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**Update on pre-diabetes: Focus on diagnostic criteria and cardiovascular risk**

Di Pino A *et al*. Pre-diabetes diagnosis and cardiovascular risk

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**Abstract**

Pre-diabetes, which is typically defined as blood glucose concentrations higher than normal but lower than the diabetes threshold, is a high-risk state for diabetes and cardiovascular disease development. As such, it represents three groups of individuals: those with impaired fasting glucose (IFG), those with impaired glucose tolerance (IGT) and those with a glycated haemoglobin (HbA1c) between 39-46 mmol/mol. Several clinical trials have shown the important role of IFG, IGT and HbA1c-pre-diabetes as predictive tools for the risk of developing type 2 diabetes. Moreover, with regard to cardiovascular disease, pre-diabetes is associated with more advanced vascular damage compared with normoglycaemia, independently of confounding factors. In view of these observations, diagnosis of pre-diabetes is mandatory to prevent or delay the development of the disease and its complications; however, a number of previous studies reported that the concordance between pre-diabetes diagnoses made by IFG, IGT or HbA1c is scarce and there are conflicting data as to which of these methods best predicts cardiovascular disease.

This review highlights recent studies and current controversies in the field. In consideration of the expected increased use of HbA1c as a screening tool to identify individuals with alteration of glycaemic homeostasis, we focused on the evidence regarding the ability of HbA1c as a diagnostic tool for pre-diabetes and as a useful marker in identifying patients who have an increased risk for cardiovascular disease. Finally, we reviewed the current evidence regarding non-traditional glycaemic biomarkers and their use as alternatives to or additions to traditional ones.

**Key words:**Pre-diabetes; Diagnostic criteria; Glycated haemoglobin; Cardiovascular risk; Non-traditional glycaemic markers

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**Core tip:** Pre-diabetes is a high-risk state for diabetes and cardiovascular disease. There are three diagnostic criteria for pre-diabetes: impaired fasting glucose (IFG), impaired glucose tolerance (IGT) and glycated haemoglobin (HbA1c) between 39-46 mmol/mol. The concordance between a pre-diabetes diagnosis made by IFG, IGT or HbA1c is scarce and there are conflicting data as to which of these methods best predicts cardiovascular disease.

This review focuses on the evidence regarding the ability of HbA1c for pre-diabetes diagnosis and as a marker for cardiovascular risk. Finally, the evidence regarding non-traditional glycaemic biomarkers as alternatives to the traditional ones is reviewed.

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**INTRODUCTION**

Pre-diabetes is a general term that refers to an intermediate stage between normal glucose homeostasis and overt type 2 diabetes mellitus. As such, it includes three groups of individuals: those with impaired fasting glucose (IFG), those with impaired glucose tolerance (IGT) and those with a glycated hemoglobin (HbA1c) between 39-46 mmol/mol (Table 1). As underlined by the American Diabetes Association (ADA), a number of previous studies reported that the concordance between pre-diabetes diagnoses made by IFG, IGT or HbA1c is scarce[1]; according with this consideration, in a study conducted on a large population of Caucasian adults the agreement between the three diagnostic criteria was only 10.4% (Figure 1)[2].

The discordance in the identification of individuals with pre-diabetes using three different diagnostic tests is not entirely unexpected given that fasting plasma glucose, 2h post oral glucose tolerance test (OGTT), and HbA1c probably reflect different aspects of glucose metabolism, and a diagnosis of pre-diabetes based on IFG, IGT, or HbA1c may represent aetiological factors leading to the development of the different prediabetic states[2]. Indeed, subjects with isolated IFG seem to have a reduced hepatic insulin sensitivity, impaired first-phase insulin secretion, and normal/near-normal muscle insulin sensitivity, while subjects with IGT should be characterized by nearly normal hepatic insulin sensitivity and marked reduced peripheral insulin sensitivity combined with defective late insulin secretion[3,4]. In contrast to IFG and IGT, HbA1c is a marker representing blood glucose concentrations over the preceding 2-3 mo and it is affected by both basal and postprandial hyperglycaemia. To date, it is still not clear if these aspects that are strictly bound to the physiopathology of pre-diabetes may have a clinical relevance in view of a possible therapeutic intervention.

Cardiovascular disease (CVD) is the leading cause of death among individuals with type 2 diabetes, accounting for 40% to 50% of all deaths[5]. Although type 2 diabetes is frequently associated with other cardiovascular risk factors, such as dyslipidemia and hypertension, it is believed that chronic hyperglycaemia *per se* is an independent risk for macrovascular complications. Currently, it is well established that macrovascular disease starts before the development of diabetes, and the slight increase in plasma glucose levels that characterize pre-diabetes have been shown to be an independent predictor for CVD. Much clinical research has focused on lifestyle or pharmacological intervention to prevent diabetes in these high risk subjects[6]; however, few studies have been conducted with specific focus on CVD prevention in this population. Since many clinical trials have failed to demonstrated a reduction in cardiovascular risk from glucose-lowering interventions in patients with overt type 2 diabetes[7,8], it is noteworthy that several studies have reported benefits in improving cardiovascular risk factors, as well as absolute CVD event rates, in people with pre-diabetes treated with glucose lowering drugs[9–11].

Since the utility of a test for pre-diabetes diagnosis is also defined by its capacity to identify the macrovascular complication risk, an important question is whether subjects with pre-diabetes according to IFG, IGT, or HbA1c have an equivalent cardiovascular risk. To date, cardiovascular risk studies comparing IFG, IGT, and HbA1c-pre-diabetic patients are sparse and the results are still controversial[12–14].

This review highlights recent studies and current controversies in the field. In consideration of the increased use of HbA1c as a marker to detect patients with alterations of glycaemic homeostasis, we thought that it could be interesting, and relevant from the clinical point of view, to evaluate the evidence regarding the ability of HbA1c to identify patients who have increased cardiovascular risk. With this specific aim we focused our attention on HbA1c as a diagnostic tool for pre-diabetes. Finally, we reviewed the current evidence regarding non-traditional glycemic biomarkers and their use as alternatives to or additions to the traditional ones.

**COMPARISON OF IFG, IGT AND HBA1C, CRITERIA IN PREDICTING TYPE 2 DIABETES**

Subjects with pre-diabetes have shown a high conversion rate to overt diabetes and much clinical research has focused on lifestyle or pharmacological intervention to prevent diabetes in these high risk subjects[6]. Subjects with an isolated alteration of glucose homeostasis (IFG, IGT or HbA1c 39-46 mmol/mol) have an incidence of diabetes of 6% per year, a value that is significantly higher compared with subjects with normoglycemia (0.5% per year)[15]. Progression to overt type 2 diabetes is 30%-40% in the next 3-8 years, with an increase of 10% when two alterations of glucose homeostasis are present[6].

According with these considerations, diagnostic and screening criteria for pre-diabetes have a relevant clinical impact; indeed, it is important to identify individuals at high risk for type 2 diabetes to prevent or delay the development of the disease and its complications.

In 2011, the ADA revised the criteria for the diagnosis of type 2 diabetes and the categories at increased risk for diabetes and the use of HbA1c measurement was recommended as another diagnostic test option already including IFG and IGT[1]. Specifically for the categories of increased risk for type 2 diabetes, the new ADA recommendations state that an HbA1c from 39-46 mmol/mol identifies individuals at high risk for diabetes to whom the term pre-diabetes may be applied.

 Indeed, both IFG and IGT present some limitations: They require fasting status and are affected by acute perturbation; furthermore, the OGTT presents some practical difficulties: it is costly, it needs time, and has lower reproducibility compared with the fasting plasma glucose measurement (FPG)[16]. HbA1c is a “picture” of the average blood glucose level over the period of 2-3 mo[17]. HbA1c has higher reproducibility than FPG; indeed, within subject coefficients of variation are 1.7% for HbA1c, and 5.7% for FPG[17,18]. Furthermore, HbA1c does not need fasting status and could better integrate chronic hyperglycaemia than FPG (Table 2). The predictive value of HbA1c for type 2 diabetes has been reported in several studies. Morris *et al*[19] has shown in a metanalysis conducted on 70 studies that the progression rate to type 2 diabetes of patients with HbA1c pre-diabetes was similar to that for ADA-defined IFG and IFG plus IGT. Moreover, the value of HbA1c in predicting type 2 diabetes has been reported four prospective studies[20–23]; of these, one assessed the use of two glycemic parameters (in particular IFG and HbA1c) for predicting the incidence of type 2 diabetes; the authors supported the combined measurement of FPG and HbA1c for predicting diabetes incidence in a 4 year follow-up using receiver operating characteristic curve (ROC) analysis. When the whole population was analysed, the ROC curve of the model including both FPG and HbA1c was greater those including FPG alone or HbA1c alone. Furthermore, the authors reported a weak correlation between HbA1c and FPG at baseline suggesting that HbA1c is not a surrogate marker of FPG[23].

 It is necessary to remember that HbA1c between 39-46 mmol/mol seems to have a lower sensitivity in identify population with pre-diabetes compared with IFG and IGT[24,25].Conversely, the use of HbA1c may also lead to the reclassification of subjects without IFG or IGT as having pre-diabetes[26]*.* On the other hand, according to the ADA statement, the lower sensitivity of HbA1c for diagnosing pre-diabetes may be offset by its ability to facilitate establishing a diagnosis[27]. Contrary to these considerations, Rosella *et al*[28] recently reported that the prevalence of undiagnosed pre-diabetes in a representative sample of Canadians was significantly higher using HbA1c measures as screening tool compared with plasma glucose diagnostic criteria. The authors hypothesized that this “reverse association” may be due to a number of factors, such as ethnic differences and the increased prevalence of pre-diabetes from 11.6% in 2003 to 35.3% in 2011[29]. Accordingly, in a study conducted in the Mexican population, Kumar *et al*[30] found a higher prevalence of adults with HbA1c pre-diabetes compared with previous studies conducted in the same population[31]*.* We reported similar findings in a recent study conducted on 380 subjects attending our out-patients clinic for diabetes and cardiovascular risk evaluation; although we did not perform an opportunistic procedure during recruitment, the group with high HbA1c and normal fasting glucose and normal glucose tolerance (NFG/NGT) represented, in this study, approximately 30% of the entire population and is, therefore, not a rare subset[32]. These observations may not be surprising; in fact, although subjects with NFG and NGT have a lower risk of developing diabetes than patients with either IFG or IGT, in several studies a significant percentage (30%-40%) of all individuals who developed type 2 diabetes had NFG and NGT at baseline[33,34]. This indicates that subjects with NFG and NGT experience a lower risk of developing diabetes compared with IFG and IGT in absolute terms; however, among these subjects there is also a subgroup at increased risk of developing diabetes and, consequently, cardiovascular diseases. From these considerations stems the need to add HbA1c,as a diagnostic tool to identify a new category of high-risk individuals[35]. Further epidemiological data are needed to characterize the real percentage of this group in the overall pre-diabetic population.

To date, it is unclear why the prevalence of pre-diabetes diagnosed by OGTT and HbA1c criteria is substantially discordant. The concentration of HbA1c depends on glucose concentrations and on factors affecting the glycation rate such as systemic oxidative stress. Previous studies reported that some characteristics, such as obesity, are associated with increased oxidative stress[36]; thus, HbA1c may not reflect the real concentration of glucose and be disproportionately high in obese subjects. Several studies investigated the effects of phenotypic characteristics such as obesity on the agreement between OGTT and HbA1c. Li *et al*[37] in a recent study conducted on a large cohort of Chinese subjects without a previous diagnosis of diabetes reported a poor agreement between HbA1c criteria and OGTT in patients independently from body mass index. Moreover, different optimal HbA1c cut-off points for pre-diabetes were reported: 38 mmol/mol for normal weight, 39 mmol/mol for overweight, and 42 mmol/mol for obese subjects.

Also other studies recommend a different cut-off point of HbA1c for diagnosis of pre-diabetes. In particular, longitudinal epidemiological studies have reported that demographic and ethnic factors may contribute to complications in using HbA1c for the diagnosis of diabetes, and the optimal diagnostic HbA1c value is debated and varies because of genetic and biological differences. Yan *et al*[38] identified optimal HbA1c cut-off points for pre-diabetes in two diverse population-based cohorts with different ages. The optimal HbA1c cut-off point for pre-diabetes diagnosis was 38 mmol/mol in the young and middle-aged population, whereas, the optimal cut-off for diagnosing pre-diabetes increased to 39 mmol/mol, in the elderly population. Furthermore, many studies have shown that racial disparities affect the performance of HbA1c for diagnosing pre-diabetes[39]. In summary, it is possible that diagnostic tests for glycemic homeostasis should be used and interpreted considering the individual phenotypic characteristics of the patients; further studies are needed to investigate the clinical usefulness of personalized cutoff values.

**COMPARISON OF IFG, IGT AND HBA1C, CRITERIA IN PREDICTING CARDIOVASCULAR RISK**

The utility of a test for pre-diabetes diagnosis is also defined by its capacity to identify the risk of micro- and macro-vascular complications and from this point of view, the high reproducibility and simplicity may make HbA1c dosage an attractive option. Previous observational studies documented that determination of HbA1c, fasting glucose and OGTT significantly predicted the development of retinopathy and nephropathy but no variables had a significant advantage for detecting the incidence or prevalence of either complication[40,41]*.* However, fasting glycaemia has a low predictive value in terms of cardiovascular disease, while 2-h post-load glycaemia and HbA1c have a higher predictive value for this chronic complication of diabetes[42].

In a recent work, we showed that arterial stiffness and carotid intima-media thickness were altered in subjects with higher HbA1c levels and similar as that observed in subjects with new onset type 2 diabetes[43]. Furthermore, when we analyzed our population including only subjects with NFG/NGT we found that the NFG/NGT subjects with HbA1c 39-46 mmol/mol showed an alteration of subclinical markers of cardiovascular risk compared with NFG/NGT with lower HbA1c and no significant differences were found compared with IGT and type 2 diabetic patients (Figure 2). According to these data, a reproducible and simple marker such as HbA1c seems to identify subjects at high cardiovascular risk that would be considered normal according to fasting glycaemia and glucose tolerance. Other studies have shown similar data reporting a positive association between the pre-diabetic stage, echogenic plague and progression of coronary artery calcification[44,45]. A recent study has analysed the routine use of HbA1c for diagnosis of pre-diabetes in patients with ST-segment elevation myocardial infarction. The study showed a similar in-hospital and long-term mortality in these patients with pre-diabetes as those with known diabetes. The authors discussed that the difficulty in performance and the presence of stress hyperglycaemia in an acutely ill patient with myocardial infarction make OGTT a rarely used diagnostic test in this setting. The use of a simple, one–time HbA1c test allowed them to identify a substantial proportion of patients with previously undiagnosed diabetes or pre-diabetes who could be targeted for risk factor modification with lifestyle interventions and tailored medical therapy[46].

The links between alteration of glucose homeostasis and vascular damage in this population is still unclear, however, several studies have emphasized that the interaction of advanced glycation end products (AGE) with their cell-surface receptor (RAGE) is implicated in triggering inflammatory processes strictly connected with cardiovascular disease[47]. A RAGE soluble form termed endogenous secretory RAGE (esRAGE) may contribute to the removal of circulating ligands, thus competing with cell-surface RAGE for ligand binding[48]. Low levels of esRAGE have been associated with cardiovascular disease and, in a recent study, we found that subjects with pre-diabetes showed low esRAGE plasma levels suggesting a decreased scavenger capacity of these subjects (Figure 2). Further analysis conducted on mononuclear cells isolated from peripheral blood samples of these patients revealed a decreased esRAGE mRNA expression[32]. The regulatory mechanism for alternative splicing to generate esRAGE remains unclear, and environmental or genetic factors may be involved. Further examinations of the molecular mechanism underlying esRAGE regulation will provide potential targets for the prevention and/or treatment of cardiovascular disease.

Our research team has further investigated the characterization of the population with HbA1c pre-diabetes (39-46 mmol/mol) also investigating other markers closely associated with metabolic abnormalities and cardiovascular risk; in a previous study we highlighted a reduced insulin response in combination with impaired suppression of glucagon secretion in subjects with pre-diabetes according to HbA1c undergoing isoglycaemic intravenous glucose infusion[49]. Other data published in 2014 indicated that the presence of pre-diabetes according to HbA1c is associated with hepatic steatosis and with an alteration in the lipid profile known to be predisposing to cardiovascular and liver diseases[50]. Moreover, we showed that the levels of 25 hydroxyvitamin D are reduced and associated with vascular damage in subjects with pre-diabetes by HbA1c with NFG/NGT (Figure 2)[51]. Based on these data, we suggest that among subjects with NFG and NGT, HbA1c may identify subjects with different cardiovascular and glycometabolic risks.

These considerations are, furthermore, supported by previous studies. Indeed, it is important to remember that many authors have documented a significant increase in the incidence of cardiovascular events with HbA1c values substantially lower than those used for diagnosis of diabetes[12]. A recent meta-analysis of six prospective cohort studies in subjects without diabetes mellitus showed a linear association of HbA1c levels with primary cardiovascular events. The observed effect estimates for increased HbA1c levels and was strongly attenuated by adjustment for cardiovascular risk factors but remained statistically significant for primary cardiovascular events, cardiovascular mortality and all-cause mortality[52].

The majority of randomized controlled trials in non-diabetic subjects with increased HbA1c failed to observe significant effects when aiming to reduce the cardiovascular risk and mortality of these individuals. In the recent IRIS trial, which involved patients without diabetes but with a recent history of ischemic stroke or transitory ischemic attack and who had insulin resistance, the rate of the primary outcome (fatal or non-fatal stroke or fatal or non-fatal myocardial infarction) was lower in the pioglitazone group compared with placebo[11]. These results, although in contrast, at least in part, with other trials conducted on patients with type 2 diabetes (BARI-2D and Pro-active), are of great interest suggesting a favourable effect of pioglitazone on the progression of subclinical atherosclerosis[53,54]. The mechanism that was responsible for the lower rates of stroke and myocardial infarction in the pioglitazone group remains unclear. A recent meta-analysis of prospective, randomized clinical trials has shown a non-significant trend towards reduced risk of fatal and non-fatal myocardial infarction, and fatal and non-fatal stroke were only reduced to borderline. However, the short average follow-up time of 3.75 years was a limitation of previous trials and further RCTs, with a larger sample size and longer follow-up, are required to explore the efficacy of non-drug and drug based approaches to reduce the cardiovascular risk of non-diabetic subjects with increased HbA1c[55].

Other studies have reported similar findings suggesting the role of HbA1c as an early marker of cardiovascular risk; however, it is pertinent to recognize that the determinants of cardiovascular risk in subjects with metabolic alterations are complex and multiple, and individual’s cardiovascular risk can’t be identified by a single laboratory test[56].

**BEYOND TRADITIONAL DIAGNOSTIC CRITERIA: THE ROLE OF NON-TRADITIONAL GLYCAEMIC MARKERS IN PREDICTING DIABETES AND CARDIOVASCULAR RISK**

As previously explained, the traditional markers of glucose homeostasis are not definitive, and their use in clinical practice may be biased by a number of clinical and analytical factors.For these reasons, there is growing interest in new serum biomarkers of hyperglycaemia to be used as alternatives or in conjunction with traditional measures. In this review, we will provide a brief overview of the properties and of the existing literature linking these emerging biomarkers with micro- and macro-vascular complications.

***One-hour post-load plasma glucose***

Recently, an increasing body of evidence has focused on subjects with a plasma glucose concentration of at least 8.6 mmol/L at 1-h during OGTT. In 2008, Abdul-Ghani *et al* demonstrated for the first time that the 1-h post-load plasma glucose concentration may be a clinical indicator that can be used to identify subjects with high risk for type 2 diabetes[57]. These observations were confirmed in other recent studies showing that the incidence rate to type 2 diabetes over a period of 5 years in subjects with NGT and 1-h post-load glycaemia > 8.6 mmol/L was 16.7%[58]. Furthermore, a 1-h post-load glycaemia value > 8.6 mmol/L was strongly associated with different predictors for future cardiovascular events[59,60].In conclusion, it seems that this glucose value may identify subjects with an intermediate cardiometabolic risk profile between NGT and IGT[57,61]. This has been observed and confirmed in populations of different ethnicities such as Mexican-American, Scandinavian Caucasian, and Asian Indian[59,61,62].Why 1-h post-load glucose is a good indicator of cardiometabolic risk is still an open question; to date it is known that chronic hyperglycaemia promotes the formation of advanced glycation end products and reactive oxygen species.

One hour post-load glycaemia provides physiopathological information since it is dependent on insulin sensitivity in skeletal muscles and beta-cell function[63].

These data might underline the importance of obtaining intermediate plasma glucose levels during oral glucose tolerance test[59,64]. However, from the clinical point of view, 1-h post-load glycaemia requires, in any case, an OGTT, and, to date, strict lifestyle modification is the only therapy recommended from guidelines for subjects with pre-diabetes, independently from their physiopathologic profile. Furthermore, a study conducted on subjects with HbA1c pre-diabetes reported that most patients with HbA1c in the 39-46 mmol/mol range have a 1-h glucose ≥ 8.6 mmol/L; these data lead to the consideration that HbA1c may be the most practical tool to identify subjects with impaired glucose homeostasis[43].

***Fructosamine and glycated albumin***

Fructosamine and glycated albumin are both ketoamines formed from the binding of fructose to total serum protein, mostly albumin, through glycosylation. The fructosamine assay is cheaper and easier to perform than the HbA1c assay and it measures total glycated serum protein, whereas glycated albumin is reported as the proportion of total albumin[65]. Fructosamine and glycated albumin are short-term markers of glucose homeostasis; indeed, they provide information on blood glucose levels over the previous 2-3 wk[66]. This depends on the rapid turnover of glycated proteins, that in contrast to HbA1c, is independent from the turnover of red blood cells or hemoglobin characteristics. Similar to HbA1c, blood for fructosamine dosage can be obtained in any moment of the day, without regard to recent food intake. Both fructosamine and glycated albumin are associated with future risk of diabetes, independently from fasting glucose and HbA1c[67,68]. Another recent study explored the ability of HbA1c, fructosamine and glycated albumin to detect pre-diabetes and whether there would be added diagnostic value in combining HbA1c with fructosamine or glycated albumin. The study, conducted on US Africans, showed that HbA1c, fructosamine and glycated albumin detected almost 50% of Africans with pre-diabetes; however, combining HbA1c with glycated albumin (but not with fructosamine) made it possible to identify nearly 80% of Africans with pre-diabetes, as reported in previous studies[69]. Furthermore, the authors reported that pre-diabetic patients identified by glycated protein were younger and with a lower BMI, as previously reported. It is still not clear why glycated plasma proteins are inversely related to body size, however, this observation could be of clinical relevance and it may support the use of glycated albumin to enhance the detection of pre-diabetes in specific populations, such as the non-obese.

Evidence derived from prospective studies regarding the link between non-traditional markers and micro and macro-vascular complications are limited. Data from the Atherosclerosis Risk in Communities (ARIC) Study have shown that glycated albumin predicted chronic kidney disease over two decades of follow-up with a similar magnitude to those observed for HbA1c[69]. Other evidence has come from cross-sectional studies. A recent analysis from the ARIC Study has shown an association between glycated albumin and retinopathy, with a pattern of association very similar to that observed for HbA1c[69]. Furthermore, in other studies conducted on adults without diagnosed diabetes, glycated albumin was associated with subclinical atherosclerosis, kidney and cardiovascular disease[70].

A potential limitation to the clinical use of these markers may be that, to date, there are no established clinical cut-off points and the assays are not standardized across instruments. Particular caution should be used in pathological conditions that can impact albumin metabolism including anaemia, malnutrition, nephrotic syndrome and liver cirrhosis.

To date, fructosamine and glycated albumin are not incorporated in clinical guidelines, however, they may be useful complements to HbA1c in clinical practice, mainly when HbA1c testing is inaccessible or when the result might not be reliable.

***1,5-anhydroglucitol***

1,5-anhydroglucitol (1,5-AG) is a monosaccharide primarily derived from dietary sources and is a non-traditional biomarker of hyperglycaemia . During euglycaemia, serum 1,5-AG is typically maintained at a constant concentration (12-40 ug/mL). It is freely filtered from the glomeruli and a small amount, dependent on dietary intake, is excreted with the urine. The remaining amount is reabsorbed in the renal tubule. In conditions of hyperglycaemia (> 8.9-10 mmol/L) glucose blocks renal tubular reabsorption of 1,5-AG resulting in a drop in 1,5-AG serum levels; therefore, an inverse association exists between hyperglycaemia and 1,5-AG. Clinically, 1,5-AG may be used as a marker of short-term glycaemic variability, reflecting hyperglycaemic episodes over 1-2 wk. It is probable that HbA1c, 1,5-AG is a non-fasting test, but it includes information about glycaemic excursion that is not included in HbA1c dosage.

Previous studies found a significant association between 1,5-AG and the subsequent development of diabetes with a magnitude that was significant but weaker compared with fructosamine and glycated albumin[68]. However, consistent with its pathophysiology, 1,5-AG was no longer associated with incident diabetes among people with a normal fasting glucose < 5.6 mmol/L or HbA1c < 39 mmol/mol, suggesting a limited usefulness for 1,5-AG in the setting of normal glucose and HbA1c levels. According to this data 1,5-AG seems to be a biomarker suitable for detecting glycaemic variations in patients with HbA1c between 53-64 mmol/mol (for example, to monitor a patient’s response to changes in medication) rather than in subjects with pre-diabetes.

Few studies have assessed the relationship of 1,5-AG with micro and macro-vascular complications. Cross-sectional studies have reported associations between 1,5-AG serum levels, subclinical atherosclerosis, prevalent retinopathy and coronary heart disease in subjects with and without diabetes[71,72]. A recent study observed a threshold effect, with little evidence of risk for cardiovascular events at the “non-diabetic” 1,5-AG concentration of 10-15 ug/mL. However, most of the study group were diabetic subjects, and in the categorical analysis the association with the clinical outcomes was largely confined to the subjects with diabetes[73].

**CONCLUSION**

The measurement of HbA1c appears to be a reliable diagnostic approach to identify patients at high risk for diabetes and cardiovascular disease; it seems to provide several advantages, especially in settings where OGTT is rarely used and never repeated as a confirmatory test, and eliminates a long series of biological and analytical limits. In most conditions HbA1c could became the reference method, provided that its assay is aligned with international standards. The budget/cost benefit of replacing glucose with HbA1c remains unclear and it is necessary to acquire additional information.

Finally, alternative biomarkers of glucose homeostasis may have a clinical use in identifying subjects at risk for diabetes and cardiovascular disease (mostly 1-h post-load glycaemia) and for short-term evaluation of glucose homeostasis in settings in which HbA1c may present some bias (fructosamine, glycated albumin and 1,5-AG). It is possible that one or more of these biomarkers may be of clinical usefulness, however, long-term prospective studies are needed to demonstrate whether their clinical use may be useful to improve outcomes and patient care.

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**REFERENCES**

1 **American Diabetes Association**. Standards of medical care in diabetes--2014. *Diabetes Care* 2014; **37** Suppl 1: S14-S80 [PMID: 24357209 DOI: 10.2337/dc14-S014]

2 **Marini MA**, Succurro E, Castaldo E, Cufone S, Arturi F, Sciacqua A, Lauro R, Hribal ML, Perticone F, Sesti G. Cardiometabolic risk profiles and carotid atherosclerosis in individuals with prediabetes identified by fasting glucose, postchallenge glucose, and hemoglobin A1c criteria. *Diabetes Care* 2012; **35**: 1144-1149 [PMID: 22399698 DOI: 10.2337/dc11-2032]

3 **DeFronzo RA**, Abdul-Ghani M. Assessment and treatment of cardiovascular risk in prediabetes: impaired glucose tolerance and impaired fasting glucose. *Am J Cardiol* 2011; **108**: 3B-24B [PMID: 21802577 DOI: 10.1016/j.amjcard.2011.03.013]

4 **Abdul-Ghani MA**, Tripathy D, DeFronzo RA. Contributions of beta-cell dysfunction and insulin resistance to the pathogenesis of impaired glucose tolerance and impaired fasting glucose. *Diabetes Care* 2006; **29**: 1130-1139 [PMID: 16644654 DOI: 10.2337/diacare.2951130]

5 **de Marco R**, Locatelli F, Zoppini G, Verlato G, Bonora E, Muggeo M. Cause-specific mortality in type 2 diabetes. The Verona Diabetes Study. *Diabetes Care* 1999; **22**: 756-761 [PMID: 10332677 DOI: 10.2337/diacare.22.5.756]

6 **Knowler WC**, Barrett-Connor E, Fowler SE, Hamman RF, Lachin JM, Walker EA, Nathan DM. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. *N Engl J Med* 2002; **346**: 393-403 [PMID: 11832527 DOI: 10.1056/NEJMoa012512]

7 **Patel A**, MacMahon S, Chalmers J, Neal B, Billot L, Woodward M, Marre M, Cooper M, Glasziou P, Grobbee D, Hamet P, Harrap S, Heller S, Liu L, Mancia G, Mogensen CE, Pan C, Poulter N, Rodgers A, Williams B, Bompoint S, de Galan BE, Joshi R, Travert F. Intensive blood glucose control and vascular outcomes in patients with type 2 diabetes. *N Engl J Med* 2008; **358**: 2560-2572 [PMID: 18539916 DOI: 10.1056/NEJMoa0802987]

8 **Gerstein HC**, Miller ME, Byington RP, Goff DC, Bigger JT, Buse JB, Cushman WC, Genuth S, Ismail-Beigi F, Grimm RH, Probstfield JL, Simons-Morton DG, Friedewald WT. Effects of intensive glucose lowering in type 2 diabetes. *N Engl J Med* 2008; **358**: 2545-2559 [PMID: 18539917 DOI: 10.1056/NEJMoa0802743]

9 **Tripathy D**, Schwenke DC, Banerji M, Bray GA, Buchanan TA, Clement SC, Henry RR, Kitabchi AE, Mudaliar S, Ratner RE, Stentz FB, Musi N, Reaven PD, DeFronzo RA. Diabetes Incidence and Glucose Tolerance after Termination of Pioglitazone Therapy: Results from ACT NOW. *J Clin Endocrinol Metab* 2016; **101**: 2056-2062 [PMID: 26982008 DOI: 10.1210/jc.2015-4202]

10 **Chiasson JL**, Josse RG, Gomis R, Hanefeld M, Karasik A, Laakso M. Acarbose treatment and the risk of cardiovascular disease and hypertension in patients with impaired glucose tolerance: the STOP-NIDDM trial. *JAMA* 2003; **290**: 486-494 [PMID: 12876091 DOI: 10.1001/jama.290.4.486]

11 **Kernan WN**, Viscoli CM, Furie KL, Young LH, Inzucchi SE, Gorman M, Guarino PD, Lovejoy AM, Peduzzi PN, Conwit R, Brass LM, Schwartz GG, Adams HP, Berger L, Carolei A, Clark W, Coull B, Ford GA, Kleindorfer D, O'Leary JR, Parsons MW, Ringleb P, Sen S, Spence JD, Tanne D, Wang D, Winder TR. Pioglitazone after Ischemic Stroke or Transient Ischemic Attack. *N Engl J Med* 2016; **374**: 1321-1331 [PMID: 26886418 DOI: 10.1056/NEJMoa1506930]

12 **Selvin E**, Steffes MW, Zhu H, Matsushita K, Wagenknecht L, Pankow J, Coresh J, Brancati FL. Glycated hemoglobin, diabetes, and cardiovascular risk in nondiabetic adults. *N Engl J Med* 2010; **362**: 800-811 [PMID: 20200384 DOI: 10.1056/NEJMoa0908359]

13 **Nakagami T**. Hyperglycaemia and mortality from all causes and from cardiovascular disease in five populations of Asian origin. *Diabetologia* 2004; **47**: 385-394 [PMID: 14985967 DOI: 10.1007/s00125-004-1334-6]

14 **Qiao Q**, Dekker JM, de Vegt F, Nijpels G, Nissinen A, Stehouwer CD, Bouter LM, Heine RJ, Tuomilehto J. Two prospective studies found that elevated 2-hr glucose predicted male mortality independent of fasting glucose and HbA1c. *J Clin Epidemiol* 2004; **57**: 590-596 [PMID: 15246127 DOI: 10.1016/j.jclinepi.2003.10.007]

15 **Tuomilehto J**, Lindström J, Eriksson JG, Valle TT, Hämäläinen H, Ilanne-Parikka P, Keinänen-Kiukaanniemi S, Laakso M, Louheranta A, Rastas M, Salminen V, Uusitupa M. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. *N Engl J Med* 2001; **344**: 1343-1350 [PMID: 11333990 DOI: 10.1056/NEJM200105033441801]

16 **Ko GT**, Chan JC, Woo J, Lau E, Yeung VT, Chow CC, Cockram CS. The reproducibility and usefulness of the oral glucose tolerance test in screening for diabetes and other cardiovascular risk factors. *Ann Clin Biochem* 1998; **35 ( Pt 1)**: 62-67 [PMID: 9463740]

17 **Barr RG**, Nathan DM, Meigs JB, Singer DE. Tests of glycemia for the diagnosis of type 2 diabetes mellitus. *Ann Intern Med* 2002; **137**: 263-272 [PMID: 12186517]

18 **Braga F**, Dolci A, Mosca A, Panteghini M. Biological variability of glycated hemoglobin. *Clin Chim Acta* 2010; **411**: 1606-1610 [PMID: 20688052 DOI: 10.1016/j.cca.2010.07.030]

19 **Morris DH**, Khunti K, Achana F, Srinivasan B, Gray LJ, Davies MJ, Webb D. Progression rates from HbA1c 6.0-6.4% and other prediabetes definitions to type 2 diabetes: a meta-analysis. *Diabetologia* 2013; **56**: 1489-1493 [PMID: 23584433 DOI: 10.1007/s00125-013-2902-4]

20 **Edelman D**, Olsen MK, Dudley TK, Harris AC, Oddone EZ. Utility of hemoglobin A1c in predicting diabetes risk. *J Gen Intern Med* 2004; **19**: 1175-1180 [PMID: 15610327 DOI: 10.1111/j.1525-1497.2004.40178.x]

21 **Inoue K**, Matsumoto M, Kobayashi Y. The combination of fasting plasma glucose and glycosylated hemoglobin predicts type 2 diabetes in Japanese workers. *Diabetes Res Clin Pract* 2007; **77**: 451-458 [PMID: 17346846 DOI: 10.1016/j.diabres.2007.01.024]

22 **Droumaguet C**, Balkau B, Simon D, Caces E, Tichet J, Charles MA, Eschwege E. Use of HbA1c in predicting progression to diabetes in French men and women: data from an Epidemiological Study on the Insulin Resistance Syndrome (DESIR). *Diabetes Care* 2006; **29**: 1619-1625 [PMID: 16801588 DOI: 10.2337/dc05-2525]

23 **Sato KK**, Hayashi T, Harita N, Yoneda T, Nakamura Y, Endo G, Kambe H. Combined measurement of fasting plasma glucose and A1C is effective for the prediction of type 2 diabetes: the Kansai Healthcare Study. *Diabetes Care* 2009; **32**: 644-646 [PMID: 19131461 DOI: 10.2337/dc08-1631.]

24 **Cowie CC**, Rust KF, Byrd-Holt DD, Gregg EW, Ford ES, Geiss LS, Bainbridge KE, Fradkin JE. Prevalence of diabetes and high risk for diabetes using A1C criteria in the U.S. population in 1988-2006. *Diabetes Care* 2010; **33**: 562-568 [PMID: 20067953 DOI: 10.2337/dc09-1524]

25 **Heianza Y**, Hara S, Arase Y, Saito K, Fujiwara K, Tsuji H, Kodama S, Hsieh SD, Mori Y, Shimano H, Yamada N, Kosaka K, Sone H. HbA1c 5·7-6·4% and impaired fasting plasma glucose for diagnosis of prediabetes and risk of progression to diabetes in Japan (TOPICS 3): a longitudinal cohort study. *Lancet* 2011; **378**: 147-155 [PMID: 21705064 DOI: 10.1016/S0140-6736(11)60472-8]

26 **Mann DM**, Carson AP, Shimbo D, Fonseca V, Fox CS, Muntner P. Impact of A1C screening criterion on the diagnosis of pre-diabetes among U.S. adults. *Diabetes Care* 2010; **33**: 2190-2195 [PMID: 20628087 DOI: 10.2337/dc10-0752]

27 **Bullard KM**, Saydah SH, Imperatore G, Cowie CC, Gregg EW, Geiss LS, Cheng YJ, Rolka DB, Williams DE, Caspersen CJ. Secular changes in U.S. Prediabetes prevalence defined by hemoglobin A1c and fasting plasma glucose: National Health and Nutrition Examination Surveys, 1999-2010. *Diabetes Care* 2013; **36**: 2286-2293 [PMID: 23603918 DOI: 10.2337/dc12-2563]

28 **Rosella LC**, Lebenbaum M, Fitzpatrick T, Zuk A, Booth GL. Prevalence of Prediabetes and Undiagnosed Diabetes in Canada (2007-2011) According to Fasting Plasma Glucose and HbA1c Screening Criteria. *Diabetes Care* 2015; **38**: 1299-1305 [PMID: 25852207 DOI: 10.2337/dc14-2474]

29 **Mainous AG**, Tanner RJ, Baker R, Zayas CE, Harle CA. Prevalence of prediabetes in England from 2003 to 2011: population-based, cross-sectional study. *BMJ Open* 2014; **4**: e005002 [PMID: 24913327 DOI: 10.1136/bmjopen-2014-005002]

30 **Kumar A**, Wong R, Ottenbacher KJ, Al Snih S. Prediabetes, undiagnosed diabetes, and diabetes among Mexican adults: findings from the Mexican Health and Aging Study. *Ann Epidemiol* 2016; **26**: 163-170 [PMID: 26872919 DOI: 10.1016/j.annepidem.2015.12.006]

31 **Guerrero-Romero F**, Rodríguez-Morán M, Pérez-Fuentes R, Sánchez-Guillén MC, González-Ortiz M, Martínez-Abundis E, Brito-Zurita O, Madero A, Figueroa B, Revilla-Monsalve C, Flores-Martínez SE, Islas-Andrade S, Rascón-Pacheco RA, Cruz M, Sánchez-Corona J. Prediabetes and its relationship with obesity in Mexican adults: The Mexican Diabetes Prevention (MexDiab) Study. *Metab Syndr Relat Disord* 2008; **6**: 15-23 [PMID: 18370832 DOI: 10.1089/met.2007.0020]

32 **Di Pino A**, Urbano F, Zagami RM, Filippello A, Di Mauro S, Piro S, Purrello F, Rabuazzo AM. Low Endogenous Secretory Receptor for Advanced Glycation End-Products Levels Are Associated With Inflammation and Carotid Atherosclerosis in Prediabetes. *J Clin Endocrinol Metab* 2016; **101**: 1701-1709 [PMID: 26885882 DOI: 10.1210/jc.2015-4069].]

33 **Unwin N**, Shaw J, Zimmet P, Alberti KG. Impaired glucose tolerance and impaired fasting glycaemia: the current status on definition and intervention. *Diabet Med* 2002; **19**: 708-723 [PMID: 12207806]

34 **Abdul-Ghani MA**, Williams K, DeFronzo R, Stern M. Risk of progression to type 2 diabetes based on relationship between postload plasma glucose and fasting plasma glucose. *Diabetes Care* 2006; **29**: 1613-1618 [PMID: 16801587 DOI: 10.2337/dc05-1711]

35 **American Diabetes Association**. Diagnosis and classification of diabetes mellitus. *Diabetes Care* 2010; **33** Suppl 1: S62-S69 [PMID: 20042775 DOI: 10.2337/dc10-S062]

36 **Furukawa S**, Fujita T, Shimabukuro M, Iwaki M, Yamada Y, Nakajima Y, Nakayama O, Makishima M, Matsuda M, Shimomura I. Increased oxidative stress in obesity and its impact on metabolic syndrome. *J Clin Invest* 2004; **114**: 1752-1761 [PMID: 15599400 DOI: 10.1172/JCI200421625.1752]

37 **Li J**, Ma H, Na L, Jiang S, Lv L, Li G, Zhang W, Na G, Li Y, Sun C. Increased hemoglobin A1c threshold for prediabetes remarkably improving the agreement between A1c and oral glucose tolerance test criteria in obese population. *J Clin Endocrinol Metab* 2015; **100**: 1997-2005 [PMID: 25751104 DOI: 10.1210/jc.2014-4139]

38 **Yan ST**, Xiao HY, Tian H, Li CL, Fang FS, Li XY, Cheng XL, Li N, Miao XY, Yang Y, Wang LC, Zou XM, Ma FL, He Y, Sai XY. The cutoffs and performance of glycated hemoglobin for diagnosing diabetes and prediabetes in a young and middle-aged population and in an elderly population. *Diabetes Res Clin Pract* 2015; **109**: 238-245 [PMID: 26059072 DOI: 10.1016/j.diabres.2015.05.047]

39 **Shimodaira M**, Okaniwa S, Hanyu N, Nakayama T. Optimal Hemoglobin A1c Levels for Screening of Diabetes and Prediabetes in the Japanese Population. *J Diabetes Res* 2015; **2015**: 932057 [PMID: 26114121 DOI: 10.1155/2015/932057]

40 **McCance DR**, Hanson RL, Charles MA, Jacobsson LT, Pettitt DJ, Bennett PH, Knowler WC. Comparison of tests for glycated haemoglobin and fasting and two hour plasma glucose concentrations as diagnostic methods for diabetes. *BMJ* 1994; **308**: 1323-1328 [PMID: 8019217 DOI: 10.1136/bmj.308.6940.1323]

41 **Colagiuri S**, Davies D. The value of early detection of type 2 diabetes. *Curr Opin Endocrinol Diabetes Obes* 2009; **16**: 95-99 [PMID: 19276801 DOI: 10.1097/MED.0b013e328329302f]

42 **Khaw KT**, Wareham N, Bingham S, Luben R, Welch A, Day N. Association of hemoglobin A1c with cardiovascular disease and mortality in adults: the European prospective investigation into cancer in Norfolk. *Ann Intern Med* 2004; **141**: 413-420 [PMID: 15381514]

43 **Di Pino A**, Scicali R, Calanna S, Urbano F, Mantegna C, Rabuazzo AM, Purrello F, Piro S. Cardiovascular risk profile in subjects with prediabetes and new-onset type 2 diabetes identified by HbA(1c) according to American Diabetes Association criteria. *Diabetes Care* 2014; **37**: 1447-1453 [PMID: 24574348 DOI: 10.2337/dc13-2357]

44 **Jørgensen L**, Jenssen T, Joakimsen O, Heuch I, Ingebretsen OC, Jacobsen BK. Glycated hemoglobin level is strongly related to the prevalence of carotid artery plaques with high echogenicity in nondiabetic individuals: the Tromsø study. *Circulation* 2004; **110**: 466-470 [PMID: 15249512 DOI: 10.1161/01.CIR.0000136809.55141.3B]

45 **Carson AP**, Steffes MW, Carr JJ, Kim Y, Gross MD, Carnethon MR, Reis JP, Loria CM, Jacobs DR, Lewis CE. Hemoglobin a1c and the progression of coronary artery calcification among adults without diabetes. *Diabetes Care* 2015; **38**: 66-71 [PMID: 25325881 DOI: 10.2337/dc14-0360]

46 **Aggarwal B**, Shah GK, Randhawa M, Ellis SG, Lincoff AM, Menon V. Utility of Glycated Hemoglobin for Assessment of Glucose Metabolism in Patients With ST-Segment Elevation Myocardial Infarction. *Am J Cardiol* 2016; **117**: 749–753 [DOI: 10.1016/j.amjcard.2015.11.060]

47 **Basta G**, Sironi AM, Lazzerini G, Del Turco S, Buzzigoli E, Casolaro A, Natali A, Ferrannini E, Gastaldelli A. Circulating soluble receptor for advanced glycation end products is inversely associated with glycemic control and S100A12 protein. *J Clin Endocrinol Metab* 2006; **91**: 4628-4634 [PMID: 16926247 DOI: 10.1210/jc.2005-2559]

48 **Koyama H**, Yamamoto H, Nishizawa Y. RAGE and soluble RAGE: potential therapeutic targets for cardiovascular diseases. *Mol Med* 2007; **13**: 625-635 [PMID: 17932553 DOI: 10.2119/2007-00087.Koyama]

49 **Calanna S**, Scicali R, Di Pino A, Knop FK, Piro S, Rabuazzo AM, Purrello F. Alpha- and beta-cell abnormalities in haemoglobin A1c-defined prediabetes and type 2 diabetes. *Acta Diabetol* 2014; **51**: 567-575 [PMID: 24442427 DOI: 10.1007/s00592-014-0555-5]

50 **Calanna S**, Scicali R, Di Pino A, Knop FK, Piro S, Rabuazzo AM, Purrello F. Lipid and liver abnormalities in haemoglobin A1c-defined prediabetes and type 2 diabetes. *Nutr Metab Cardiovasc Dis* 2014; **24**: 670–676 [DOI: 10.1016/j.numecd.2014.01.013]

51 **Zagami RM**, Di Pino A, Urbano F, Piro S, Purrello F, Rabuazzo AM. Low circulating Vitamin D levels are associated with increased arterial stiffness in prediabetic subjects identified according to HbA1c. *Atherosclerosis* 2015; **243**: 395-401 [DOI: 10.1016/j.atherosclerosis.2015.09.038]

52 **Schöttker B,** Rathmann W, Herder C, Thorand B, Wilsgaard T, Njølstad I, Siganos G, Mathiesen EB, Saum KU, Peasey A, Feskens E, Boffetta P, Trichopoulou A, Kuulasmaa K, Kee F, Brenner H. HbA1c levels in non-diabetic older adults – No J-shaped associations with primary cardiovascular events, cardiovascular and all-cause mortality after adjustment for confounders in a meta-analysis of individual participant data from six cohort studies. *BMC Med* 2016; **14**: 26 [DOI: 10.1186/s12916-016-0570-1]

53 **Wilcox R**, Bousser MG, Betteridge DJ, Schernthaner G, Pirags V, Kupfer S, Dormandy J. Effects of pioglitazone in patients with type 2 diabetes with or without previous stroke: results from PROactive (PROspective pioglitAzone Clinical Trial In macroVascular Events 04). *Stroke* 2007; **38**: 865-873 [PMID: 17290029 DOI: 10.1161/01.STR.0000257974.06317.49]

54 **Frye RL**, August P, Brooks MM, Hardison RM, Kelsey SF, MacGregor JM, Orchard TJ, Chaitman BR, Genuth SM, Goldberg SH, Hlatky MA, Jones TL, Molitch ME, Nesto RW, Sako EY, Sobel BE. A randomized trial of therapies for type 2 diabetes and coronary artery disease. *N Engl J Med* 2009; **360**: 2503-2515 [PMID: 19502645 DOI: 10.1056/NEJMoa0805796]

55 **Hopper I**, Billah B, Skiba M, Krum H. Prevention of diabetes and reduction in major cardiovascular events in studies of subjects with prediabetes: meta-analysis of randomised controlled clinical trials. *Eur J Cardiovasc Prev Rehabil* 2011; **18**: 813-823 [PMID: 21878448 DOI: 10.1177/1741826711421687]

56 **Bobbert T**, Mai K, Fischer-Rosinsky A, Pfeiffer AF, Spranger J. A1C is associated with intima-media thickness in individuals with normal glucose tolerance. *Diabetes Care* 2010; **33**: 203-204 [PMID: 19808917 DOI: 10.2337/dc09-1009]

57 **Abdul-Ghani MA**, Abdul-Ghani T, Ali N, Defronzo RA. One-hour plasma glucose concentration and the metabolic syndrome identify subjects at high risk for future type 2 diabetes. *Diabetes Care* 2008; **31**: 1650-1655 [PMID: 18487478]

58 **Fiorentino TV**, Marini MA, Andreozzi F, Arturi F, Succurro E, Perticone M, Sciacqua A, Hribal ML, Perticone F, Sesti G. One-Hour Postload Hyperglycemia Is a Stronger Predictor of Type 2 Diabetes Than Impaired Fasting Glucose. *J Clin Endocrinol Metab* 2015; **100**: 3744-3751 [PMID: 26274345 DOI: 10.1210/jc.2015-2573]

59 **Succurro E**, Marini MA, Arturi F, Grembiale A, Lugarà M, Andreozzi F, Sciacqua A, Lauro R, Hribal ML, Perticone F, Sesti G. Elevated one-hour post-load plasma glucose levels identifies subjects with normal glucose tolerance but early carotid atherosclerosis. *Atherosclerosis* 2009; **207**: 245-249 [PMID: 19410252 DOI: 10.1016/j.atherosclerosis.2009.04.006]

60 **Succurro E**, Arturi F, Lugarà M, Grembiale A, Fiorentino TV, Caruso V, Andreozzi F, Sciacqua A, Hribal ML, Perticone F, Sesti G. One-hour postload plasma glucose levels are associated with kidney dysfunction. *Clin J Am Soc Nephrol* 2010; **5**: 1922-1927 [PMID: 20595688 DOI: 10.2215/CJN.03240410]

61 **Abdul-Ghani MA**, Lyssenko V, Tuomi T, DeFronzo RA, Groop L. Fasting versus postload plasma glucose concentration and the risk for future type 2 diabetes: results from the Botnia Study. *Diabetes Care* 2009; **32**: 281-286 [PMID: 19017778 DOI: 10.2337/dc08-1264]

62 **Priya M**, Anjana RM, Chiwanga FS, Gokulakrishnan K, Deepa M, Mohan V. 1-hour venous plasma glucose and incident prediabetes and diabetes in Asian indians. *Diabetes Technol Ther* 2013; **15**: 497-502 [PMID: 23550555 DOI: 10.1089/dia.2013.0025]

63 **Defronzo RA**. The triumvirate: β-cell, muscle, liver. A collusion responsible for NIDDM. *Diabetes* 1988; **37**: 667–87 [PMID: 3289989 DOI: 10.2337/diab.37.6.667]

64 **Sciacqua A**, Miceli S, Carullo G, Greco L, Succurro E, Arturi F, Sesti G, Perticone F. One-hour postload plasma glucose levels and left ventricular mass in hypertensive patients. *Diabetes Care* 2011; **34**: 1406-1411 [PMID: 21515837 DOI: 10.2337/dc11-0155]

65 **Lee JE**. Alternative biomarkers for assessing glycemic control in diabetes: fructosamine, glycated albumin, and 1,5-anhydroglucitol. *Ann Pediatr Endocrinol Metab* 2015; **20**: 74-78 [PMID: 26191510 DOI: 10.6065/apem.2015.20.2.74]

66 **Ikezaki H**, Furusyo N, Ihara T, Hayashi T, Ura K, Hiramine S, Mitsumoto F, Takayama K, Murata M, Kohzuma T, Ai M, Schaefer EJ, Hayashi J. Glycated albumin as a diagnostic tool for diabetes in a general Japanese population. *Metabolism* 2015; **64**: 698-705 [PMID: 25817605 DOI: 10.1016/j.metabol.2015.03.003]

67 **Juraschek SP**, Steffes MW, Miller ER, Selvin E. Alternative markers of hyperglycemia and risk of diabetes. *Diabetes Care* 2012; **35**: 2265-2270 [PMID: 22875225 DOI: 10.2337/dc12-0787]

68 **Sumner AE**, Duong MT, Aldana PC, Ricks M, Tulloch-reid MK, Lozier JN, Chung ST, Sacks DB. A1C Combined With Glycated Albumin Improves Detection of Prediabetes in Africans. *Afri Ame Study* 2015; **1**: 1-7 [DOI: 10.2337/dc15-1699]

69 **Selvin E**, Rawlings AM, Grams M, Klein R, Sharrett AR, Steffes M, Coresh J. Fructosamine and glycated albumin for risk stratification and prediction of incident diabetes and microvascular complications: a prospective cohort analysis of the Atherosclerosis Risk in Communities (ARIC) study. *Lancet Diabetes Endocrinol* 2014; **2**: 279-288 [PMID: 24703046 DOI: 10.1016/S2213-8587(13)70199-2]

70 **Lu L**, Pu LJ, Xu XW, Zhang Q, Zhang RY, Zhang JS, Hu J, Yang ZK, Lu AK, Ding FH, Shen J, Chen QJ, Lou S, Fang DH, Shen WF. Association of serum levels of glycated albumin, C-reactive protein and tumor necrosis factor-alpha with the severity of coronary artery disease and renal impairment in patients with type 2 diabetes mellitus. *Clin Biochem* 2007; **40**: 810-816 [PMID: 17499233 DOI: 10.1016/j.clinbiochem.2007.03.022]

71 **Kim WJ**, Park CY, Park SE, Rhee EJ, Lee WY, Oh KW, Park SW, Kim SW, Park HS, Kim YJ, Song SJ, Ahn HY. Serum 1,5-anhydroglucitol is associated with diabetic retinopathy in Type 2 diabetes. *Diabet Med* 2012; **29**: 1184-1190 [PMID: 22332964 DOI: 10.1111/j.1464-5491.2012.03613.x]

72 **Watanabe K**, Suzuki T, Ouchi M, Suzuki K, Ohara M, Hashimoto M, Yamashita H, Okazaki M, Ishii K, Oba K. Relationship between postprandial glucose level and carotid artery stiffness in patients without diabetes or cardiovascular disease. *BMC Cardiovasc Disord* 2013; **13**: 11 [PMID: 23442745 DOI: 10.1186/1471-2261-13-11]

73 **Selvin E**, Rawlings A, Lutsey P, Maruthur N, Pankow JS, Steffes M, Coresh J. Association of 1,5-Anhydroglucitol With Cardiovascular Disease and Mortality. *Diabetes* 2016; **65**: 201-208 [PMID: 26395741 DOI: 10.2337/db15-0607]

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**Table 1 Diagnostic criteria for categories at increased risk of diabetes**

|  |  |  |
| --- | --- | --- |
| **Category** | **Marker** | **Diagnostic range** |
| IFG | Fasting plasma glycemia | ≥ 5.6 mmol/L (100 mg/dL)≤ 6.9 mmol/L (126 mg/dL) |
| IGT | 2-h post-load glycemia  | ≥ 7.8 mmol/L (140 mg/dL)≤ 11.0 mmol/L (200 mg/dL) |
| HbA1c-prediabetes  | HbA1c | ≥ 39 mmol/mol (5.7 %)≤ 47 mmol/mol (6.5 %)  |

IFG: Impaired fasting glucose; IGT: Impaired glucose tolerance; HbA1c: Glycated haemoglobin.

**Table 2 Main points supporting/not supporting the use of glycated haemoglobin as diagnostic tool for diagnosis of pre-diabetes**

|  |  |
| --- | --- |
| **Supporting** | **Not supporting** |
| HbA1c may better integrate chronic hyperglycaemia than fasting and 2-h post-load glycaemia | HbA1c seems to have a lower sensitivity in pre-diabetes diagnosis |
| HbA1c predicts microvascular complications (rethinopathy and nephropathy) similarly to fasting and 2-h post-load glycaemia | Standardization of HbA1c assay needs to be improved |
| HbA1c has a higher predictive value than fasting plasma glucose in predicting cardiovascular disease | Common, and not always known, clinical conditions (haemoglobinophaties, malaria, anaemia, blood loss) may significantly interfere with HbA1c assay |
| HbA1c has a greater pre-analytical stability than blood glucose |
| HbA1c assay does not need fasting status | Ethnic differences in HbA1c assayare not well characterized |
| HbA1c is not affected by acute perturbations (exercize, stress, diet) | The low biological variability of HbA1c provideslittle information on pathophysiological processes involved in pre-diabetes |
| HbA1c biological variability is lower than fasting and 2-h post-load glycemia |
| HbA1c may be an attractiveoption in settings in which OGTT is not used and rarely repeated | Glucose assessment is cheaper thant HbA1c assay |

HbA1c: Glycated haemoglobin; OGTT: Oral glucose tolerance test.

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**Figure 1 Agreement between glycated haemoglobin pre-diabetes, impaired fasting glucose and impaired glucose tolerance[2].**

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**Figure 2 Intima media thickness, endogenous receptor for advanced glycation end-products, S100A12 and 5-hydroxyvitamin D according to glucose tolerance and glycated haemoglobin levels.** IMT: Intima-media thickness; esRAGE: Endogenous receptor for advanced glycation end-products; 25(OH)D: 25-hydroxyvitamin D; NFG: Normal fasting glucose; NGT: Normal glucose tolerance; IFG: Impaired fasting glucose; IGT: Impaired glucose tolerance; DT2: Type 2 diabetes.