

Suboptimal Performance of Blood Glucose Meters in an Antenatal Diabetes Clinic

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OBJECTIVE—The objective of this study was to evaluate the performance of blood glucose meters in diabetes associated with pregnancy (DP).

RESEARCH DESIGN AND METHODS—Finger-prick blood glucose levels measured using six different glucose meters on 102 patients with DP attending an antenatal clinic were compared with laboratory plasma glucose results. HbA_{1c} and hematocrit were also measured.

RESULTS—The plasma glucose range was 2.2–9.4 mmol/L with hematocrit 33–37% and mean HbA_{1c} 5.5% ± 0.56 (SD). All meters provided plasma equivalent results except one, which reported whole blood glucose that was adjusted to plasma equivalent values. The absolute glucose difference [meter – plasma glucose] was 0.232 ± 0.69 to 0.725 ± 0.62 mmol/L mean ± SD and bias ranged from 6.1 to 15.8%. Two meters were affected by hematocrit <36% (*P* < 0.05).

CONCLUSIONS—Blood glucose meters in current use are not optimally accurate when compared with plasma glucose measurement in DP. Recognition of this deviation is essential to prevent inappropriate treatment of DP.

It is increasingly recognized that very modest levels of hyperglycemia can be associated with adverse fetal outcomes in diabetes associated with pregnancy (DP) (1–4). Self-monitoring of blood glucose using glucose meters and appropriate diet/insulin therapy has been shown to improve glycemic control and fetal/maternal outcomes (2–6). There are no evidence-based criteria for required accuracy of glucose meters for management of diabetes or specifically for DP. However, there are numerous recommendations and analytical performance goals proposed. The American Diabetes Association (ADA) stipulates the most stringent goals, aiming for an analytical error <5% or total error (user plus analytical) <10% (7–13). Standards Australia (ISO15197.2)

and the National Committee for Clinical Laboratory Standards (NCCLS) recommend less stringent goals of ±20% at glucose concentration >4.2 mmol/L and within ± 0.83 mmol/L bias at glucose concentration <4.2 mmol/L (8–13). Although the performance of glucose meters appears to be within the less stringent NCCLS criteria for monitoring diabetes outside pregnancy, the glucose meter performance is variable when applied to DP (9,10). Any difference in performance of glucose meters would be particularly significant in the narrow therapeutic range recommended for DP (1–4). These factors together with recent changes to glucose strip technology, including recalibration to report plasma-equivalent results, prompted us to evaluate the accuracy

of glucose meters in an antenatal clinic setting.

RESEARCH DESIGN AND METHODS

Finger-prick samples were obtained from 102 patients attending an antenatal clinic for management of DP in a 6-month period. Single-use lancets were used, and the first drop of blood was removed with a sterile tissue. Subsequent drops from the same site were applied onto strips for simultaneous analysis on six different types of glucose meters (duplicate for each) in random order. Specialized diabetes research nurses performed these tests at the time of routine venous blood collection, allowing us to obtain plasma glucose, HbA_{1c}, and hematocrit results measured on the same day. Type of diabetes and treatment including vitamin intake were noted. The meters were calibrated each day according to manufacturer specifications. The venous blood samples were centrifuged and analyzed within 30 min of collection.

Plasma glucose was analyzed in the laboratory using Hexokinase/G6PD/ADP-NADP/NADPH reference method (Modular-PPE, Roche Diagnostics, Indianapolis, IN) (14). Five glucose meters (Accu-Chek Advantage-II and Accu-Chek Performa with GDH/PQQ strips, 2 OptiumXceed [with GDH/NAD 5- and 20-s reading strips], and the FreeStyle Lite with GDH/PQQ strips) and a sixth glucose meter Stat-Strip with GO/NAD strips were used. Five meters provided plasma-equivalent glucose readings. The measurements from the sixth meter that provided whole blood glucose readings (Accu-Chek Advantage-II) were adjusted to plasma-equivalent values for the comparison (13).

Statistical and clinical analysis

Imprecision was evaluated by replicate analysis of glucose measurements on the duplicate meters using plasma samples (*n* = 20) with mean glucose concentration 5.6 mmol/L and low and mid control solutions for each meter (*n* = 20). Accuracy was evaluated using these meter readings against the plasma glucose measured in

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Received 28 July 2010 and accepted 24 October 2010.

DOI: 10.2337/dc10-1457

This article contains Supplementary Data online at <http://care.diabetesjournals.org/lookup/suppl/doi:10.2337/dc10-1457/-/DC1>.

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the laboratory. The absolute glucose difference was calculated as = (meter – plasma glucose) in mmol/L, and the bias% was calculated as = [(meter – plasma glucose)/plasma glucose] × 100. The Bland-Altman method was undertaken to examine the difference between glucose meter and plasma glucose results. To determine any influence in hematocrit levels, the mean glucose differences were stratified by hematocrit levels <36 and ≥36% and compared with a two sample *t* test. All results are given as ranges and/or mean ± SD.

RESULTS—The 102 patients had three types of diabetes: gestational diabetes (*n* = 84), type 2 diabetes (*n* = 8), and type 1 diabetes (*n* = 10). Sixty-three were on insulin, and the rest were on dietary treatment. The range of various parameters tested was: glucose 2.2–9.4 mmol/L, hematocrit 29–43%, and HbA_{1c} 4.4–8.4% (mean 5.5% ± 0.56). The imprecision, given as percent coefficient of variation (CV%), and total error (user plus analytical) calculated as bias% + 1.96CV% is given in Table 1.

The overall absolute meter variations were 0.232 ± 0.69 to 0.725 ± 0.62 mmol/L and 6.10–15.76% bias when expressed as a percentage (Table 1). When glucose readings were grouped by hematocrit levels a significant difference (*P* < 0.05) for the two OptiumXceed meters at hematocrit <36% was observed,

whereas the other four meters did not have any significant difference with change in hematocrit (10).

CONCLUSIONS—This study shows that that the current glucose meters are not optimally accurate when compared with plasma glucose measurement. Some can vary by as much as 2 mmol/L, and this may lead to misclassification and inappropriate treatment of DP (Supplementary Fig. 1 and Supplementary Fig. 2 and modified Clarke's Error Grids [15], Supplementary Fig. 3) including over treatment with insulin and under recognition of hypoglycemia.

One of the main strengths of this study is the use of finger-prick capillary samples collected essentially, as they would be by patients for comparing with the laboratory results. This is sometimes required in the management of DP, especially if there is doubt about meter performance and poor correlation with clinical assessment. The testing of a variety of meters with newer enzyme/cofactor systems and the capture of data over a narrow range of blood glucose levels seen during pregnancy, where relatively small variations can be clinically important, are the other strengths of this study. A single strip lot number was used for each meter, to minimize variability between lots associated with some strip systems. The samples were collected between 09.00 and 12.30 h and immediate postprandial

(<1 h) samples were excluded to minimize the known lag between finger-prick and plasma glucose. Specialized diabetes nurses performed the tests in this study. It is recognized that in the hands of non-specialized users there may be more day-to-day variations in technique and meter performance. However, it was not the purpose of this study to measure the effects of technical skills on results.

This study identifies a significant and underemphasized clinical problem in the management of DP. Awareness of the potential inaccuracies of glucose readings is important in advising DP patients on diet and insulin adjustments. This study demonstrates that some of the meter systems appear to have technology-producing results closer to ADA goals, which were thought to be unrealistic or unattainable when they were proposed (Table 1). Although the ADA goals for performance should remain as a target for manufacturers to improve their performance, in our opinion meters with an analytical error (bias) <10%, total error <15%, and no hematocrit interference would be minimum for monitoring and managing DP.

Acknowledgments—The authors acknowledge Roche Diagnostics for supply of the Accu-Chek meters and strips; Abbott Diabetes Care for the supply of OptiumXceed, FreeStyle Lite meters and strips; and Nova Biomedical for the supply of Stat-Strip meter and strips.

M.M. has served on an advisory board for and received a consultancy fee from Roche Diagnostics and LifeScan. No other potential conflicts of interest relevant to this article were reported.

N.J.P. researched data, prepared study design, conducted the study, collected data, and wrote the article. L.M. assisted in statistical design and data analysis and reviewed and edited the article. M.I.C. performed finger-prick glucose measurements, conducted the study, collected data, and reviewed and edited the article. M.M. was the study co-coordinator, contributed to discussion, and reviewed and edited the article. D.K.-S.Y. contributed to discussion and reviewed and edited the article. S.M.T. was joint senior researcher, contributed to discussion, and reviewed and edited the article. G.P.R. was joint senior researcher and assisted in study design, contributed to discussion, and reviewed and edited the article.

Some of the results of this study were presented at the Australasian Diabetes in Pregnancy Society 2009 annual meeting in Adelaide, South Australia, by N.J.P. as an invited speaker.

The authors also acknowledge the staff in the endocrine and biochemistry laboratories and the staff as well as the patients in the outpatient antenatal care unit at Royal Prince

Table 1—Difference between blood glucose meters and plasma blood glucose

Meters	Mean difference*		95% Limits of agreement ± 2 SD		Mean bias (%)†	Mean total analytical error +1.96* CV (%)	Coefficient of variation between meters (%)
	(mmol/L)	SD (mmol/L)					
ACA	0.361	0.55	−0.749	1.470	8.99	14.87	−0.220
OPT20s	0.572	0.66	−0.747	1.890	13.08	26.21	2.597
ACP	0.385	0.57	−0.758	1.528	9.04	15.65	−0.299
OPT5s	0.725	0.62	−0.523	1.972	15.76	32.14	−0.796
FSL	0.232	0.69	−1.157	1.622	6.37	17.07	1.416
STAT	0.256	0.54	−0.817	1.329	6.10	12.29	−0.623

ADA stipulates the most stringent goals, aiming for an analytical error <5% or total error (user plus analytical) <10%. All meters were calibrated to provide plasma glucose results, except one that reported capillary whole blood glucose, and adjusted plasma values were calculated as whole blood glucose = plasma glucose × [1 – (0.0024 × HCT)] for the Accu-Chek Advantage-II meter (13). ACA, Accu-Chek Advantage-II (Roche Diagnostics, Mannheim, Germany) strips Lot No. 450808; OPT20s, OptiumXceed 20 s strips Lot No. 54277 (Abbott Diabetes Care, Alameda, CA); ACP, Accu-Chek Performa (Roche Diagnostics) strips Lot No. 320151; OPT5s, OptiumXceed 5 s strips Lot No. 99884–5 (Abbott Diabetes Care); FSL, FreeStyle Lite (Abbott Diabetes Care) strips Lot No. 0820633; STAT, Stat-Strip (Nova Biomedical, Waltham, MA) strips Lot No. 0308273249. *Mean difference = (mean of the meters – plasma glucose). †[(meter – plasma glucose)/plasma glucose] × 100.

Alfred Hospital (Sydney, Australia) for their assistance in completing this project.

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