View 2 (Measuring Control)
Consensus Statement: Postprandial Blood Glucose

Individuals with diabetes are at increased risk of developing microvascular complications (retinopathy, nephropathy, and neuropathy) and cardiovascular disease (CVD). The Diabetes Control and Complications Trial (DCCT) and U.K. Prospective Diabetes Study (UKPDS) showed that treatment programs resulting in improved glycemic control, as measured by HbA1c, reduced the microvascular complications of diabetes. The effect of these treatment programs on reducing CVD was less clear. However, some epidemiological studies suggest that there may be a relationship between glycemic levels and CVD.

In the management of diabetes, health care providers usually assess glycemic control with fasting plasma glucose (FPG) and premeal glucose measurements, as well as by measuring HbA1c. Therapeutic goals for HbA1c and preprandial glucose levels have been established based on the results of controlled clinical trials. Unfortunately, the majority of patients with diabetes fail to achieve their glycemic goals. Elevated postprandial glucose (PPG) concentrations may contribute to suboptimal glycemic control. Postprandial hyperglycemia is also one of the earliest abnormalities of glucose homeostasis associated with type 2 diabetes and is markedly exaggerated in diabetic patients with fasting hyperglycemia.

Several therapies targeted toward lowering PPG excursions are now available and have been shown to improve glycemic control as measured by HbA1c. However, many questions remain unanswered regarding the definition of PPG and, perhaps most importantly, whether postprandial hyperglycemia has a unique role in the pathogenesis of diabetic complications and should be a specific target of therapy. To address these issues and to provide guidance to health care providers, the American Diabetes Association (ADA) convened a consensus development conference on 24–26 January 2001 in Atlanta, Georgia.

A seven-member panel of experts in diabetes, endocrinology, and metabolism heard selected abstracts and presentations from invited speakers. The panel was then asked to develop a consensus position on the following questions:

1. How is PPG defined?
2. What is the relationship among PPG, FPG, and HbA1c?
3. What is the contribution of PPG to the long-term complications of diabetes?
4. Under what circumstances should people with diabetes be tested for PPG?
5. What are the benefits and risks of specifically lowering PPG in an effort to achieve better glycemic control?
6. What additional research needs to be performed to clarify the role of PPG in the medical management of diabetes?
**QUESTION 1: How is PPG defined?**

The word postprandial means after a meal; therefore, PPG concentrations refer to plasma glucose concentrations after eating. Many factors determine the PPG profile. In nondiabetic individuals, fasting plasma glucose concentrations (i.e., following an overnight 8- to 10-h fast) generally range from 70 to 110 mg/dl. Glucose concentrations begin to rise ~10 min after the start of a meal as a result of the absorption of dietary carbohydrates. The PPG profile is determined by carbohydrate absorption, insulin and glucagon secretion, and their coordinated effects on glucose metabolism in the liver and peripheral tissues.

The magnitude and time of the peak plasma glucose concentration depend on a variety of factors, including the timing, quantity, and composition of the meal. In nondiabetic individuals, plasma glucose concentrations peak ~60 min after the start of a meal, rarely exceed 140 mg/dl, and return to preprandial concentrations within 2-3 h. Even though glucose concentrations have returned to preprandial levels by 3 h, absorption of the ingested carbohydrate continues for at least 5-6 h after a meal.

Since people with type 1 diabetes have no endogenous insulin secretion, the time and height of peak insulin concentrations, and resultant glucose levels, are dependent on the amount, type, and route of insulin administration. In type 2 diabetic patients, peak insulin levels are delayed and are insufficient to control PPG excursions adequately. In type 1 and type 2 diabetic individuals, abnormalities in insulin and glucagon secretion, hepatic glucose uptake, suppression of hepatic glucose production, and peripheral glucose uptake all contribute to higher and more prolonged PPG excursions than in nondiabetic individuals.

Because the absorption of food persists for 5-6 h after a meal in both diabetic and nondiabetic individuals, the optimal time to measure postprandial glucose concentration must be determined. Practical considerations limit the number of blood samples that can be obtained. In general, a measurement of plasma glucose 2 h after the start of a meal is practical, generally approximates the peak value in patients with diabetes, and provides a reasonable assessment of postprandial hyperglycemia. Specific clinical conditions, such as gestational diabetes or pregnancy complicated by diabetes, may benefit from testing at 1 h after the meal.

**QUESTION 2: What is the relationship among PPG, FPG, and HbA1c?**

Hemoglobin A1c is a measure of the degree to which hemoglobin is glycosylated in erythrocytes and is expressed as a percentage of total hemoglobin concentration. It reflects the exposure of erythrocytes to glucose in an irreversible and time- and concentration-dependent manner. HbA1c levels provide an indication of the average blood glucose concentration during the preceding 2-3 months, incorporating both pre- and postprandial glycemia.

Because blood glucose concentrations vary widely during a 24-h period and from day to day in diabetes, the measurement of HbA1c is the most accepted indicator of long-term glycemic control. However, the HbA1c level does not provide a measure of the magnitude or frequency of short-term fluctuations of blood glucose, which are particularly great in type 1 diabetes.

The relative contributions of FPG and PPG to HbA1c have been studied only recently. Data from several large cohorts with either type 1 or type 2 diabetes were presented at the conference. In general, FPG, PPG, and especially mean plasma glucose (MPG) concentrations, defined by the average of multiple measurements of glucose taken throughout the day, are highly correlated with HbA1c. In contrast, postprandial glucose excursions (PPGE), defined as the change in glucose concentration from before to after a meal, and the incremental glucose (or pre-oral glucose tolerance test [OGTT]) value, are poorly correlated with HbA1c.

Several analyses have shown a strong correlation between HbA1c and MPG ($r = 0.81–0.95$), with each 1% change in HbA1c corresponding to a change in MPG of ~35 mg/dl. The relationship between timed blood glucose measurements and HbA1c in type 1 diabetic patients was examined in recent analyses of DCCT data presented at the conference. Small differences were detected in the relationship between HbA1c and plasma glucose at different times during the day ($r = 0.66-0.76$), with bedtime and postlunch plasma glucose correlating most strongly with HbA1c, and fasting and postbreakfast plasma glucose correlating less well. No specific time point or combination of time points, including mean preprandial or mean postprandial glucose levels, correlated as well with HbA1c as the MPG.

In type 2 diabetes, a study performed in Pima Indians showed that correlations of HbA1c with FPG and PPG measured 1 and 2 h after an oral glucose load or a test meal were indistinguishable ($r = 0.6–0.7$). Similar results from a European population were presented at the conference. In another study in type 2 diabetic patients, the effects of different glucose lowering therapies on the relationship among HbA1c, FPG, and PPG were analyzed in a 24-week randomized clinical trial involving three treatment groups (a rapid-acting insulin secretagogue, an insulin sensitizer, and a combination of both agents) and a placebo group. FPG was found to correlate best with HbA1c ($r = 0.62-0.67$); the correlation with PPG was weaker ($r = 0.22–0.56$) and was inconsistent across the three treatment and placebo groups. There was no significant correlation between HbA1c and PGE.

In summary, there are insufficient data to determine accurately the relative contribution of the FPG and PPG to HbA1c. It appears that FPG is somewhat better than PPG in predicting HbA1c, especially in type 2 diabetes.

**QUESTION 3: What is the contribution of PPG to the long-term complications of diabetes?**

Controlled clinical trials, such as the DCCT1 and the Stockholm Diabetes Study3 in type 1 diabetes and the Kumamoto Study4 and UKPDS5 in type 2 diabetes, have established that therapies directed at achieving normal glycemia are effective in reducing the development and delaying the progression of long-term microvascular diabetic complications.

Even before these clinical trials were completed, observational studies demonstrated a positive association between retinopathy and hyperglycemia. The epidemiological studies relied predominantly on measures of chronic glycemia, such as HbA1c. In the relatively few studies in which HbA1c, FPG, and 2-h OGTT value were measured, all were similarly associated with the risk for retinopa-
analyses of the DCCT5 and UKPDS 6ing glucose goals. Epidemiological
cose-lowering therapy to attain fast-
diabetes, the UKPDS adjusted glu-
mom postprandial levels. In type 2
focused on lowering the 90- to 120-
achieved, further attention was
premeal targets had been select-
e. There are no compa-
people with type 1 or type 2 diabetes
examining whether PPG monitoring
improves outcomes.

Are there other clinical situations in
which PPG monitoring should be con-
sidered part of the overall treatment
plan? There are no adequate random-
ized clinical trial data to answer this
question, but the following are clinical
situations in which PPG monitoring
could be considered:

A. Suspected postprandial hyper-
glycemia. In patients who achieve
their premeal glucose targets, but
whose overall glycemic control as
determined by Hba1c is inap-
propriately high, PPG monitoring and
therapy to minimize PGGEs may
be beneficial.

B. Monitoring treatment aimed at
specifically lowering PPG. In
patients with type 1 or type 2 dia-
betes who are treated with glucose-
lowering agents expected primarily
to reduce PPG, monitoring may be
useful in titrating these treatments or
in confirming that patients have
in fact responded to the interven-
tion. It is also possible that PPG
monitoring may be beneficial to
evaluate the effect of changes in
nutrition or exercise patterns.

C. Hypoglycemia. Hypoglycemia in
the postprandial period is rare
except in response to exercise or
rapid-acting insulin analogs.

There are insufficient data either to
support or to refute the need for
extensive or routine PPG monitoring
in diabetes, except in the setting of
pregnancy. Since self-monitoring of
blood glucose represents a significant
financial and personal burden for
patients, decisions regarding PPG
monitoring should be based on the
needs and responses of individual
patients. The decision to recommend
a glucose monitoring plan should be
made judiciously, accompanied with
specific patient education, and
reviewed and modified regularly by
the health care team.

**QUESTION 5: What are the benefits and risks of specifically lowering PPG in an effort to achieve better glycemic control?**

Randomized clinical trials have
demonstrated that a reduction in the
long-term complications of diabetes is
proportional to average glycemia as
determined by Hba1c. However, it is
unclear whether reducing PPG pro-
vides additional improvements in
Hba1c.

What, if any, are the documented
benefits of specifically lowering PPG?
The definitive answer to this question
can only come from well-designed,
randomized, controlled clinical trials.
The availability of oral agents and
insulin analogs that specifically target
postprandial glucose levels has pro-
ticed tools to perform such studies.

Alpha-glucosidase inhibitors, rapid-
acting oral insulin secretagogues, and
rapid-acting insulin analogs predomi-
nantly lower PPG. They also reduce
Hba1c. It is unclear, however, to what
extent Hba1c is lowered by these
drugs because of their effects on PPG
as compared with their effects on
FPG. Furthermore, it is not clear
whether therapies that target PPG pro-
vide unique benefits relative to other
pharmacological therapies that lower
Hba1c comparably. Performing such
studies will be important.

It has been suggested that agents
that specifically lower PPG may
decrease the risk of hypoglycemia and
weight gain. These claims have not
been consistently supported by ran-
domized, controlled studies. There
appear to be no unique risks associat-
ed with the specific lowering of PPG
to achieve Hba1c goals.

**QUESTION 6: What additional research needs to be performed to clarify the role of PPG in the medical management of diabetes?**

There are several issues that should be
considered when designing studies to
examine PPG. Studies should be per-
formed in well-defined patient groups;
at a minimum, separation of patients
by type of diabetes is necessary. It is
also quite likely that results of studies
in patients with impaired fasting glu-
cose and/or impaired glucose toler-
ance may be different from those in
patients with type 2 diabetes and dif-
frent degrees of fasting hyper-
glycemia. In particular, elderly
patients, in whom postprandial hyper-
glycemia may be the most prevalent
abnormality in glucose homeostasis,
may warrant special attention. In studies of the impact of PPG on diabetic complications, it is important to differentiate between microangiopathy and macroangiopathy as end points. Finally, attention must be paid to differences in therapeutic programs (e.g., nutrition therapy versus oral antihyperglycemic agents versus insulin) and type of oral glucose-lowering drugs used. Given these general principles, the following specific questions should be addressed:

A. How do we best assess postprandial hyperglycemia and the relationships among FPG, PPG, and HbA1c? The term postprandial hyperglycemia is used very loosely because its assessment has not been standardized. Some of the most obvious unresolved issues related to the definition of PPG include: 1) use of a carefully defined meal test versus the OGGT; 2) variations in size and macronutrient content of test meals; 3) timing of blood sampling after standard meals or glucose challenge; and 4) how often any of these measurements should be made in order to provide meaningful information. Resolving these issues, in the appropriate experimental setting, will provide information to define more precisely the nature of the relationships among FPG, PPG, and HbA1c. This information is also necessary to address broader issues, such as the relative importance of PPG and FPG in assessing glycemic control and/or predicting the risk for diabetic complications.

B. What is the clinical utility of using measurements of PPG to improve glycemic control? At present, HbA1c measurements are the "gold standard" for assessing long-term glycemic control. The fundamental question to be answered is whether measuring premeal glucose, FPG, or PPG, alone or in combination, will be most helpful in adjusting treatment to achieve HbA1c goals while minimizing hypoglycemia. Although useful insights concerning these issues have been gained from retrospective analyses, definitive answers require intervention studies. These studies should determine whether treatments aimed at controlling FPG and PPG result in lower HbA1c than do treatments that predominantly affect FPG and/or premeal glucose levels.

C. In the presence of equivalent HbA1c values, does an excessive rise in PPG uniquely affect chronic diabetic complications? It is unclear whether excessive excursions of PPG have a significant impact on the development of diabetic microvascular and macrovascular complications independent of HbA1c levels. To address this fundamental question, studies must be designed to control FPG versus PPG levels while aiming to achieve similar and acceptable HbA1c levels.

Because CVD is the major cause of morbidity and mortality in patients with diabetes, and in type 2 diabetes in particular, understanding the impact on CVD events of treatments directed at specifically lowering PPG is crucial. Furthermore, the relationship between PPG excursions and both the well-established risk factors and the more recently identified putative mechanisms for CVD should be examined.

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Appendix

Consensus Panel
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*These Panel members disclosed that within the past year they have received honoraria, consulting fees, or research grant support or hold stock in one or more of the companies providing support for this conference.

Speakers at the Conference
Paul J. Beisswenger, M D; Antonio Ceriello, M D; William C. Duckworth, M D; William C. Knowler, M D, DrPH; James B. Marks, M D, M PH; Michele M. Uggeo, M D; and F. John Service, M D, PhD.

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