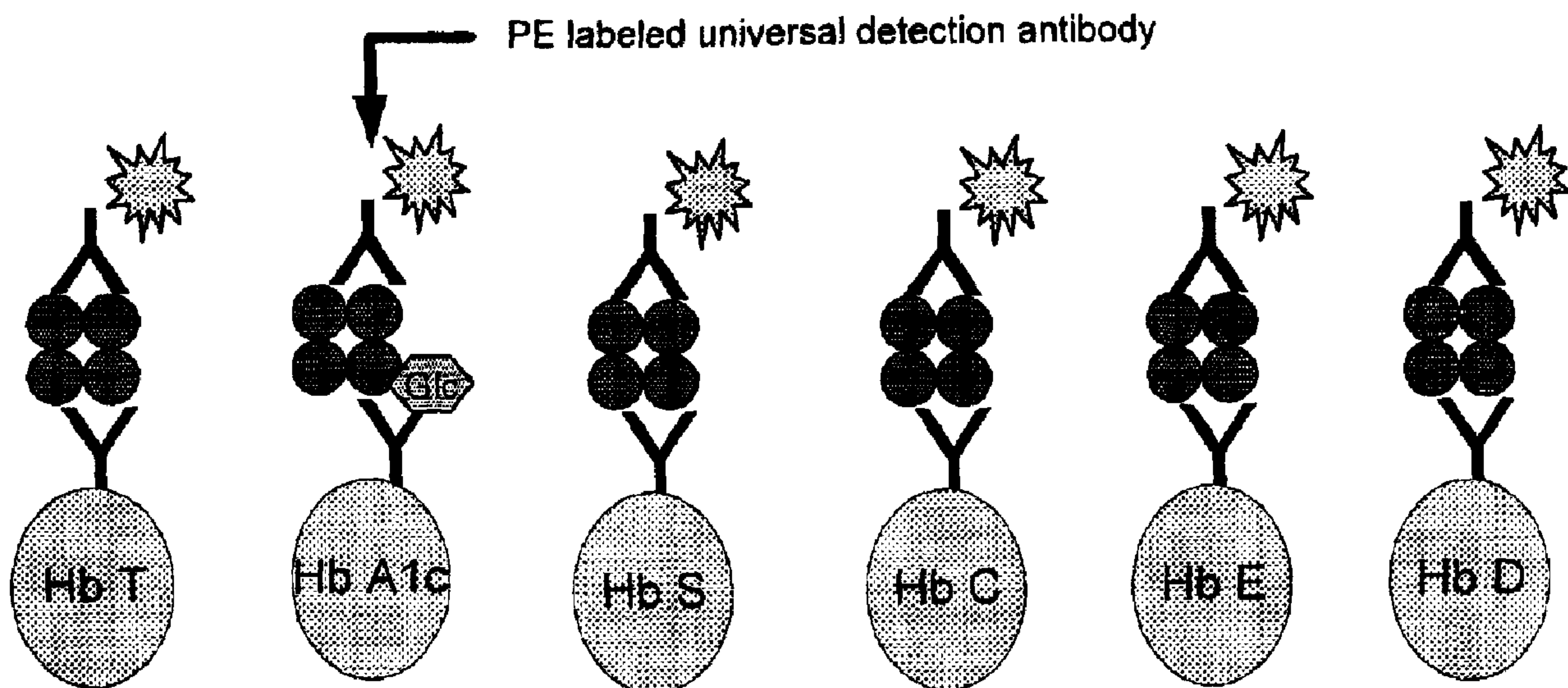




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(54) **Titre : IMMUNO-ESSAIS MULTIPLEX POUR HEMOGLOBINE, VARIATIONS D'HEMOGLOBINE ET FORMES GLYCATEES**
(54) **Title: MULTIPLEX IMMUNOASSAYS FOR HEMOGLOBIN, HEMOGLOBIN VARIANTS, AND GLYCATED FORMS**



(57) **Abrégé/Abstract:**

Hemoglobin, its variants, and glycated forms of each are determined individually in a multiplex assay that permits correction of the measured level of HbA1c to account for glycated variants and other factors related to the inclusion of the variants in the sample. New antibodies that are particularly well adapted to the multiplex assay are also provided.



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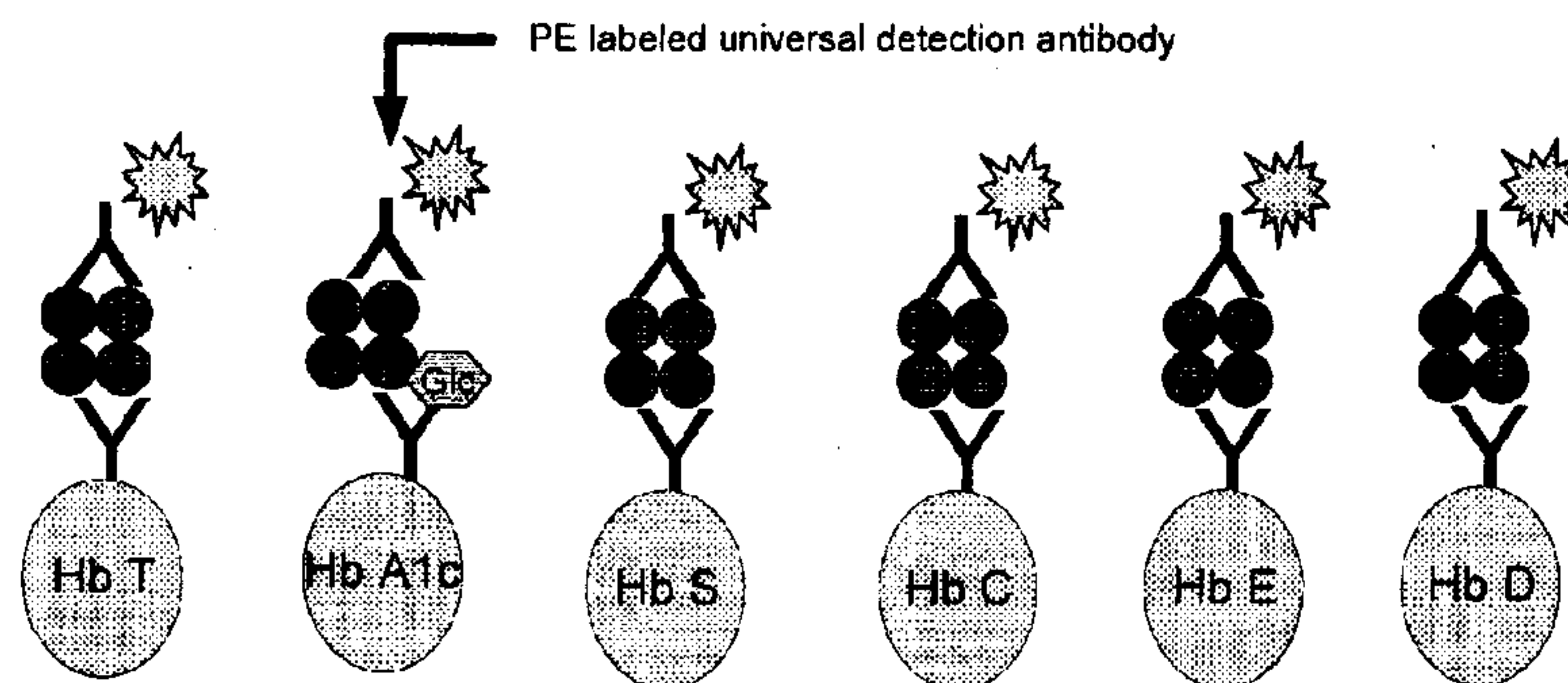
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**FIG. 1**

(57) Abstract: Hemoglobin, its variants, and glyated forms of each are determined individually in a multiplex assay that permits correction of the measured level of HbA1c to account for glyated variants and other factors related to the inclusion of the variants in the sample. New antibodies that are particularly well adapted to the multiplex assay are also provided.

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MULTIPLEX IMMUNOASSAYS FOR HEMOGLOBIN, HEMOGLOBIN VARIANTS, AND GLYCATED FORMS

SEQUENCE LISTING

5 [0001] This description contains a sequence listing in electronic form in ASCII text format. A copy of the sequence listing in electronic form is available from the Canadian Intellectual Property Office.

BACKGROUND OF THE INVENTION

1. Field of the Invention

10 [0002] This invention lies in the field of assays for glycated hemoglobin.

2. Description of the Prior Art

[0003] For individuals suffering from type 1 or type 2 diabetes mellitus, maintenance of glycemic control is of prime importance, and such maintenance requires the determination of the level of hemoglobin A_{1c} in the blood of these individuals. With diabetes reaching global epidemic proportions, it is particularly important to have accurate and reproducible HbA_{1c} assays. HbA_{1c} assays are also used in the screening of individuals for diabetes.

[0004] HbA_{1c} measurements for both patient monitoring and screening are taken as an average over the lifetime of an erythrocyte. This average is compromised by several physiological conditions, notable among which are the presence of hemoglobin variants and thalassemias in the patient's blood. Hemoglobin variants are prevalent among certain ethnic groups and in certain geographical regions. Of the over 800 variants known worldwide, the most common are HbS, HbC, HbD, and HbE. HbS is most prevalent among individuals of African descent, HbD among individuals of Punjabi Indian descent, and HbE among individuals of Southeast Asia. Other known forms of hemoglobin are HbF (fetal hemoglobin) and HbA₂, both of which can be

elevated in thalassemia, a relatively common condition characterized by an imbalance of hemoglobin alpha and beta subunits. Beta thalassemias can also occur in the presence of HbE and HbS, and the combined sickle/beta thalassemia trait occurs most frequently among individuals of Mediterranean descent. Variants and thalassemias can cause inaccuracies in HbA_{1c} measurements by affecting such factors as red blood cell survival and glycosylation rates. Variants also affect immunologically determined levels of glycated hemoglobin since immunoreactivity differs from one glycated variant to the next and also between glycated variants and HbA itself. Health care professionals must therefore know of the presence of variants and their proportions relative to HbA as well as the presence of thalassemias to achieve a proper determination of glycemic control.

[0005] Determinations of hemoglobin variants are typically done separately from determinations of HbA_{1c} regardless of whether a variant is actually known to be present. Antibodies to specific variants have been developed for this purpose, and the following is a sampling of reports on such antibodies:

[0006] HbS: Jensen, R.H., *et al.*, "Monoclonal antibodies specific for sickle cell hemoglobin," *Hemoglobin* 9(4), 349-362 (1985)

[0007] HbS: Epstein, N., *et al.*, "Monoclonal antibody-based methods for quantitation of hemoglobins: application to evaluating patients with sickle cell anemia treated with hydroxyurea," *Eur. J. Haematol.* 57(1), 17-24 (1996)

[0008] HbA: Rosenthal, M.A., *et al.*, "Binding specificity of a monoclonal antibody to human HbA," *Hemoglobin* 19(3-4), 191-196 (1995)

[0009] HbS and HbC: Garver, E.A., *et al.*, "Screening for hemoglobins S and C in newborn and adult blood with a monoclonal antibody in an ELISA procedure," *Annals of Hematology* 60(6), 334-338 (1990)

[0010] Hb with single amino acid substitutions: Stanker, L.H., *et al.*, "Monoclonal antibodies recognizing single amino acid substitutions in hemoglobin," *J. Immunol.* 136(11), 4174-4180 (1986)

[0011] Hb variants: Moscoso, H., *et al.*, "Enzyme immunoassay for the identification of hemoglobin variants," *Hemoglobin* 14(4), 389-98 (1990)

[0012] Hb variants: Schultz, J.C., "Utilization of monoclonal antibody-based assay HemoCard in screening for and differentiating between genotypes of sickle cell disease and other hemoglobinopathies," *J. Clin. Lab. Anal.* **9**(6), 366-374 (1995)

[0013] Despite these reports and others, determinations of variants are presently performed by either high performance liquid chromatography (HPLC) or electrophoresis. HPLC can indeed be a rapid means of obtaining the HbA_{1c} level, but extended HPLC gradients are needed for detecting and quantifying the variants and thalassemias, since in HPLC impurities co-elute with the variants, and different variants tend to co-elute with each other. In fact, certain variants cannot be resolved by HPLC, even with the most optimized HPLC gradients. Typically, separate HPLC methods for rapid A_{1c} measurements and variant and thalassemia testing are used, therefore making it impossible to simultaneously determine the A_{1c} level and variant or thalassemia status by HPLC, much less in a rapid manner.

[0014] Assays that provide simultaneous detection of multiple analytes are termed "multiplex" assays, and disclosures of multiplex assays using affinity-type binding reactions on the surfaces of beads that are then detected by flow cytometry are disclosed in the following patents:

[0015] Watkins, M.I., *et al.*, "Magnetic particles as solid phase for multiplex flow assays," US 6,280,618 B2, issued August 28, 2001

[0016] Watkins, M.I., *et al.*, "Magnetic particles as solid phase for multiplex flow assays," US 6,872,578 B2, issued March 29, 2005

[0017] Thomas, N., "Multiple assay method," US 6,913,935 B1, issued July 5, 2005

[0018] Hechinger, M., "Platelet immunoglobulin bead suspension and flow cytometry," US 6,933,106 B1, issued August 23, 2005

[0019] Hechinger, M., "Anti-platelet immunoglobulin bead positive control," US 6,951,716 B1, issued October 4, 2005

[0020] Watkins, M.I., *et al.*, "Multi-analyte diagnostic test for thyroid disorders," US 7,271,009 B1, issued September 8, 2007

[0021] Bell, M.L., "Assay procedures and apparatus," US 7,326,573 B2, issued February 5, 2008

[0022] Song, Y., *et al.*, “Multiplex protein interaction determinations using glutathione-GST binding,” US 2002/0115116 A1, published August 22, 2002

5 [0023] The success of multiplex assays for certain combinations of analytes does not however provide assurance, or even a high level of expectation, that similar success will be achieved for all combinations of analytes, particularly combinations with a high level of homology among the analytes. Hemoglobin and its variants and glycated forms are one such combination. Multiplex assays involve a plurality of different immunoreactants in intimate mixture in a common reaction medium, which creates competition among the immunoreactants for the different analytes, more so than in media where a single immunoreactant is present, and the cross-reactivities occur in multiple
10 directions. The bead sets themselves must also be differentiated at the same time as the immunoassays are performed. This differentiation, whether by the use of different dyes on different bead sets, a different size for each bead set, or other known differentiation factors, adds a further level of complexity and further opportunities for cross-talk.

SUMMARY

15 [0024] The present disclosure is based on the discovery that hemoglobin variants can be differentiated from each other and from HbA_{1c} and from total hemoglobin, and the levels of each measured, in a multiplex immunoassay. The assay can, *e.g.*, detect a single variant in addition to HbA_{1c} and total hemoglobin or two or more variants and total hemoglobin. When two or more variants are detected, different combinations of variants can be selected, although preferably the assay
20 will include the four most common variants, HbS, HbC, HbE, and HbD. The assay may also include the measurement of HbA₂ and HbF. This disclosure thus provides methods for detecting and identifying the presence of hemoglobin variants in a patient’s blood. This disclosure also provides methods for measuring the level of HbA_{1c} relative to total hemoglobin while correcting the result for the presence of variants that may also be present. Here as well, the correction can be for individual
25 variants or combinations of variants. This disclosure also provides methods for the simultaneous detection of A_{1c} and hemoglobin variants without correction, which is useful in certain cases. A still further aspect disclosed herein is the measurement of levels of particular variants in glycated form. When a variant is known to be present, the glycated version of that variant can be measured and added to the level of HbA_{1c} to obtain an accurate indication of total glycated hemoglobin.

[0025] In a further aspect, this disclosure provides antibodies having selective binding affinity for hemoglobin variants and can be used in the methods disclosed herein. Some embodiments involve a monoclonal antibody that has selective binding affinity for HbC and glycated HbC, wherein the monoclonal antibody binds to an HbC minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1); or to an HbC minimal epitope comprising the amino acid sequence TX₁KE or LTX₁KE (SEQ ID NO:2),
 5 wherein X₁ is one of the 20 common naturally occurring amino acids. Some embodiments involve a monoclonal antibody having selective binding affinity for HbS and glycated HbS, wherein the monoclonal antibody binds to an HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3); or to an HbS minimal epitope comprising the amino acid sequence PVEX₂X₃A (SEQ ID NO:4) or
 10 LTPVEX₂X₃A (SEQ ID NO:5), wherein each of X₂ and X₃ is an amino acid independently selected from the 20 common naturally occurring amino acids. Some embodiments involve a monoclonal antibody having selective binding affinity for HbE and glycated HbE, wherein the antibody binds to an HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6); or to an HbE minimal epitope comprising the amino acid sequence DEVGGK (SEQ ID NO:7) or EVX₄X₅K, wherein each of X₄ and X₅ is an
 15 amino acid independently selected from the 20 common naturally occurring amino acids. Some embodiments involve a monoclonal antibody having selective binding affinity for HbD and glycated HbD, where the monoclonal antibody binds to an HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8); or to an HbD minimal epitope comprising the amino acid sequence GX₆QFX₇PP (SEQ ID NO:9) or QFX₇PP (SEQ ID NO:10), wherein each of X₆ and X₇ is an amino acid independently selected from
 20 the 20 common naturally occurring amino acids.

[0026] Methods disclosed herein also may employ an antibody, either a polyclonal antibody or monoclonal antibody that selectively binds total hemoglobin (in comparison to non-hemoglobin polypeptides). In some embodiments, a pan-reactive polyclonal antibody binds to one or more epitopes present in the following regions of alpha globin and beta globin: alpha globin
 25 ⁴⁹SHGSAQVKGHGKKVADALTNAVAHVDDMPNALSALSDHLHA HKLRRVDPV⁹⁶ (SEQ ID NO:11); beta globin ¹⁵WGKVNVDDEVGGEALG³⁰ (SEQ ID NO:12), ⁴⁵FGDLSTP⁵¹ (SEQ ID NO:13), and ⁷⁶AHLDNLKGTFFAT⁸⁷ (SEQ ID NO:14). In some embodiments, a pan reactive antibody is a monoclonal or polyclonal antibody that binds to the epitope ⁹SAVTALWGKVN²⁰ (SEQ ID NO:15) (beta globin) or ⁸KSAVTALWGKVN²⁰ (SEQ ID NO:16) or ¹¹VTALW¹⁵ (SEQ ID NO:17) or to a
 30 beta globin minimal epitope that comprises the sequence ALWG (SEQ ID NO:18) or VTX₉LW (SEQ ID NO:19), wherein X₉ is one of the 20 common naturally occurring amino acids. An antibody for

use herein may bind to an epitope on beta globin, *e.g.* ⁸KSAVTALWGK VNV²⁰ (SEQ ID NO:16), ⁵⁸PKVKAHGKKVLGAF⁷¹ (SEQ ID NO:20) or ⁸⁷TLSELHCDKLHVDPENFR¹⁰⁴ (SEQ ID NO:21) (beta globin).

5 [0027] This disclosure further provides monoclonal antibodies that selectively bind to glycosylated forms of hemoglobin, including binding to both normal and variant hemoglobins, but do not bind to non-glycosylated forms of hemoglobin. A glycosylated residue ¹V and residue ²H are typically important for binding for such antibodies.

[0028] Methods disclosed herein may additionally comprise detecting other hemoglobin variants using antibodies, *e.g.*, monoclonal antibodies, that selectively bind such variants.

10 [0029] In typical embodiments, an antibody for use herein has a K_D that is anywhere in the range of from about 10^{-6} M to about 10^{-12} M. In some embodiments, the antibody has a K_D that is anywhere in the range of from about 10^{-7} M to about 10^{-11} M. In other embodiments, the antibody has a K_D anywhere in the range of about 10^{-8} M to about 10^{-10} M. Typically the K_D is in the nM range, *e.g.*, anywhere from about 10^{-9} M to about 10^{-10} M.

15 [0030] The claimed invention relates to a method for individually detecting a plurality of hemoglobin-containing analytes comprising HbA_{1c}, and at least a first hemoglobin variant, if present, selected from the group consisting of HbS, HbC, HbE, and HbD in a single sample of blood cell lysate, said method comprising: (a) incubating said sample with a population of beads, said population consisting of a plurality of subpopulations in a common mixture, each bead of said
20 population having bonded thereto one of a plurality of classifier dyes that are equal in number to said analytes and that are selected such that said classifier dyes, and thereby said subpopulations, are differentiable from each other by fluorescent emissions emitted by said classifier dyes upon excitation, each said subpopulation further having bonded thereto an antibody having selective binding affinity toward one of said analytes, to cause each analyte to bind to a different bead
25 subpopulation through the antibodies bonded to said subpopulations, wherein an antibody having selective binding affinity for the first hemoglobin variant selectively binds the first hemoglobin variant and its glycosylated form; (b) with said analytes bound to the beads of said subpopulations, incubating said population with a labeled antibody that binds to all of said analytes, thereby labeling said analytes thus bound; and (c) with said bound analytes so labeled, detecting labels bound to said

bound analytes while differentiating said labels so detected according to subpopulations by fluorescent emissions, thereby individually detecting said analytes.

[030A] The claimed invention also relates to a method for determining the proportion of HbA1c relative to total hemoglobin in a sample of blood cell lysate, adjusted for the possible presence in said lysate of at least one hemoglobin variant selected from the group consisting of HbS, HbC, HbE, and HbD that interferes with the measurement of HbA1c, said method comprising: (a) incubating said sample with a population of beads, said population consisting of a plurality of subpopulations in a common mixture, each bead of said population having bonded thereto one of a plurality of classifier dyes selected such that said classifier dyes, and thereby said subpopulations, are differentiable from each other by fluorescent emissions emitted by said classifier dyes upon excitation, each said subpopulation further having bonded thereto an antibody having selective binding affinity toward one of a plurality of analytes, said plurality comprising HbA1c and said hemoglobin variant, to cause each of said analytes to bind to a different bead subpopulation through the antibody bonded thereto, wherein an antibody having selective binding affinity for the hemoglobin variant selectively binds the hemoglobin variant and its glycated form; (b) with said analytes bound to the beads of said subpopulations, incubating said population with a labeled antibody that binds to all of said analytes, thereby labeling said analytes so bound; (c) with said bound analytes so labeled, detecting labels bound to said bound analytes while differentiating said labels so detected according to subpopulations by fluorescent emissions, thereby individually detecting concentrations of said analytes in said sample; and (d) determining from said concentrations the proportion of HbA1c relative to total hemoglobin, adjusted for the concentration of said hemoglobin variant by an adjustment factor empirically derived from a predetermined relation between said hemoglobin variant concentration and the concentration of said HbA1c so detected.

[030B] The claimed invention also relates to a method for determining the proportion of a glycated form of a hemoglobin variant wherein the hemoglobin variant is selected from the group consisting of HbS, HbC, HbE, and HbD relative to total hemoglobin in a sample of blood cell lysate, said method comprising: (a) incubating said sample with a population of beads, said population consisting of a plurality of subpopulations in a common mixture, each bead of said population having bonded thereto one of a plurality of classifier dyes selected such that said classifier dyes, and thereby said subpopulations, are differentiable from each other by fluorescent emissions emitted by said classifier dyes upon excitation, each said subpopulation further having bonded thereto one of a plurality of

antibodies comprising: a first such antibody having selective binding affinity for a first analyte consisting of both said glycated form of the hemoglobin variant and HbA_{1c}, and a second such antibody having selective binding affinity for a second analyte consisting of both said hemoglobin variant and said glycated form of the hemoglobin variant, to cause said first analyte and said second analyte to bind to said first and second antibodies, respectively; (b) with said first and second analytes so bound, incubating said population with a labeled antibody that binds to all of said analytes, thereby labeling said analytes so bound; (c) with said bound analytes so labeled, detecting said labels while differentiating said labels so detected according to subpopulations by fluorescent emissions, thereby detecting concentrations of said first and second analytes in said sample; and (d) determining a concentration of total hemoglobin, and determining from said concentrations the proportion of said first analyte relative to total hemoglobin, and adjusting said proportion for the concentration of said second analyte relative to total hemoglobin by an adjustment factor empirically derived from a predetermined relation between said hemoglobin variant concentration and the concentration of total hemoglobin so detected, thereby determining the proportion of a glycated hemoglobin variant relative to total hemoglobin.

[030C] The claimed invention also relates to a method for quantifying a plurality of hemoglobin-containing analytes comprising HbA_{1c} and a hemoglobin variant, if present, in a single sample of blood cell lysate, said method comprising: (a) incubating said sample with a population of beads in a common mixture, said population comprising a subpopulation to detect HbA_{1c} and one or more further subpopulations, each of which detects a hemoglobin variant, wherein: (i) each bead of said subpopulation to detect HbA_{1c} has bonded thereto a fluorescent dye and each bead of said one or more subpopulations to detect a hemoglobin variant has bonded thereto a fluorescent dye, which may be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different dye that distinguishes each of the one or more subpopulations; and (ii) each bead of said subpopulation to detect HbA_{1c} further has bonded thereto an anti-HbA_{1c} antibody having selective binding affinity towards HbA_{1c} and each bead of said one or more subpopulations to detect a hemoglobin variant has bonded thereto a monoclonal antibody that has selective binding affinity towards the variant and a glycated form of the variant to cause each analyte to bind to a different bead subpopulation through the antibody bonded to said subpopulations, wherein: one subpopulation of the one or more further subpopulations detects HbC, if present in the sample, and has bonded thereto an anti-HbC monoclonal antibody having selective binding affinity towards HbC and glycated HbC; or one subpopulation of the one or more further subpopulations detects HbS, if present in the sample, and has bonded thereto an anti-HbS monoclonal antibody having selective binding affinity towards HbS and glycated HbS; and (b)

individually detecting the subpopulations of beads that have been incubated with said sample in accordance with step (a) to quantify the HbA_{1c} and hemoglobin variant in the sample using a competitive immunoassay, wherein the competitive immunoassay comprises further incubating the population of beads with a plurality of hemoglobin protein antigens, each hemoglobin protein antigen
 5 attached to a solid support at a separate site, wherein the plurality of hemoglobin protein antigens comprises a peptide that selectively binds the anti-HbA_{1c} antibody, and a peptide that selectively binds the anti-HbC monoclonal antibody or a peptide that selectively binds the anti-HbS monoclonal antibody.

[030D] Also claimed are monoclonal antibodies that selectively bind to hemoglobin variants and glycosylated forms thereof wherein the antibody binds to: a HbC minimal epitope ⁴TPKEKSAVT¹² (SEQ
 10 ID NO:1); a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3); a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK²⁶ (SEQ ID NO:7); or a HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8) or ¹¹⁹GKQFTPP¹²⁵ (SEQ ID NO:46).

[030E] These and other features, objects, and advantages will be better understood from the description that follows.

15 BRIEF DESCRIPTION OF THE FIGURES

[0031] FIG. 1 provides a schematic depicting an example of a sandwich immunoassay for measuring glycosylated hemoglobin and hemoglobin variants.

[0032] FIG. 2 is a plot of comparative data between a series of multiplex assays in accordance with the present invention and a series of HPLC assays.

20 DETAILED DESCRIPTION OF THE INVENTION AND PREFERRED EMBODIMENTS

[0033] The hemoglobin variants to be detected by the present invention are any of the known variants reported in the literature or otherwise known to clinicians and researchers skilled in technology of hemoglobin, glycosylated hemoglobin, and diabetes. As noted above, the four most common hemoglobin
 25 variants are HbS, HbC, HbE, and HbD, although other variants can be detected in addition to these four or in place of one or more of them. For example, two variants that are elevated in beta thalassemia are HbF and HbA₂. The binding members used for each of these variants in the multiplex assay are generally monoclonal antibodies, preferably those that are developed expressly for the multiplex assay. The antibodies preferably bind to epitopes on

the variants that distinguish each variant from the other variants to minimize cross-reactivity, and most importantly that distinguish the variants from the wild-type hemoglobin A0. In embodiments of the invention requiring the use of a value for the concentration of total hemoglobin in the sample, the concentration can be determined either by an immunoassay method or a non-immunoassay method. An example of a non-immunoassay method is the determination of optical density. Other examples will be readily apparent to those skilled in the hemoglobin art. In embodiments where total hemoglobin is determined by immunoassay, the determination can be performed as part of the multiplex assay. The antibody for total hemoglobin in the multiplex assay can be either a monoclonal antibody or a polyclonal antibody, and the antibody for HbA_{1c} can be either a polyclonal antibody or a monoclonal antibody, preferably a monoclonal antibody.

Antibodies

[0034] As used herein, an "antibody" refers to a protein functionally defined as a binding protein and structurally defined as comprising an amino acid sequence that is recognized by one of skill as being derived from the framework region of an immunoglobulin-encoding gene of an animal that produces antibodies. An antibody can consist of one or more polypeptides substantially encoded by immunoglobulin genes or fragments of immunoglobulin genes. The recognized immunoglobulin genes include the kappa, lambda, alpha, gamma, delta, epsilon and mu constant region genes, as well as myriad immunoglobulin variable region genes. Light chains are classified as either kappa or lambda. Heavy chains are classified as gamma, mu, alpha, delta, or epsilon, which in turn define the immunoglobulin classes, IgG, IgM, IgA, IgD and IgE, respectively.

[0035] A typical immunoglobulin (antibody) structural unit is known to comprise a tetramer. Each tetramer is composed of two identical pairs of polypeptide chains, each pair having one "light" (about 25 kD) and one "heavy" chain (about 50 kD). The N-terminus of each chain defines a variable region of about 100 to 110 or more amino acids primarily responsible for antigen recognition. The terms variable light chain (V_L) and variable heavy chain (V_H) refer to these light and heavy chains, respectively.

[0036] The term antibody as used herein includes antibody fragments that retain binding specificity. For example, there are a number of well characterized antibody fragments. Thus, for example, pepsin digests an antibody C-terminal to the disulfide linkages in the hinge region to

produce F(ab)'₂, a dimer of Fab which itself is a light chain joined to V_H-C_H1 (Fd) by a disulfide bond. The F(ab)'₂ may be reduced under mild conditions to break the disulfide linkage in the hinge region thereby converting the (Fab')₂ dimer into an Fab' monomer. The Fab' monomer is essentially a Fab with all or part of the hinge region (see, Fundamental Immunology, W.E. Paul, ed., Raven Press, N.Y. (1993), for a more detailed description of other antibody fragments). While various antibody fragments are defined in terms of the digestion of an intact antibody, one of skill will appreciate that fragments can be synthesized de novo either chemically or by utilizing recombinant DNA methodology. Thus, the term “antibody” also includes antibody fragments produced either by the modification of whole antibodies or synthesized using recombinant DNA methodologies. Antibodies include dimers such as V_H-V_L dimers, V_H dimers, or V_L dimers, including single chain antibodies. Alternatively, the antibody can be another fragment, such as a disulfide-stabilized Fv (dsFv). Other fragments can also be generated using known techniques, including using recombinant techniques. In some embodiments, antibodies include those that have been displayed on phage or generated by recombinant technology using vectors where the chains are secreted as soluble proteins, e.g., scFv, Fv, Fab, (Fab')₂ or generated by recombinant technology using vectors where the chains are secreted as soluble proteins.

[0037] As used here, an “immunological binding member having selective binding affinity” for an antigen, e.g., a hemoglobin variant, is typically an antibody. In some embodiments, a binding member having selective binding affinity for an antigen may be a peptide, e.g., that can be identified by screening peptide libraries, that has a selective binding interaction with the antigen.

[0038] In one aspect, the invention provides monoclonal antibodies that bind to Hb A_{1c} as well as monoclonal antibodies that specifically bind to hemoglobin variants HbS, HbC, HbE, and HbD. The sequence of hemoglobin beta chain is as follows (SEQ ID NO:22):

VHLTPEEKSAVTALWGKVNVDEVGGEALGRLLVVYPWTQRFFESFGDLSTPDAVMG
 NPKVKAHGKKVLGAFSDGLAHLNKGTFATLSELHCDKLHVDPENFRLLGNVLVC
 VLAHHFGKEFTPPVQAAYQKVVAGVANALAHKYH

The positions of amino acid residues in the hemoglobin beta chain referred to herein is with reference to this amino acid sequence unless otherwise specified.

[0039] Hb A_{1c} is glycated at the N-terminal valine. The most prevalent beta-chain point mutations are HbS (Glu 6 → Val); HbC (Glu 6 → Lys); HbE (Glu 26 → Lys) and HbD (Glu 121 → Gln). The Glu 6, Glu 26, and Glu 121 positions are indicated in the beta chain sequence by underline.

5 [0040] HbA₂ and HbF can also be determined in the assay of the present invention. Hemoglobin A₂ has two alpha chains and two delta chains; and hemoglobin F has two alpha and two gamma chains.

[0041] In the context of this invention, the term “specifically binds” or “specifically (or selectively) immunoreactive with,” or “having a selective affinity for” refers to a binding
10 reaction where the antibody binds to the antigen of interest. In the context of this invention, the antibody binds to the antigen of interest, *e.g.*, HbS, including the glycated form of HbS, with an affinity that is at least 100-fold better than its affinity for other antigens, *e.g.*, other hemoglobin variants such as HbA₀ or HbC.

[0042] “Reactivity” as used herein refers to the relative binding signal from the reactions of an
15 antibody with the antigen to which it specifically binds versus other antigens, such as other hemoglobin variants and or wild-type HbA₀. Reactivity is assessed using appropriate buffers that permit the antigen and antibody to bind. Reactivity can be determined, *e.g.*, using a direct or sandwich ELISA assay. For example, a direct format assay for determining reactivity with wildtype hemoglobin and/or hemoglobin variants, can be used in which the antigen is directly
20 bound to the ELISA plate, and the various antibodies are added to see which ones bind, followed by interrogation using a labeled anti-mouse antibody such as a phycoerythrin-labeled antibody. In the sandwich format, the monoclonal antibody is bound to the bead, followed by addition of antigen, followed by interrogation with phycoerythrin-labeled universal detection antibody, *e.g.*, a phycoerythrin-labeled universal detection antibody, that binds all hemoglobin species. Thus, in
25 an example using the sandwich format, reactivity can be defined as the relative fluorescent signal produced when the specific antigen, *e.g.*, an HbS hemoglobin variant, is bound versus another antigen, *e.g.*, a wildtype hemoglobin. An antibody is considered to be specific for an antigen if it exhibits a 2-fold, typically at least a 3- or 4-fold increase, in reactivity for the reference antigen compared to another antigen that is tested.

30 [0043] “Epitope” or “antigenic determinant” refers to a site on an antigen to which an antibody binds. Epitopes can be formed both from contiguous amino acids or noncontiguous amino acids

juxtaposed by tertiary folding of a protein. Epitopes formed from contiguous amino acids are typically retained on exposure to denaturing solvents whereas epitopes formed by tertiary folding are typically lost on treatment with denaturing solvents. An epitope typically includes at least 3, and more usually, at least 5 or 8-10 amino acids in a unique spatial conformation. Methods of epitope mapping are well known in the art (see, *e.g.*, Epitope Mapping Protocols in Methods in Molecular Biology, Vol. 66, Glenn E. Morris, Ed (1996)). A “minimal” epitope in the current invention is typically determined by measuring binding of the antibody to overlapping peptides covering the entire amino acid sequence of beta or alpha globin and identifying the amino acid sequence shared by all bound peptides. Important amino acids in the “minimal” epitope are typically identified by alanine scanning.

[0044] As understood in the art, a “minimal” epitope may include substitutions, *e.g.*, at positions that are not important for binding, *e.g.*, as determined using alanine scanning. Such substitutions include conservative substitutions where the alteration results in the substitution of an amino acid with a chemically similar amino acid. Conservative substitution tables providing functionally similar amino acids are well known in the art. The following are examples from among the twenty common naturally occurring amino acids of amino acids that may be substituted for one another: alanine and glycine; aspartic acid and glutamic acid; asparagine and glutamine; arginine and lysine; serine and threonine. Other conservative substitutions include substitutions of one amino acid in the following group with another amino acid in the group: isoleucine, leucine, methionine, and valine. Phenylalanine, tyrosine, and tryptophan are also examples of residues that may be substituted for one another.

[0045] Table 1 provides examples of immunogens utilized to generate specific monoclonal antibodies to hemoglobin and hemoglobin variants.

Table 1
Examples of Peptide Immunogens

Hemoglobin target	Peptide Name	sequence	SEQ ID NO:
Hemoglobin and variants	H1	H2N-VHLTPEEKSAVTALW-C-CONH2	23
	H2	H2N-VHLTPEEASASTASW-C-CONH2	24
	H2bis	H2N-VHLTPEEKSASTASW-C-CONH2	25
HbS	H3	H2N-VHLTPVEKSAVTALW-C-CONH2	26
HbC	H4	H2N-VHLTPKEKSAVTALW-C-CONH2	27
HbE	H5	H2N-CYG-NVDEVGGKALGRLLV-CONH2	28
	H5bis	H2N-CYG-VTALWGKVNDEVGGK-CONH2	29
	H10	H2N-C-Hx-EVGGKALG-CONH2	30
	H10bis	H2N-EVGGKALG-Hx-C-CONH2	31
HbD	H6	H2N-CYG-VLAHHFGKQFTPPVQAA-CONH2	32
	H6bis	H2N-QFTPPVQAAYQKV VAGV-GYC-CONH2	33
	H9	H2N-GKQFTGKQFTGKQFT-GYC-CONH2	34
	H11	H2N-C-Hx-HFGKQFTP-CONH2	35
	H11bis	H2N-HFGKQFTP-Hx-C-CONH2	36
HbA _{1c}	GP1	Glucose-HN-VHLTPEE-Hx-C-CONH2	37
	GP3	1-deoxyfructopyranosyl-HN-VHLTPEE-Hx-C-CONH2	38
	Glycated H2	Glucose-HN-VHLTPEEASASTASW-C-CONH2	39

[0046] Table 2 provides examples of immunization regimens utilized to generate specific
5 monoclonal antibodies to hemoglobin and hemoglobin variants.

Table 2

Examples of immunization regimens

Injection sequence	HbS	HbC	HbE	HbD	HbA1c	HbA and variants
1	native HbS antigen	H4-KLH	H5bis-KLH	denatured HbD + H6-KLH	GP3-KLH	native HbA0
2	H3-KLH	H4-KLH	H5bis-KLH	denatured HbD + H6-KLH	GP3-KLH	H1-KLH
3	H3-KLH	H4-KLH	H5bis-KLH	denatured HbD + H6-KLH	GP3-KLH	native HbA0
4	denatured HbS + H3-KLH	denatured HbC	H5bis-KLH	denatured HbD + H6-KLH	GP3-KLH	H1-KLH
5	denatured HbS + H3-KLH	H4-KLH	denatured HbE	denatured HbD + H6-KLH		
6	denatured HbS + H3-KLH	H4-KLH	denatured HbE	denatured HbD		
7			denatured HbE	denatured HbD + H6-KLH		
8			H5bis-KLH	denatured HbD + H6-KLH		
9			H5bis-KLH	denatured HbD + H6-KLH		
10			denatured HbE + H5bis-KLH	denatured HbD + H6-KLH		
11			denatured HbE + H5bis-KLH			
12			denatured HbE + H5bis-KLH			
Route of injection	Subcutaneous And intraperitoneal	Subcutaneous and intraperitoneal	Subcutaneous and intraperitoneal	Subcutaneous and intraperitoneal	Intraperitoneal	Subcutaneous and intraperitoneal

HbS antibodies

[0047] Hemoglobin variant HbS has a point mutation in which glutamic acid at position 6 of the hemoglobin beta chain is mutated to a valine.

[0048] Anti-HbS antibodies of the invention that are selective for HbS have the following binding characteristics: the antibody bind to HbS with an affinity that is at least 100-fold lower (*i.e.*, better)

than its affinity for HbC and HbA0. In some embodiments, the antibody binds to the minimal HbS epitope ⁵PVEKSAVT¹² (SEQ ID NO:40). Such an antibody may have a reactivity in which the reactivity is such that the valine at position 6 can be replaced by an isoleucine, but replacement with other amino acids at that position results in a 2-fold, often a three-fold or greater decrease in reactivity. In some embodiments, ³LTP⁵, ⁷E, and ¹⁰A are also important for binding.

[0049] In some embodiments, the antibody binds to a minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3). In some embodiments, the antibody may have a reactivity where the valine at position 6 can be replaced by an isoleucine or alanine, but substitution with other amino acids at that positions results in a two-fold, often a three-fold or greater decrease in reactivity. In some embodiments, ²HLTPVEK⁸ (SEQ ID NO:41) and ¹⁰A are also important for binding.

[0050] In some embodiments, an antibody that binds to an HbS minimal epitope, *e.g.*, ⁵PVEKSAVT¹² (SEQ ID NO:40). may bind to variants of the HbS minimal epitope that have the valine at position 6, such as a minimal epitope comprising ⁵PVEX₂X₃A¹⁰ (SEQ ID NO:4), where X₂ and X₃ can be independently selected from the 20 common naturally occurring amino acids, *e.g.*, conservative substitutions of K and S, respectively.

[0051] The antibody typically is an IgG, *e.g.*, the antibody may have an IgG1, IgG2, or IgG3 isotype. In some embodiments, the light chain constant region is a kappa chain. In other embodiments, the light chain constant region may be a lambda chain.

[0052] In one embodiment, an HbS antibody of the invention is raised against the immunogen HbS and H3-KLH: H₂N-VHLTPVEKSAVTALW-C-CONH₂ (SEQ ID NO:26). In other embodiments, the immunogen is either a combination of H3-KLH: H₂N-VHLTPVEKSAVTALW-C-CONH₂ (SEQ ID NO:26) and purified native and/or denatured HbS protein, or sequential or serial immunizations using the individual components of the above immunogens. Carrier proteins other than KLH can also be used. Examples are albumin and ovalbumin, and further examples will be readily apparent to those skilled in the art.

[0053] As understood in the art and illustrated by Table 1 above, many variations of immunogens can be used to obtain the desired antibody. For example, peptide immunogen H3-KLH: H₂N-VHLTPVEKSAVTALW-C-CONH₂ (SEQ ID NO:26) may also have a C-terminal carboxylate, rather than a C-terminal carboxamide. In some embodiments, the cysteine linker moiety may be spaced with a Hx residue, which is 6-amino hexanoic acid, or a spacer, such as a Gly-Gly spacer sequence may be employed. Further, the peptide sequence may also vary.

[0054] An anti-HbS antibody typically binds to both glycosylated and nonglycosylated forms of HbS with similar affinity. For example, an anti-HbS antibody typically selectively binds to both glycosylated and non-glycosylated HbS with a binding reactivity in which there is less than a three-fold reactivity difference, typically less than a two-fold reactivity difference, between binding to glycosylated vs. non-glycosylated HbS.

Anti-HbC antibodies

[0055] Hemoglobin variant HbC has a lysine substituted for the glutamic acid at position 6 of the hemoglobin beta chain. An anti-HbC monoclonal antibody for use in the invention typically binds to HbC with an affinity that is at least 100 times greater than the affinity of the antibody for HbS and HbA0. In some embodiments, the monoclonal antibody binds to the minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1). In some embodiments, the antibody has a binding specificity such that residues important for binding are residues ³LT⁴ and ⁶K. In some embodiments, residues important for binding may be ³LT⁴ and ⁶KE⁷. The binding specificity also allows for substitution of lysine by arginine or histidine at position 6, but substitution of other amino acids results in at least a 2-fold, typically a 3-fold or greater loss in reactivity. In other embodiments, the reactivity of the HbC antibody is such that the lysine at position 6 may be substituted with an arginine, tyrosine, asparagine, glutamine or glycine, but substitution with other amino acids residues results in a loss of reactivity.

[0056] In some embodiments, an antibody that binds to a HbC minimal epitope, *e.g.*, ⁴TPKEKSAVT¹² (SEQ ID NO:1), may bind to variants of the HbC minimal epitope that have the K at position 6, such as a minimal epitope comprising ⁴TX₁KE⁷ or ³LTX₁KE⁷ (SEQ ID NO:2) where X₁ can be one of the 20 common naturally occurring amino acids.

[0057] The antibody typically is an IgG, *e.g.*, the antibody may have an IgG1, IgG2, or IgG3 isotype. In some embodiments, the light chain constant region is a kappa chain. In other embodiments, the light chain constant region may be a lambda chain.

[0058] An antibody of the invention may be raised against the immunogen H4-KLH: H₂N-VHLTPKEKSAVTALW-C-CONH₂ (SEQ ID NO:27). Examples of other peptide immunogens are listed in Table 1, and here again, other common carrier proteins can be used in place of KLH. In some embodiments, the immunization is performed using a combination of the peptide and purified native and/or denatured HbC protein. In some embodiments, sequential or serial immunizations are performed using the individual components of the above immunogens. An exemplary immunization protocol is shown in Table 2. As explained above in the section relating to anti-HbS antibodies, one of

skill can readily design other immunogenic peptides to obtain an antibody having the desired HbC binding specificity.

[0059] An anti-HbC antibody typically binds to both glycosylated and nonglycosylated forms of HbC with similar affinity. For example, an anti-HbC antibody typically selectively binds to both glycosylated and non-glycosylated HbC with a binding reactivity in which there is less than a three-fold reactivity difference, typically less than a two-fold reactivity difference, between binding to glycosylated vs. non-glycosylated HbC.

Anti-HbE antibodies

[0060] HbE has a lysine substituted for the glutamic acid at position 26 of the hemoglobin beta chain. An anti-HbE monoclonal antibody of the invention is typically at least 4-fold or 5-fold more reactive, often at least 10-fold more reactive, with HbE in comparison to HbA. In some embodiments, the monoclonal antibody binds to the minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6). In some embodiments such an anti-Hb-E antibody has a binding specificity for ²²EVGGK²⁶ (SEQ ID NO:6) that is dependent on ²²E and in which ²¹D, ²³V, and ²⁶K are important for binding. In some embodiments, the antibody has a binding specificity that is dependent on E22 and in which D21, V23 and K26 are important for binding. In some embodiments, the antibody has a binding specificity such that substitution of the K at position 26 with S, T, A, R, Q or G preserves at least 50%, typically at least 70% or greater of the binding activity. In some embodiments, substitution of the K at position 26 with S, T, A, R or V preserves at least 50%, typically at least 70% or greater, of the binding activity.

[0061] In some embodiments, an antibody that binds to a HbE minimal epitope, *e.g.*, ²²EVGGK²⁶ (SEQ ID NO:6) may bind to variants of the HbE minimal epitope that have the K at position 26, such as a minimal epitope comprising ²¹DEVGGK²⁶ (SEQ ID NO:7) or ²²EVX₄X₅K²⁶, where X₄ and X₅ can be independently selected from the 20 common naturally occurring amino acids, *e.g.*, conservative substitutions of G.

[0062] The antibody typically is an IgG, *e.g.*, the antibody may have an IgG1, IgG2, or IgG3 isotype. In some embodiments, the light chain constant region is a kappa chain. In other embodiments, the light chain constant region may be a lambda chain.

[0063] An anti-HbE antibody of the invention can be obtained, *e.g.*, using the immunogen H5bis-KLH: H₂N-CYG-VTALWGKVNVDDEVGGK-CONH₂ (SEQ ID NO:29). In some embodiments, the antibody is raised against an immunogen H5bis-KLH : H₂N-CYG-VTALWGKVNVDDEVGGK-CONH₂ (SEQ ID NO:29) with mixtures or sequential injections of peptide, native HbE antigen, and

HbE denatured antigen. Examples of peptide immunogens are provided in Table 1. Peptide immunogens can be used in combination with one another, either with or without denatured or native HbE. Exemplary immunization protocols are provided in Table 2. As explained above in the section relating to anti-HbS antibodies, one of skill can readily design other immunogenic peptides to obtain an antibody having the desired HbE binding specificity. The reader is again referred to Table 1 for examples of other peptide immunogens.

[0064] An anti-HbE antibody typically binds to both glycosylated and nonglycosylated forms of HbE with similar affinity. For example, an anti-HbE antibody typically selectively binds to both glycosylated and non-glycosylated HbE with a binding reactivity in which there is less than a three-fold reactivity difference, typically less than a two-fold reactivity difference, between binding to glycosylated vs. non-glycosylated HbE.

Anti-HbD antibodies

[0065] HbD has a glutamine substituted for a glutamic acid at position 121 of the hemoglobin beta chain. An anti-HbD monoclonal antibody of the invention is typically at least 3-fold, or greater more reactive with HbD in comparison to HbA. In some embodiments, the antibody binds to the minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8). In some embodiments, the antibody has a binding specificity where residues ¹¹⁹G, ¹²¹QF¹²², and ¹²⁴PP¹²⁵ are important for binding.

[0066] In some embodiments, an antibody that binds to a HbD minimal epitope, *e.g.*, ¹²¹QFTPP¹²⁵ (SEQ ID NO:8), may bind to variants of the HbE minimal epitope that have the Q at position 121, such as a minimal epitope comprising ¹¹⁹GX₆QFX₇PP¹²⁵ (SEQ ID NO:9) or ¹²¹QFX₇PP¹²⁵ (SEQ ID NO:10), where X₆ and X₇ can be independently selected from the 20 common naturally occurring amino acids, *e.g.*, conservative substitutions of K and T, respectively.

[0067] The antibody typically is an IgG, *e.g.*, the antibody may have an IgG1 or IgG2 isotype. In some embodiments, the light chain constant region is a kappa chain. In other embodiments, the light chain constant region may be a lambda chain.

[0068] An anti-HbD antibody of the invention can be raised, for example, against the immunogen H6-KLH: H₂N-CYGVLAHHFGKQFTPPVQAA-CONH₂ (SEQ ID NO:32), or against mixtures of native and/or denatured HbD and H6-KLH: H₂N-CYGVLAHHFGKQFTPPVQAA-CONH₂ (SEQ ID NO:32), or by using combinations of, or sequential injections of, the various immunogens. Other immunogenic peptides useful in obtaining an antibody having the desired HbD binding specificity will be readily apparent to those skilled in the art.

[0069] An anti-HbD antibody typically binds to both glycosylated and nonglycosylated forms of HbD with similar affinity. For example, an anti-HbD antibody typically selectively binds to both glycosylated and non-glycosylated HbD with a binding reactivity in which there is less than a three-fold reactivity difference, typically less than a two-fold reactivity difference, between binding to glycosylated vs. non-glycosylated HbD.

Pan-reactive antibodies

[0070] The invention also provides pan-reactive antibodies for use in the invention. Such antibodies bind to multiple forms of hemoglobin. Pan-reactive antibodies can be produced using a number of different immunogens, including H5bis-KLH: H₂N-CYGV¹TALWGKVN²VDEVGGK-CONH₂ (SEQ ID NO:29) or H1-KLH: H₂N-VHLTPEEKSAVTALW-C-CONH₂ (SEQ ID NO:23). Such peptide immunogens can be injected either in a mixture with native or denatured HbA₀, or sequentially with native and/or denatured HbA₀. As understood in the art, any number of Hb immunogens can be used to obtain a Hb antibody that selectively binds to HbA₀ as well as Hb variants. Pan-reactive antibodies may be monoclonal or polyclonal. Pan-reactive antibodies can also be obtained by immunization with native or denatured hemoglobin without using peptide immunogens.

[0071] In some embodiments, a pan-reactive polyclonal antibody for use in the invention binds to one or more epitopes present in the following regions of alpha globin and beta globin: alpha globin ⁴⁹SHGSAQVKGHGKKVADALTNAVAHVDDMPNALSALSDHLHAHKLRRVDPV⁹⁶ (SEQ ID NO:11), beta globin ¹⁵WGKVN²⁰VDEVGGEALG²⁹ (SEQ ID NO:12), ⁴⁵FGDLSTP⁵¹ (SEQ ID NO:13), and ⁷⁶AHLDNLKGT⁸⁷FAT⁸⁷ (SEQ ID NO:14).

[0072] In one embodiment, a pan-reactive antibody binds to the beta globin epitope ⁹SAVTALWGKVN²⁰ (SEQ ID NO:15). In some embodiments, the antibody binds to the beta globin epitope ¹¹VTALW¹⁵ (SEQ ID NO:17). In some embodiments ¹¹VT¹² and ¹⁴LW¹⁵ are important for binding.

[0073] In some embodiments, a pan-reactive antibody binds to beta and alpha globin epitopes that contain the following sequences: a beta globin minimal epitope ⁸KSAVTALWGKVN²⁰ (SEQ ID NO:16), a beta globin minimal epitope ⁵⁸PKVKAHGKKVLGAF⁷¹ (SEQ ID NO:20) and a beta globin minimal epitope ⁸⁷TLSELHCDKLHVDPENFR¹⁰⁴ (SEQ ID NO:21). In some embodiments residues ¹³ALWG¹⁶ (SEQ ID NO:18) are important for binding.

[0074] The antibody typically is an IgG, *e.g.*, the antibody may have an IgG1, IgG2, or IgG3 isotype. In some embodiments, the light chain constant region is a kappa chain. In other embodiments, the light chain constant region may be a lambda chain.

[0075] A pan-reactive antibody used in the invention is broadly reactive to hemoglobin and binds to both glycosylated and non-glycosylated forms of hemoglobin A and variants such as HbS, HbC, HbD, and HbE.

[0076] In some embodiments of the invention, a pan-reactive antibody that binds to multiple forms of hemoglobin is used as a labeled binding member that binds to all of the analytes, thereby labeling the bound analytes. Thus, for example, a labeled pan-reactive polyclonal antibody that

binds to the epitopes: alpha globin

⁴⁹SHGSAQVKGHGKKVADALTNAVAHVDDMPNALSALSDHLHAHKLRRVDPV⁹⁶ (SEQ ID NO:11), beta globin ¹⁶GKVNVDDEVGGEALG²⁹ (SEQ ID NO:42), ⁴⁶GDLSTP⁵¹ (SEQ ID NO:43), and ⁷⁸LDNLKGTFTAT⁸⁷ (SEQ ID NO:44) can be used as a universal detection antibody that binds to all of the analytes (forms of hemoglobin) being assayed, thereby labeling the bound analytes.

Anti-HbA_{1c} antibodies

[0077] The invention additionally provides anti-HbA_{1c} antibodies that have a binding specificity for glycosylated hemoglobin. Such antibodies can be produced using an immunogen such as GP3-KLH: 1-deoxyfructopyranosyl-HN-VHLTPEE-Hx-C-CONH₂ (SEQ ID NO:38). The antibody can be an IgG, for example, and can have an IgG₁, IgG₂, or IgG₃ isotype. In some embodiments, the light chain constant region is a lambda chain. In other embodiments, the light chain constant region is a kappa chain.

[0078] An anti-HbA_{1c} antibody of the invention is highly specific for glycosylated hemoglobin, including HbA_{1c}, HbS_{1c}, HbD_{1c}, HbE_{1c}, and HbC_{1c}, and does not recognize non-glycosylated forms of hemoglobin (*i.e.*, the antibody has at least a 100-fold greater affinity for HbA_{1c}, HbS_{1c}, HbD_{1c}, HbE_{1c}, and HbC_{1c} than for the non-glycosylated forms). Such antibodies typically have a binding specificity for glycosylated N-terminal peptide where both glycosylated valine 1 and histidine 2 are important residues for binding.

[0079] An A_{1c} monoclonal antibody has a binding specificity in competitive binding experiments such that the glycosylated peptide GP3 (1-deoxyfructopyranosyl-HN-VHLTPEE-Hx-C-

CONH₂; SEQ ID NO:38) competes for binding to native HbA_{1c}, but unglycated peptides such as RW1a (VHLTPEE-CONH₂; SEQ ID NO:45) do not.

HbF and HbA₂ antibodies

5 [0080] HbF and HbA₂ can also be assayed using the methods of the invention. Antibodies that selectively bind to HbF relative to HbA₀ or other Hb proteins; or to HbA₂ relative to HbA₀ or other Hb proteins, can be obtained using immunogens comprising peptide sequences that are specific to HbF or sequences that are specific to HbA₂, as there are multiple differences in the delta and gamma chains relative to the A₀ beta chain.

Generation of antibodies

10 [0081] The anti-hemoglobin antibodies of the invention can be raised against hemoglobin proteins, or fragments, or produced recombinantly. Any number of techniques well known in the art can be used to determine antibody binding specificity. See, e.g., Harlow & Lane, Antibodies, A Laboratory Manual (1988) for a description of immunoassay formats and conditions that can be used to determine specific immunoreactivity of an antibody

15 [0082] In some embodiments, an antibody for use in the invention, e.g., a hemoglobin antibody that binds various forms of hemoglobin, a hemoglobin antibody specific for a variant, or a hemoglobin antibody specific for glycated hemoglobin, is a polyclonal antibody. For example, an antibody specific for a hemoglobin variant can be an affinity-purified monospecific polyclonal antibody. Methods of preparing polyclonal antibodies are known to the skilled artisan (e.g.,
20 Harlow & Lane, Antibodies, A Laboratory manual (1988); Methods in Immunology). Polyclonal antibodies can be raised in a mammal by one or more injections of an immunizing agent and, if desired, an adjuvant.

[0083] In some embodiments, the antibody for use in the invention, e.g., an antibody that binds to multiple forms of hemoglobin, an antibody that is specific for a hemoglobin variant (and the
25 glycated hemoglobin variant), or an antibody that is specific for glycated hemoglobin, is a monoclonal antibody. Monoclonal antibodies may be prepared using hybridoma methods, such

as those described by Kohler & Milstein, *Nature* 256:495 (1975). In a hybridoma method, a mouse, rat, rabbit, or other appropriate host animal, is typically immunized with an immunizing agent to elicit lymphocytes that produce or are capable of producing antibodies that will specifically bind to the immunizing agent. Alternatively, the lymphocytes may be immunized *in vitro*.

[0084] As stated above, antibodies of the invention can be generated using any number of immunogens and immunization protocols. In some embodiments, the immunogen is a peptide that is administered in combination with a native or denatured hemoglobin protein. As understood in the art, an immunogen may be administered multiple times. In embodiments in which a combination is employed, the combination of antigens may be administered concurrently, or sequentially, in any order. In some embodiments, a peptide immunogen is a KLH conjugate, however, carrier proteins other than KLH can be used, *e.g.*, BSA conjugates can be used.

Assay conditions using the antibodies

[0085] In the practice of this invention, hemoglobin A_{1c}, hemoglobin variants, and total hemoglobin can be measured via a variety of immunoassay formats. One example is the sandwich format, in which a specific antibody to the analyte is attached to the solid phase bead, and detection is accomplished by interrogating the beads with one or more antibodies to the hemoglobin species. A universal antibody which binds to all hemoglobin species can be used for the interrogation, but two or more detection antibodies can also be used. An example is shown in FIG. 1, where individual antibodies are used that are specific to total hemoglobin, HbA_{1c}, and the four most prevalent hemoglobin variation species HbS, HbC, HbE, and HbD, respectively, are bound to separate subpopulations of beads, while a universal antibody that binds to all hemoglobin species and that bears phycoerythrin (PE) as a label is used. In a sandwich assay format, the quantity of antibody for each assay is selected such that the analyte (the particular form of hemoglobin to which the assay is directed) is in excess, so that the antibodies are the limiting reagents in the binding reactions. Competition between the antibody for total hemoglobin and the antibodies for the individual hemoglobins, for example, is thereby minimized. By adjusting the assay parameters and selection of the appropriate antibodies in a manner within the skill of the art, however, a competitive assay format can also be utilized for multiplexed detection of hemoglobin species.

[0086] While the multiplex assay can be utilized on mammalian blood samples in general, the assay is of particular value to samples of human blood. Blood samples are prepared for the assay by lysis of the cells and dilution of the lysate to a concentration suitable for immunoassay. Each of these steps is performed by methods known in the art. Dilution can be achieved with water, solutions containing saponin, or any other diluent that will not affect the hemoglobins or their immunological binding activity, and the degree of dilution can vary widely. In most cases, the dilution will be within the range of about 1:25 to about 1:3000. The hemoglobins in the lysate can be denatured before or after dilution of the lysate and used in the assay, or the lysate can be used without denaturation of the hemoglobins. In most cases, denaturation is preferred, and can be performed by methods known in the art.

[0087] The levels of HbA_{1c} and each of the variants are preferably each expressed as a percentage of total hemoglobin in the sample. For determinations of degrees of glycation in the presence of a hemoglobin variant, the invention offers three options. One option, which is compatible with the currently accepted method, is the determination of the HbA_{1c} level by the result from the HbA_{1c} bead only, normalized to total hemoglobin. The second option is the determination of the total hemoglobin glycation by adding the percent of the glycated form of the variant to the percent HbA_{1c}. The third option, which is useful in the event that the determination of HbA_{1c} is adversely affected by the presence of the variant, is to adjust the as-measured percent HbA_{1c} by a correction factor that is a function of the detected level of the variant. The function can be determined empirically by a relation that can be independently determined by separate assays, including non-multiplex assays. The correction factor can be one that is applied either to the HbA_{1c} concentration after the concentration has been normalized with respect to total hemoglobin, or to the concentration prior to normalization.

[0088] To illustrate the correction of the HbA_{1c} value, assays were performed on samples from ten patients, using both a bead-based assay (BioPlex 2200™ of Bio-Rad Laboratories, Inc., Hercules, California, USA) in accordance with the present invention and an HPLC assay (Variant™ II of Bio-Rad Laboratories, Inc.), both assays determining percent HbA_{1c} as a function of increasing percentage of HbC. The results are shown in Table 3 and in FIG. 2, in which the "Difference Ratio" = (%A_{1c} Variant II - %A_{1c} BioPlex 2200)/(%A_{1c} Variant II).

Table 3

Patient ID	% HbC	-----% A _{1c} -----		Difference Ratio	Adjusted BioPlex Value	Difference from Target	
		BioPlex 2200	Variant II (Target)			Adjusted	Unadjusted
PT 200	31.8	6.06	5.9	-0.03	5.73	0.17	-0.16
PT 219	32.1	6.30	5.8	-0.09	5.98	-0.18	-0.50
PT 265	33.7	5.71	5.4	-0.06	5.37	0.03	-0.31
PT 622	34.1	6.20	5.9	-0.05	5.87	0.03	-0.30
PT 658	33.9	5.92	5.9	0.00	5.59	0.31	-0.02
PT 667	33.5	6.00	5.8	-0.03	5.67	0.13	-0.20
PT m832	32.1	6.14	6.1	-0.01	5.81	0.29	-0.04
PT m837	37.6	5.80	5.5	-0.05	5.47	0.03	-0.30
PT m908	39.2	5.37	4.6	-0.17	5.03	-0.43	-0.77
PT m923	41.1	5.53	4.8	-0.15	5.19	-0.39	-0.73
average difference →						0.00	-0.33

[0089] While various mathematical models can be used to quantify the relationship of the percent HbA_{1c} difference as a function of percent hemoglobin C (or any hemoglobin variant), the mathematical model used in this example is a simple linear regression model. Using this model, the values obtained from the BioPlex 2200 immunoassay can be corrected to yield a result comparable to the reference method. This is demonstrated by the average difference of the adjusted BioPlex 2200 percent HbA_{1c} value relative to the target percent HbA_{1c} value determined by the reference Variant II method. In Table 3 and FIG. 2, the average difference is zero for the adjusted HbA_{1c} values compared to -0.33 for the corresponding unadjusted values. The corrected HbA_{1c} value shown in the table provides a better estimate of the glycemic index of the individual.

[0090] The BioPlex 2200 bead-based immunoassay used in the obtaining the data in Table 3 and FIG. 2 utilizes an antibody that binds HbA_{1c} and all hemoglobin variants including HbS, HbC, HbD, and HbE. All glycosylated variants and HbA₀ are bound with approximately the same affinity and avidity by the antibody. The immunoassay result thus represents total glycosylated hemoglobin, which in the case of a heterozygous hemoglobin AS variant, is the combined value that includes both the HbA_{1c} and HbS_{1c} species. In individuals exhibiting a hemoglobin variant phenotype, the proportion of the glycosylated hemoglobin corresponding to the variant provides an improved measure of glycemic status. The percent HbS_{1c} in the sample is obtained by multiplying the total percent HbA_{1c} plus HbS_{1c} value by the proportion of HbS in the sample.

For example, for a patient sample with a total glycosylated hemoglobin value of 5.54% (consisting of HbA_{1c} and HbS_{1c}), multiplying this value by the proportion of HbS in the sample of 38.8% yields a value for HbS_{1c} of 2.14%. The remainder of the glycosylated material is HbA_{1c} at 3.4%. This again is but one mathematical model; more sophisticated mathematical models can be used to provide more accurate results as needed.

[0091] The beads that provide the surfaces on which the binding reactions occur in the practice of this invention can be formed of any material that is inert to the assay materials and to the components of the sample itself, and that is solid and insoluble in the sample and in any other solvents or carriers used in the assay. Polymers are preferred, and the beads are preferably microparticles. The polymeric can be any material that can be formed into a microparticle and is capable of coupling to an antibody at a region on the antibody that does not interfere with the antigen-binding regions of the antibody. In embodiments in which fluorescent labels are used, preferred polymers are also those that produce at most a minimal level of autofluorescence. Examples of suitable polymers are polyesters, polyethers, polyolefins, polyalkylene oxides, polyamides, polyurethanes, polysaccharides, celluloses, and polyisoprenes. Crosslinking is useful in many polymers for imparting structural integrity and rigidity to the microparticle. Magnetic beads can also be used.

[0092] Attachment of the antibodies to the surfaces of the beads can be achieved by electrostatic attraction, specific affinity interaction, hydrophobic interaction, or covalent bonding. Covalent bonding is preferred. Functional groups for covalent bonding can be incorporated into the polymer structure by conventional means, such as the use of monomers that contain the functional groups, either as the sole monomer or as a co-monomer. Examples of suitable functional groups are amine groups ($-\text{NH}_2$), ammonium groups ($-\text{NH}_3^+$ or $-\text{NR}_3^+$),

hydroxyl groups (—OH), carboxylic acid groups (—COOH), and isocyanate groups (—NCO). Useful monomers for introducing carboxylic acid groups into polyolefins, for example, are acrylic acid and methacrylic acid. Linking groups can also be used for increasing the density of the antibodies on the solid phase surface and for decreasing steric hindrance to increase the range and sensitivity of the assay. Examples of suitable useful linking groups are polylysine, polyaspartic acid, polyglutamic acid and polyarginine.

[0093] The size range of the beads can vary and particular size ranges are not critical to the invention. In most cases, the aggregated size range of the beads lies within the range of from about 0.3 micrometers to about 100 micrometers in diameter, and preferably within the range of from about 0.5 micrometers to about 40 micrometers.

[0094] Multiplexing with the use of beads in accordance with this invention is achieved by assigning the beads to two or more groups, also referred to herein as bead sets or subpopulations. Each group will have affixed thereto an antibody selected for either a hemoglobin variant, a glycated variant, HbA_{1c} , or total hemoglobin, and will be separable or at least distinguishable from the other group(s) by a “differentiation parameter.” The “differentiation parameter” can be any distinguishable characteristic that permits separate detection of the assay result in one group from those in the other groups. One example of a differentiation parameter is the particle size, with each group having a size range that does not overlap with the size ranges of the other groups. The widths of the size ranges and the spacing between mean diameters of different size ranges are selected to permit differentiation of the groups by flow cytometry according to size, and will be readily apparent to those skilled in the use of and instrumentation for flow cytometry. In this specification, the term “mean diameter” refers to a number average diameter. In most cases, a preferred size range width is one with a CV of about $\pm 5\%$ or less of the mean diameter, where CV is the coefficient of variation and is defined as the standard deviation of the particle diameter divided by the mean particle diameter times 100 percent. The minimum spacing between mean diameters among the various size ranges can vary depending on the size distribution, the ease of segregating beads by size for purposes of attaching different antibodies, and the type and sensitivity of the flow cytometry equipment. In most cases, best results will be achieved when the mean diameters of different size ranges are spaced apart by at least about 6% of the mean diameter of one of the size ranges, preferably at least about 8% of the mean diameter of one of the size ranges and most preferably at least about 10% of the mean diameter of one of the size ranges. Another preferred size range width relation is that in which the standard

deviation of the particle diameters within each size range is less than one third of the separation of the mean diameters of adjacent size ranges.

[0095] Another example of a differentiation parameter that can be used to distinguish among the various groups of beads is fluorescence. Differentiation by fluorescence is accomplished by
5 incorporating fluorescent materials in the beads, the materials having different fluorescent emission spectra for each group of beads and being distinguishable on this basis.

[0096] Fluorescence can thus be used both as a differentiation parameter and as a means for detecting that binding has occurred in the assays performed on the beads. The latter can be achieved by fluorescent labels serving as assay reporters. Thus, while individual groups can be
10 distinguished by emitting different emission spectra, and the emission spectra used for group differentiation purposes can themselves differ from the emission spectra of the assay reporters. An example of a fluorescent substance that can be used as a differentiation parameter is fluorescein and an example of a substance that can be used for the assay detection is phycoerythrin. Different bead groups can be distinguished from each other by being dyed with
15 different concentrations of fluorescein. Different bead groups can be distinguished by using fluorescent materials that have different fluorescence intensities or that emit fluorescence at different wavelengths. The dyes can also be used in combinations to produce a plurality of fluorescent emissions at different wavelengths, and the wavelength difference can be used both as the differentiation parameter and as a means of distinguishing the differentiation parameter
20 from the assay reporter.

[0097] Still other examples of useful differentiation parameters are light scatter, light emission, or combinations of light scatter and emission. Side-angle light scatter varies with particle size, granularity, absorbance and surface roughness, while forward-angle light scatter is mainly affected by size and refractive index. Any of these qualities can thus be used as the
25 differentiation parameter.

[0098] According to one means of differentiation, the beads will have two or more fluorochromes incorporated within them so that each bead in the array will have at least three distinguishable parameters associated with it, *i.e.*, side scatter together with fluorescent emissions at two separate wavelengths. A red fluorochrome such as Cy5 can thus be used
30 together with an orange fluorochrome such as Cy5.5. Additional fluorochromes can be used to

expand the system further. Each bead can thus contain a plurality of fluorescent dyes at varying wavelengths.

[0099] Still another example of a differentiation parameter that can be used to distinguish among the various groups of beads is absorbance. When light is applied to beads the absorbance of the light by the beads is indicated mostly by the strength of the laterally (side-angle) scattered light while the strength of the forward-scattered light is relatively unaffected. Consequently, the difference in absorbance between various colored dyes associated with the beads is determined by observing differences in the strength of the laterally scattered light.

[0100] A still further example of a differentiation parameter that can be used to distinguish among the various groups of beads is the number of beads in each group. The number of beads of each group in an assay is varied in a known way, and the count of beads having various assay responses is determined. The various responses are associated with a particular assay by the number of beads having each response.

[0101] As the above examples illustrate, a wide array of parameters or characteristics can be used as differentiation parameters to distinguish the beads of one group from those of another. The differentiation parameters may arise from size, composition, physical characteristics that affect light scattering, excitable fluorescent or colored dyes that impart different emission spectra and/or scattering characteristics to the beads, or different concentrations of one or more fluorescent dyes. When the differentiation parameter is a fluorescent dye or color, it can be coated on the surface of the beads, embedded in the beads, or bound to the molecules of the bead material. Thus, fluorescent beads can be manufactured by combining the polymer material with the fluorescent dye, or by impregnating the beads with the dye. Beads with dyes already incorporated and thereby suitable for use in the present invention are commercially available, from suppliers such as Spherotech, Inc. (Libertyville, Illinois, USA) and Molecular Probes, Inc. (Eugene, Oregon, USA). A list of vendors of flow cytometric products can be found on the Internet, *e.g.*, at the world wide web molbio.princeton.edu/facs/FCMsites.html site.

[0102] Detection and differentiation in accordance with this invention are performed by flow cytometry. Methods of and instrumentation for flow cytometry are known in the art, and those that are known can be used in the practice of the present invention. Flow cytometry in general resides in the passage of a suspension of beads or microparticles as a stream past a light beam and electro-optical sensors, in such a manner that only one particle at a time passes through the

region. As each particle passes this region, the light beam is perturbed by the presence of the particle, and the resulting scattered and fluorescent light are detected. The optical signals are used by the instrumentation to identify the subgroup to which each particle belongs, along with the presence and amount of label, so that individual assay results are achieved.

- 5 Descriptions of instrumentation and methods for flow cytometry are found in the literature. Examples are McHugh, "Flow Microsphere Immunoassay for the Quantitative and Simultaneous Detection of Multiple Soluble Analytes," *Methods in Cell Biology* **42**, Part B (Academic Press, 1994); McHugh *et al.*, "Microsphere-Based Fluorescence Immunoassays Using Flow Cytometry Instrumentation," *Clinical Flow Cytometry*, Bauer, K.D., *et al.*, eds.
- 10 (Baltimore, Maryland, USA: Williams and Williams, 1993), pp. 535-544; Lindmo *et al.*, "Immunometric Assay Using Mixtures of Two Particle Types of Different Affinity," *J. Immunol. Meth.* **126**: 183-189 (1990); McHugh, "Flow Cytometry and the Application of Microsphere-Based Fluorescence Immunoassays," *Immunochemica* **5**: 116 (1991); Horan *et al.*, "Fluid Phase Particle Fluorescence Analysis: Rheumatoid Factor Specificity Evaluated by
- 15 Laser Flow Cytophotometry," *Immunoassays in the Clinical Laboratory*, 185-189 (Liss 1979); Wilson *et al.*, "A New Microsphere-Based Immunofluorescence Assay Using Flow Cytometry," *J. Immunol. Meth.* **107**: 225-230 (1988); Fulwyler *et al.*, "Flow Microsphere Immunoassay for the Quantitative and Simultaneous Detection of Multiple Soluble Analytes," *Meth. Cell Biol.* **33**: 613-629 (1990); Coulter Electronics Inc., United Kingdom Patent No.
- 20 1,561,042 (published February 13, 1980); and Steinkamp *et al.*, *Review of Scientific Instruments* **44**(9): 1301-1310 (1973).

EXAMPLE 1

[0103] This example presents the binding activities of six hemoglobin candidate antibodies for use in the practice of this invention. The six antibodies are:

- | | | |
|----|-----------------------------|--|
| 25 | 19E10-E7 (HbS specific) | 7B3-2C3-1G10 (HbD specific) |
| | 12C8-A11 (HbC specific) | 13G7-E8-3H3 (HbA _{1c} specific) |
| | 4A10-2D6-2G8 (HbE specific) | 3E5-DLE10-3A3 (pan-reactive). |

[0104] 19E10-E7 binds to a beta globin minimal epitope ⁵PVEKSAVT¹² (SEQ ID NO:40). ⁵PVE⁷ and A¹⁰ are important for binding. L³ and T⁴ also contribute to binding activity. Additional epitope mapping experiments showed that V⁶ can be replaced with I without loss of binding activity.

5 [0105] 12C8-A11 binds to a beta globin minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1). T⁴ and K⁶ are important for binding. L³ also contributes to binding. Additional epitope mapping experiments showed that K⁶ can be replaced with R without reducing binding activity.

10 [0106] 4A10-2D6-2G8 binds a beta globin minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6). ²²EV²³ and K²⁶ are important for binding. D²¹ also contributes to binding. Additional epitope mapping experiments showed that K²⁶ can be replaced with S or T without loss of binding activity.

[0107] 7B3-2C3-1G10 binds to a beta globin minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8). G¹¹⁹ also contributes to binding.

15 [0108] The antibody binding kinetics were analyzed using the ProteOn XPR36™ (Bio-Rad Laboratories, Inc.) for protein-protein interactions. The different antibodies (10 µg of each) were amine-coupled to the sensor chip such that one antibody was immobilized per channel. Antigen was employed in the range of from 200 to 13 nM. The results of the kinetic analysis are summarized in Table 4 below.

20 [0109] Each antibody had a high affinity for its specific hemoglobin. The pan-reactive antibody also had good affinity constants to the different antigens, but lower than the affinity constant exhibited by the specific variant antibodies for their respective antigens. Except for 19E10-E7, all of the variant antibodies did not bind HbA0, so the affinity constants were essentially zero. For the 19E10-E7 anti-HbS antibody, a low level of binding to HbA0 was
25 observed, with an affinity constant of 6.5×10^{-7} M, which is 2 logs less than the affinity constant for HbS.

Table 4

Kinetics analysis for 6 specific monoclonal antibodies to hemoglobin and hemoglobin variants

19E10-E7	k_a (1/Ms)	K_d (1/s)	K_D (M)
HbS	$7.6 \cdot 10^4$	$6.3 \cdot 10^{-4}$	$8.3 \cdot 10^{-9}$
12C8-A11	k_a (1/Ms)	K_d (1/s)	K_D (M)
HbC	$7.3 \cdot 10^4$	$4.5 \cdot 10^{-4}$	$6.1 \cdot 10^{-9}$
4A10-2D6	k_a (1/Ms)	K_d (1/s)	K_D (M)
HbE	$7.1 \cdot 10^4$	$6.2 \cdot 10^{-5}$	$8.7 \cdot 10^{-10}$
7B3-2C3	k_a (1/Ms)	K_d (1/s)	K_D (M)
HbD	$1.4 \cdot 10^5$	$1.1 \cdot 10^{-3}$	$7.4 \cdot 10^{-9}$
13G7-E8	k_a (1/Ms)	K_d (1/s)	K_D (M)
HbA _{1c}	$1.2 \cdot 10^4$	$2.3 \cdot 10^{-5}$	$1.9 \cdot 10^{-9}$
3E5-DLE10	k_a (1/Ms)	K_d (1/s)	K_D (M)
HbS	$3.9 \cdot 10^4$	$7.9 \cdot 10^{-4}$	$2.0 \cdot 10^{-8}$
HbE	$2.9 \cdot 10^4$	$4.4 \cdot 10^{-4}$	$1.5 \cdot 10^{-8}$
HbD	$3.4 \cdot 10^4$	$1.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-8}$
HbA _{1c}	$3.7 \cdot 10^4$	$9.4 \cdot 10^{-4}$	$2.5 \cdot 10^{-8}$
HbC	$4.5 \cdot 10^4$	$7.4 \cdot 10^{-4}$	$1.6 \cdot 10^{-8}$
HbA0	$1.4 \cdot 10^4$	$3.4 \cdot 10^{-3}$	$2.4 \cdot 10^{-7}$

EXAMPLE 2

[0110] This examples demonstrates the measurement of hemoglobin A_{1c} and hemoglobin
5 variant proteins as percentages of total hemoglobin using a sandwich immunoassay in
accordance with this invention. Solid phase capture bead immunoreagents were developed

utilizing the six monoclonal antibodies specific to HbA₀, HbA_{1c}, HbS, HbC, HbE, and HbD described in Example 1.

[0111] Antibodies to each of the six target antigens were coupled covalently to paramagnetic beads. Each bead was dyed to contain a specific fluorescent signal that was unique to each antibody, to enable subsequent differentiation in a flow cytometry detector. The six antibody-coupled beads were mixed to create a multiplex bead reagent. A detection antibody reagent was prepared using a phycoerythrin-labelled polyclonal antibody with reactivity to all hemoglobin species. A diagram of the various beads and the species bound to each in the assay is shown in FIG. 1.

[0112] The assay was performed by adding samples of whole blood and calibrators (5μL) to a solution of buffered denaturant (10μL), to expose all of the epitopes of the hemoglobin species present in the samples in order to make them available for binding by the solid phase antibodies. After denaturation for 10 minutes at 37 degrees, the bead reagent (250 μL) was added to the samples, followed by an additional incubation for 20 minutes at 37 degrees. The reaction mixture was washed four times with phosphate-buffered saline containing 0.1% Tween-20™ (PBST, 100 μL each) detergent to remove all of the unbound proteins from the sample, leaving the beads with their bound hemoglobin targets. The beads were re-suspended in PBST containing phycoerythrin-labelled antibody reagent (25 μL), and incubated for 20 minutes at 37 degrees Celsius.

[0113] After washing four times with PBST (100 μL each), the beads were resuspended in PBST and processed through a Luminex™ flow cytometry detector to interrogate the beads for binding of the individual hemoglobin species present in the samples. For example, samples from homozygous hemoglobin AA individuals exhibited signal from the HbA_{1c} and HbA₀ beads, and samples from heterozygous hemoglobin variant individuals exhibited signal from the HbA₀, HbA_{1c} and the specific hemoglobin variant beads. The phycoerythrin-derived fluorescent signal of each bead was measured for the samples and calibrators. A calibration curve was constructed for each hemoglobin analyte using the signal from the bead and the known dose of the respective calibrators. The concentration of the hemoglobin analytes in each sample was determined from their fluorescent signal and the established dose-response of the calibration curve. Percent HbA_{1c} and percent hemoglobin variant, if any, in the samples were determined by dividing the concentration of hemoglobin A_{1c} or variant hemoglobin protein by the concentration of HbA₀,

each derived from their respective bead. In the case of heterozygous hemoglobin variant-containing samples (such as HbAS, for example), the percent A_{1c} value derived from the ratio of the A_{1c} to HbA₀ concentrations was adjusted when needed using the concentration of the hemoglobin variant present in the sample, to provide a value that best reflected the true
5 glycemic index of the individual.

[0114] In the claims appended hereto, the term “a” or “an” is intended to mean “one or more.” The term “comprise” and variations thereof such as “comprises” and “comprising,” when preceding the recitation of a step or an element, are intended to mean that the addition
10 of further steps or elements is optional and not excluded. Any discrepancy between any reference material cited herein or any prior art in general and an explicit teaching of this specification is intended to be resolved in favor of the teaching in this specification. This includes any discrepancy between an art-understood definition of a word or phrase and a definition explicitly provided in this specification of the same word or phrase.

What is claimed is:

1. A method for individually detecting a plurality of hemoglobin-containing analytes comprising HbA_{1c}, and at least a first hemoglobin variant, if present, selected from the group consisting of HbS, HbC, HbE, and HbD in a single sample of blood cell lysate, said method comprising:

(a) incubating said sample with a population of beads, said population consisting of a plurality of subpopulations in a common mixture, each bead of said population having bonded thereto one of a plurality of classifier dyes that are equal in number to said analytes and that are selected such that said classifier dyes, and thereby said subpopulations, are differentiable from each other by fluorescent emissions emitted by said classifier dyes upon excitation, each said subpopulation further having bonded thereto an antibody having selective binding affinity toward one of said analytes, to cause each analyte to bind to a different bead subpopulation through the antibodies bonded to said subpopulations, wherein an antibody having selective binding affinity for the first hemoglobin variant selectively binds the first hemoglobin variant and its glycated form;

(b) with said analytes bound to the beads of said subpopulations, incubating said population with a labeled antibody that binds to all of said analytes, thereby labeling said analytes thus bound; and

(c) with said bound analytes so labeled, detecting labels bound to said bound analytes while differentiating said labels so detected according to subpopulations by fluorescent emissions, thereby individually detecting said analytes.

2. The method of claim 1, wherein the antibody having selective binding affinity for the first hemoglobin variant is a monoclonal antibody.

3. The method of claim 1 or 2, wherein said method comprises individually detecting a second hemoglobin variant, if present, selected from the group consisting of HbS, HbC, HbE, and HbD, and wherein an antibody having selective binding affinity for the second hemoglobin variant selectively binds the second hemoglobin variant and its glycated form.

4. The method of claim 3, wherein the antibody having selective binding affinity for the second hemoglobin variant is a monoclonal antibody.

5. The method of any one of claims 1 to 4, wherein an antibody having selective binding affinity for HbA1c is a monoclonal antibody.

6. The method of any one of claims 1 to 5, wherein an antibody having selective binding affinity for HbC and its glycated form binds to a HbC minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1).

7. The method of any one of claims 1 to 6, wherein an antibody having selective binding affinity for HbS and its glycated form binds to a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3).

8. The method of any one of claims 1 to 7, wherein an antibody having selective binding affinity for HbE and its glycated form binds to a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK²⁶ (SEQ ID NO:7).

9. The method of any one of claims 1 to 8, wherein an antibody having selective binding affinity for HbD and its glycated form binds to a HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8) or ¹¹⁹GKQFTPP¹²⁵ (SEQ ID NO:46).

10. The method of any one of claims 1 to 9, wherein the first hemoglobin variant is HbC.

11. The method of any one of claims 1 to 9, wherein the first hemoglobin variant is HbS.

12. The method of any one of claims 1 to 9, wherein the first hemoglobin variant is HbE.

13. The method of any one of claims 1 to 9, wherein the first hemoglobin variant is HbD.

14. The method of any one of claims 1 to 13, wherein said plurality of bead subpopulations does not include a subpopulation binding to total hemoglobin, and said method further comprises determining total hemoglobin by a non-immunoassay method.

15. The method of any one of claims 1 to 13, wherein said plurality of bead subpopulations comprises a subpopulation with an antibody having selective binding affinity for total hemoglobin.

16. The method of claim 15, wherein said antibody having selective binding affinity toward total hemoglobin is a monoclonal antibody.

17. The method of claim 15 or 16, wherein the antibody having selective binding affinity for total hemoglobin binds to a beta globin chain minimal epitope ⁹SAVTALWGKVNV²⁰ (SEQ ID NO:15), ⁸KSAVTALWGKVNV²⁰ (SEQ ID NO:16), or ¹¹VTALW¹⁵ (SEQ ID NO:17).

18. The method of any one of claims 1 to 13, wherein said plurality of bead subpopulations comprises a subpopulation comprising a polyclonal antibody having selective binding affinity toward total hemoglobin.

19. The method of any one of claims 1 to 18, wherein the blood cell lysate is a denatured blood cell lysate.

20. The method of any one of claims 1 to 19, wherein the sample is from a diabetic patient.

21. A method for determining the proportion of HbA1c relative to total hemoglobin in a sample of blood cell lysate, adjusted for the possible presence in said lysate of at least one hemoglobin variant selected from the group consisting of HbS, HbC, HbE, and HbD that interferes with the measurement of HbA1c, said method comprising:

(a) incubating said sample with a population of beads, said population consisting of a plurality of subpopulations in a common mixture, each bead of said population having bonded thereto one of a plurality of classifier dyes selected such that

said classifier dyes, and thereby said subpopulations, are differentiable from each other by fluorescent emissions emitted by said classifier dyes upon excitation, each said subpopulation further having bonded thereto an antibody having selective binding affinity toward one of a plurality of analytes, said plurality comprising HbA1c and said hemoglobin variant, to cause each of said analytes to bind to a different bead subpopulation through the antibody bonded thereto, wherein an antibody having selective binding affinity for the hemoglobin variant selectively binds the hemoglobin variant and its glycated form;

(b) with said analytes bound to the beads of said subpopulations, incubating said population with a labeled antibody that binds to all of said analytes, thereby labeling said analytes so bound;

(c) with said bound analytes so labeled, detecting labels bound to said bound analytes while differentiating said labels so detected according to subpopulations by fluorescent emissions, thereby individually detecting concentrations of said analytes in said sample; and

(d) determining from said concentrations the proportion of HbA1c relative to total hemoglobin, adjusted for the concentration of said hemoglobin variant by an adjustment factor empirically derived from a predetermined relation between said hemoglobin variant concentration and the concentration of said HbA1c so detected.

22. The method of claim 21, wherein an antibody having selective binding affinity for the hemoglobin variant is a monoclonal antibody.

23. The method of claim 21 or 22, wherein an antibody having selective binding affinity for HbA1c is a monoclonal antibody.

24. The method of claim 21, 22 or 23, wherein said plurality of analytes further comprises total hemoglobin.

25. The method of any one of claims 21 to 23, wherein said plurality of bead subpopulations does not include a subpopulation binding to total hemoglobin, and said method further comprises determining total hemoglobin by a non-immunoassay method.

26. The method of any one of claims 21 to 24, wherein said plurality of bead subpopulations comprises a subpopulation with an antibody having selective binding affinity toward total hemoglobin.

27. The method of claim 26, wherein said antibody having selective binding affinity toward total hemoglobin is a monoclonal antibody.

28. The method of claim 26 or 27, wherein said antibody having selective binding affinity toward total hemoglobin binds to a beta globin chain minimal epitope ⁹SAVTALWGKVN²⁰ (SEQ ID NO:15), ⁸KSAVTALWGKVN²⁰ (SEQ ID NO:16), or ¹¹VTALW¹⁵ (SEQ ID NO:17).

29. The method of any one of claims 21 to 24, wherein said plurality of bead subpopulations comprises a subpopulation with a polyclonal antibody having selective binding affinity toward total hemoglobin.

30. The method of any one of claims 21 to 29, wherein the blood cell lysate is a denatured blood cell lysate.

31. The method of any one of claims 21 to 30, wherein an antibody having selective binding affinity for HbC and its glycated form binds to a HbC minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1).

32. The method of any one of claims 21 to 31, wherein an antibody having selective binding affinity for HbS and its glycated form binds to a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3).

33. The method of any one of claims 21 to 32, wherein an antibody having selective binding affinity for HbE and its glycated form binds to a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK² (SEQ ID NO:7).

34. The method of any one of claims 21 to 33, wherein an antibody having selective binding affinity for HbD and its glycated form binds to a HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8) or ¹¹⁹GKQFTPP¹²⁵ (SEQ ID NO:46).

35. The method of any one of claims 21 to 34, wherein said hemoglobin variant is HbC.

36. The method of any one of claims 21 to 34, wherein said hemoglobin variant is HbS.

37. The method of any one of claims 21 to 34, wherein said hemoglobin variant is HbE.

38. The method of any one of claims 21 to 34, wherein said hemoglobin variant is HbD.

39. The method of any one of claims 21 to 38, wherein the sample is from a diabetic patient.

40. A method for determining the proportion of a glycated form of a hemoglobin variant wherein the hemoglobin variant is selected from the group consisting of HbS, HbC, HbE, and HbD relative to total hemoglobin in a sample of blood cell lysate, said method comprising:

(a) incubating said sample with a population of beads, said population consisting of a plurality of subpopulations in a common mixture, each bead of said population having bonded thereto one of a plurality of classifier dyes selected such that said classifier dyes, and thereby said subpopulations, are differentiable from each other by fluorescent emissions emitted by said classifier dyes upon excitation, each said subpopulation further having bonded thereto one of a plurality of antibodies comprising:

a first such antibody having selective binding affinity for a first analyte consisting of both said glycated form of the hemoglobin variant and HbA1c, and

a second such antibody having selective binding affinity for a second analyte consisting of both said hemoglobin variant and said glycated form of the hemoglobin variant,

to cause said first analyte and said second analyte to bind to said first and second antibodies, respectively;

(b) with said first and second analytes so bound, incubating said population with a labeled antibody that binds to all of said analytes, thereby labeling said analytes so bound;

(c) with said bound analytes so labeled, detecting said labels while differentiating said labels so detected according to subpopulations by fluorescent emissions, thereby detecting concentrations of said first and second analytes in said sample; and

(d) determining a concentration of total hemoglobin, and determining from said concentrations the proportion of said first analyte relative to total hemoglobin, and adjusting said proportion for the concentration of said second analyte relative to total hemoglobin by an adjustment factor empirically derived from a predetermined relation between said hemoglobin variant concentration and the concentration of total hemoglobin so detected, thereby determining the proportion of a glycated hemoglobin variant relative to total hemoglobin.

41. The method of claim 40, wherein one or both of the first and second antibodies is a monoclonal antibody.

42. The method of claim 41, wherein both antibodies are monoclonal antibodies.

43. The method of claim 40, 41 or 42, wherein said plurality of antibodies further comprises a third such antibody having selective binding affinity for total hemoglobin.

44. The method of claim 43, wherein the third antibody is a monoclonal antibody.

45. The method of claim 43 or 44, wherein the third antibody binds to a beta globin chain minimal epitope ⁹SAVTALWGKVN²⁰ (SEQ ID NO:15), ⁸KSAVTALWGKVN²⁰ (SEQ ID NO:16), or ¹¹VTALW¹⁵ (SEQ ID NO:17).

46. The method of claim 43, wherein the third antibody is a polyclonal antibody.

47. The method of claim 40, 41 or 42, wherein said plurality of antibodies does not include an antibody having selective binding affinity for total hemoglobin, and said concentration of total hemoglobin step (d) is determined by a non-immunoassay method.

48. The method of any one of claims 40 to 47, wherein said second analyte is HbC and its glycated form and the second antibody binds to a HbC minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1).

49. The method of any one of claims 40 to 47, wherein the second analyte is HbS and its glycated form and the second antibody binds to a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3).

50. The method of any one of claims 40 to 47, wherein the second analyte is HbE and its glycated form and the second antibody binds to a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK²⁶ (SEQ ID NO:7).

51. The method of any one of claims 40 to 47, wherein the second analyte is HbD and its glycated form and the second antibody binds to a HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8) or ¹¹⁹GKQFTPP¹²⁵ (SEQ ID NO:46).

52. The method of any one of claims 40 to 51, wherein the sample is from a diabetic patient.

53. A monoclonal antibody that selectively binds to hemoglobin variant HbC and glycated HbC, wherein the antibody binds to a HbC minimal epitope ⁴TPKEKSAVT¹² (SEQ ID NO:1).

54. A monoclonal antibody that selectively binds to hemoglobin variant HbS and glycated HbS, wherein the antibody binds to a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3).

55. A monoclonal antibody that selectively binds to hemoglobin variant HbE and glycated HbE, wherein the antibody binds to a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK²⁶ (SEQ ID NO:7).

56. A monoclonal antibody that selectively binds to hemoglobin variant HbD and glycated HbD, wherein the antibody binds to a HbD minimal epitope $^{121}\text{QFTPP}^{125}$ (SEQ ID NO:8) or $^{119}\text{GKQFTPP}^{125}$ (SEQ ID NO:46).

57. A method for quantifying a plurality of hemoglobin-containing analytes comprising HbA_{1c} and a hemoglobin variant, if present, in a single sample of blood cell lysate, said method comprising:

(a) incubating said sample with a population of beads in a common mixture, said population comprising a subpopulation to detect HbA_{1c} and one or more further subpopulations, each of which detects a hemoglobin variant, wherein:

(i) each bead of said subpopulation to detect HbA_{1c} has bonded thereto a fluorescent dye and each bead of said one or more subpopulations to detect a hemoglobin variant has bonded thereto a fluorescent dye, which may be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different dye that distinguishes each of the one or more subpopulations; and

(ii) each bead of said subpopulation to detect HbA_{1c} further has bonded thereto an anti-HbA_{1c} antibody having selective binding affinity towards HbA_{1c} and each bead of said one or more subpopulations to detect a hemoglobin variant has bonded thereto a monoclonal antibody that has selective binding affinity towards the variant and a glycated form of the variant to cause each analyte to bind to a different bead subpopulation through the antibody bonded to said subpopulations, wherein:

one subpopulation of the one or more further subpopulations detects HbC, if present in the sample, and has bonded thereto an anti-HbC monoclonal antibody having selective binding affinity towards HbC and glycated HbC; or

one subpopulation of the one or more further subpopulations detects HbS, if present in the sample, and has bonded thereto an anti-HbS monoclonal antibody having selective binding affinity towards HbS and glycated HbS; and

(b) individually detecting the subpopulations of beads that have been incubated with said sample in accordance with step (a) to quantify the HbA_{1c} and hemoglobin

variant in the sample using a competitive immunoassay, wherein the competitive immunoassay comprises further incubating the population of beads with a plurality of hemoglobin protein antigens, each hemoglobin protein antigen attached to a solid support at a separate site, wherein the plurality of hemoglobin protein antigens comprises a peptide that selectively binds the anti-HbA_{1c} antibody, and a peptide that selectively binds the anti-HbC monoclonal antibody or a peptide that selectively binds the anti-HbS monoclonal antibody.

58. The method of claim 57, wherein the population of beads comprises a subpopulation that detects total hemoglobin, wherein each bead of the subpopulation to detect total hemoglobin has bonded thereto a fluorescent dye which may be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different fluorescent dye that distinguishes the subpopulation to detect total hemoglobin from other subpopulations, and an antibody having selective binding affinity towards all hemoglobin-containing analytes; and further, wherein the plurality of hemoglobin protein antigens comprises a hemoglobin protein that binds to the antibody having selective binding affinity towards all hemoglobin-containing analytes.

59. The method of claim 58, wherein said antibody having selective binding affinity towards all hemoglobin-containing analytes is a monoclonal antibody that has selective binding affinity towards all hemoglobin-containing analytes and binds to a beta globin chain minimal epitope ⁹SAVTALWGKVVN²⁰ (SEQ ID NO:15), ⁸KSAVTALWGKVVN²⁰ (SEQ ID NO:16), or ¹¹VTALW¹⁵ (SEQ ID NO:17).

60. The method of claim 57, 58 or 59, wherein the anti-HbA_{1c} antibody is a monoclonal antibody.

61. The method of any one of claims 57 to 60, wherein the anti-HbC monoclonal antibody is a monoclonal antibody that binds to a HbC minimal epitope ⁴TPKEKSAVT¹ (SEQ ID NO:1); and, wherein the anti-HbS monoclonal antibody is a monoclonal antibody that binds to a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3).

62. The method of any one of claims 57 to 61, wherein one subpopulation of the one or more further subpopulations of (ii) detects HbC.

63. The method of any one of claims 57 to 61, wherein one subpopulation of the one or more further subpopulations of (ii) detects HbS.

64. The method of any one of claims 57 to 60, wherein the population comprises the subpopulation that detects HbC, if present in the sample, and the subpopulation that detects HbS, if present in the sample, and further, wherein the plurality of hemoglobin protein antigens comprises a peptide that selective binds the anti-HbA_{1c} antibody, a peptide that selectively binds the anti-HbC monoclonal antibody, and a peptide that selectively binds the anti-HbS monoclonal antibody.

65. The method of claim 64, wherein the anti-HbC monoclonal antibody binds to a HbC minimal epitope ⁴TPKEKSAVT¹ (SEQ ID NO:1); and the anti-HbS monoclonal antibody binds to a HbS minimal epitope ³LTPVEKSAVT¹² (SEQ ID NO:3).

66. The method of any one of claims 57 to 65, wherein said population comprises a subpopulation that detects HbD, if present in the sample, wherein each bead of said subpopulation to detect HbD has bonded thereto a fluorescent dye, which may be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different fluorescent dye that distinguishes the subpopulation to detect HbD from other subpopulations, and an anti-HbD monoclonal antibody that has selective binding affinity towards HbD and the glycated form of HbD; and further, wherein the plurality of hemoglobin protein antigens comprises a peptide that selectively binds the anti-HbD monoclonal antibody.

67. The method of claim 66, wherein the anti-HbD monoclonal antibody binds to a HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8) or ¹¹⁹GKQFTPP¹²⁵ (SEQ ID NO:46).

68. The method of any one of claims 57 to 65, wherein said population comprises a subpopulation that detects HbE, if present in the sample, wherein each bead of said subpopulation to detect HbE has bonded thereto a fluorescent dye, which may be the same as

the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different fluorescent dye that distinguishes the subpopulation to detect HbE from other subpopulations, and an anti-HbE monoclonal antibody that has selective binding affinity towards HbE and the glycated form of HbE; and further, wherein the plurality of hemoglobin protein antigens comprises a peptide that selectively binds the anti-HbE monoclonal antibody.

69. The method of claim 68, wherein the anti-HbE monoclonal antibody binds to a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK²⁶ (SEQ ID NO:7).

70. The method of any one of claims 57 to 65, wherein said population comprises a subpopulation that detects HbD, if present in the sample, wherein each bead of said subpopulation to detect HbD has bonded thereto a fluorescent dye, which may be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different fluorescent dye that distinguishes the subpopulation to detect HbD from other subpopulations, and an anti-HbD monoclonal antibody that has selective binding affinity towards HbD and the glycated form of HbD; and a subpopulation that detects HbE, if present in the sample, wherein each bead of said subpopulation to detect HbE has bonded thereto a fluorescent dye, which may be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different fluorescent dye that distinguishes the subpopulation to detect HbE from other subpopulations, and an anti-HbE monoclonal antibody that has selective binding affinity towards HbE and the glycated form of HbE; and further, wherein the plurality of hemoglobin protein antigens comprises a peptide that selectively binds the anti-HbD monoclonal antibody and a peptide that selectively binds the anti-HbE monoclonal antibody.

71. The method of claim 70, wherein the anti-HbD monoclonal antibody binds to a HbD minimal epitope ¹²¹QFTPP¹²⁵ (SEQ ID NO:8) or ¹¹⁹GKQFTPP¹²⁵ (SEQ ID NO:46); and the anti-HbE monoclonal antibody binds to a HbE minimal epitope ²²EVGGK²⁶ (SEQ ID NO:6) or ²¹DEVGGK²⁶ (SEQ ID NO:7).

72. The method of any one of claims 57 to 71, wherein the population of beads further comprises a subpopulation that detects total hemoglobin, wherein each bead of the subpopulation to detect total hemoglobin has bonded thereto a fluorescent dye, which may

be the same as the fluorescent dye bonded to said subpopulation to detect HbA_{1c} or may be a different fluorescent dye that distinguishes the subpopulation to detect total hemoglobin from other subpopulations, and an antibody having selective binding affinity towards all hemoglobin-containing analytes; and wherein the plurality of hemoglobin protein antigens comprises a hemoglobin protein that binds to the antibody having selective binding affinity towards all hemoglobin-containing analytes.

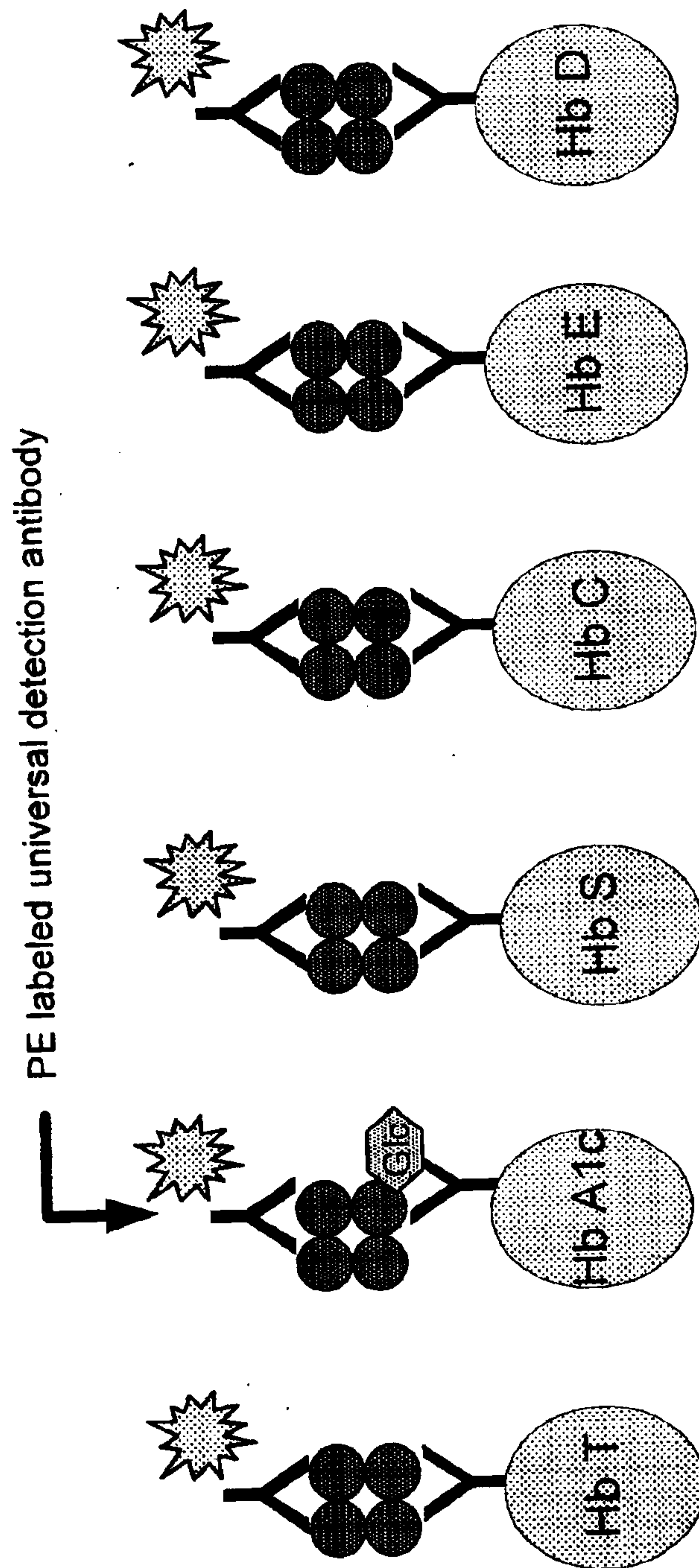
73. The method of claim 72, wherein said antibody having selective binding affinity towards all hemoglobin-containing analytes is a monoclonal antibody.

74. The method of any one of claims 57 to 71, wherein said method further comprises determining total hemoglobin in a non-immunoassay method.

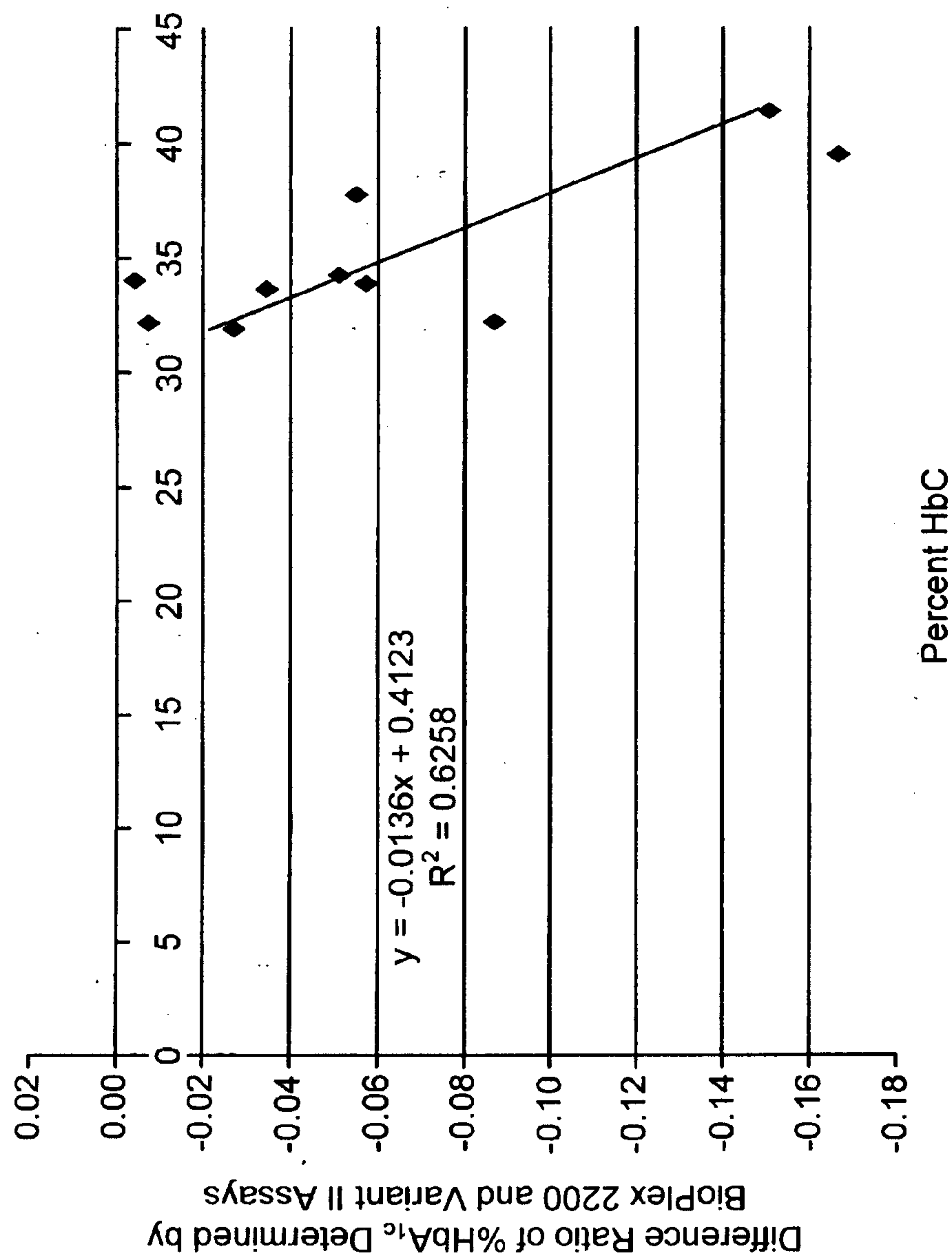
75. The method of claim any one of claims 57 to 74, wherein the blood cell lysate is a denatured blood cell lysate.

76. The method of claim any one of claims 57 to 75, wherein the sample is from a diabetic patient.

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**FIG. 1**

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**FIG. 2**

PE labeled universal detection antibody

