Journal of Diabetes Science and Technology
Volume 7, Issue 5, September 2013

ORIGINAL ARTICLE

Accuracy Evaluation of Five Blood Glucose Monitoring Systems: The North American Comparator Trial

Solveig Halldorsdottir, Ph.D., Mary Ellen Warchal-Windham, B.S., Jane F. Wallace, B.A., C.C.R.A., Scott Pardo, Ph.D., P.Stat., Joan Lee Parkes, Ph.D., C.C.R.A., and David A. Simmons, M.D.

Abstract

Background:

This study evaluated differences in accuracy between the CONTOUR® NEXT EZ (EZ) blood glucose monitoring system (BGMS) and four other BGMSs [ACCU-CHEK® Aviva (ACAP), FreeStyle Freedom Lite® (FFL), ONE TOUCH® Ultra®2 (OTU2), and TRUEtrack® (TT)].

Methods:

Up to three capillary blood samples (N = 393) were collected from 146 subjects with and without diabetes. One sample per subject was tested with fresh (natural) blood; the other samples were glycolyzed to lower blood glucose to <70 mg/dl. Meter results were compared with results from plasma from the same sample tested on a Yellow Springs Instruments (YSI) 2300 STAT Plus™ glucose analyzer. Blood glucose monitoring system accuracy was compared using mean absolute relative difference (MARD; from laboratory reference method results) and other analyses. Separate analyses on fresh (natural) samples only were conducted to determine potential effects of glycolysis on MARD values of systems utilizing glucose-oxidase-based test strip chemistry.

Results:

Across the tested glucose range, the EZ had the lowest MARD of 4.7%; the ACAP, FFL, OTU2, and TT had MARD values of 6.3%, 18.3%, 23.4%, and 26.2%, respectively. For samples with glucose concentrations <70 mg/dl, the EZ had the lowest MARD (0.65%), compared with the ACAP (2.5%), FFL (18.3%), OTU2 (22.4%), and TT (33.2%) systems.

Conclusions:

The EZ had the lowest MARD across the tested glucose ranges when compared with four other BGMSs when all samples were analyzed as well as when natural samples only were analyzed.

J Diabetes Sci Technol 2013;7(5):1294–1304

Author Affiliation: Bayer HealthCare LLC, Diabetes Care, Tarrytown, New York

Abbreviations: (ACAP) ACCU-CHEK Aviva, (AE) adverse event, (ARD) absolute relative difference, (BGMS) blood glucose monitoring system, (EZ) CONTOUR NEXT EZ, (FFL) FreeStyle Freedom Lite, (GOx) glucose oxidase, (ISO) International Organization for Standardization, (MARD) mean absolute relative difference, (NIST) National Institute of Standards and Technology, (OTU2) ONE TOUCH Ultra2, (TT) TRUEtrack, (YSI) Yellow Springs Instruments

Keywords: accuracy, blood glucose monitoring system, diabetes, glucose meter

Corresponding Author: Solveig Halldorsdottir, Ph.D., Bayer HealthCare LLC, Diabetes Care, 555 White Plains Rd., Tarrytown, NY 10591; email address solveig.halldorsdottir@bayer.com

Introduction

Self-monitoring of blood glucose plays a significant role in diabetes management. Obtaining accurate results is critical, as people with diabetes may rely on glucose meter readings to detect and properly manage hypoglycemia and hyperglycemia, titrate insulin doses and calibrate continuous glucose monitoring devices, adjust their diet and exercise, and improve their overall decision making in the management of their disease.[1,2] Therefore, performance and accuracy of blood glucose monitoring systems (BGMSs) require careful consideration and optimization.

The CONTOUR® NEXT EZ (EZ; CONTOUR XT outside the United States) BGMS was developed for use with fresh capillary whole blood samples. The system utilizes CONTOUR NEXT reagent test strips containing flavin adenine dinucleotide-glucose dehydrogenase enzyme in combination with a proprietary electron mediator.

Previous studies[3,4] examined the analytical accuracy of the EZ and revealed that the system achieved 100% of results within the new International Organization for Standardization (ISO) ISO15197:2013 accuracy criteria.[5] Moreover, >99% of results were within ±10 mg/dl or ±10% of the reference result.[3,4] The accuracy and ease of use of the EZ in the hands of people with diabetes has also been demonstrated in other studies.[6,7]

Several studies have evaluated the comparative accuracy and precision of many different BGMSs currently used for self-monitoring of blood glucose, but none have included the EZ BGMS.[8–13] The primary objective of this study was to evaluate differences in accuracy between the EZ and four other BGMSs across a wide glucose range. The secondary objective was to examine differences in accuracy between the EZ and the other BGMSs in the low glucose range (<70 mg/dl). Accuracy was assessed by calculating the deviation of meter readings from laboratory reference values, or the absolute relative difference (ARD). The mean of the ARD values was calculated to obtain the mean absolute relative difference (MARD) for each BGMS (lower MARD values indicate greater accuracy). Differences in accuracy between systems were assessed by comparing MARD values of the five BGMSs included in the trial. While currently available BGMSs have met guidelines (e.g., ISO15197 criteria) for sufficient accuracy and precision to be used by people with diabetes, MARD analysis is better suited to evaluate the differences in accuracy of multiple BGMSs in a single study. Discrete (i.e., binary) measures such as described by ISO15197 provide less information per observation than continuous measures and require much larger sample sizes to detect differences between systems. Mean absolute relative difference is a continuous measure that accounts for percentage bias of each observation and thus, correlates with ISO accuracy measurements. Mean absolute relative difference was the primary end point in another comparative study of five BGMSs[13] and has been utilized in accuracy studies of continuous glucose monitoring systems as well.[14,15]

Methods

Subjects

Eligible subjects were males and females aged 18 years or older from the community, with diabetes, and a smaller number (≤10%) without diabetes. Subjects were excluded if they had blood-borne infections such as hepatitis or human immunodeficiency virus, infections such as tuberculosis, or hemophilia or any other bleeding disorder, or were pregnant. No laboratory tests were required to assure qualification; verbal responses of subjects were accepted.

Study Design

This sponsor–investigator study, conducted at a single site in the United States (Bayer HealthCare LLC, Diabetes Care, clinical trial facility in Mishawaka, IN), evaluated the EZ (Bayer Healthcare LLC, Diabetes Care, Tarrytown, NY) and four other BGMSs: ACCU-CHEK® Aviva (ACAP; Roche Diagnostics, Indianapolis, IN) with ACCU-CHEK Aviva Plus Test Strips, FreeStyle Freedom Lite® (FFL; Abbott Diabetes Care Inc., Alameda, CA) with FreeStyle Lite® blood glucose test strips, ONE TOUCH® Ultra®2 (OTU2; LifeScan Inc., Milpitas, CA) with ONE TOUCH Ultra Blue test strips, and TRUEtrack® (TT; Nipro Diagnostics Inc., Fort Lauderdale, FL) with TRUEtrack blood glucose test strips (**Table 1**).

Table 1.
Blood Glucose Monitoring Systems Tested

Meter name	Test strip name	Test strip enzyme	Control solution	Hematocrit range (%)	Glucose range (mg/dl)
EZ	CONTOUR NEXT test strips	Glucose dehydrogenase	CONTOUR NEXT control solution, level 2	15 to 65	20 to 600 Displays "LO" below 20 mg/dl and "HI" above 600 mg/dl
ACAP	ACCU-CHEK Aviva Plus test strips	Glucose dehydrogenase	ACCU-CHEK control solution, level 1	10 to 65	20 to 600 Displays "LO" below 20 mg/dl and "HI" above 600 mg/dl
FFL	FreeStyle Lite test strips	Glucose dehydrogenase	FreeStyle control solution, level normal	15 to 65	20 to 500 Displays "LO" below 20 mg/dl and "HI" above 500 mg/dl
OTU2	ONE TOUCH Ultra Blue test strips	Glucose oxidase	ONE TOUCH ultra control solution	30 to 55	20 to 600 Displays "LOW Glucose" below 20 mg/dl and "HI Glucose" above 600 mg/dl
TT	TRUEtrack test strips	Glucose oxidase	TRUEcontrol, level 0 and level 1	30 to 55	20 to 600 Displays "LO" below 20 mg/dl and "HI" above 600 mg/dl

Study staff followed the user manual instructions for each BGMS, and all systems were tested with their respective control solutions provided with each system to ensure proper functioning (**Table 1**). An institutional review board approved the study protocol, informed consent form, and all study documents that required approval prior to study initiation. All study subjects completed the informed consent process.

The study consisted of one study visit. Subjects participated in testing when they had been fasting for at least 2 h, had not taken bolus insulin or oral agents, and had not exercised vigorously for ≥1 h prior to glucose testing.

Subjects washed and dried their hands thoroughly. A trained operator performed an initial finger stick using the Tenderlett™ (International Technidyne Corp., Edison, NJ) single-use lancing device; blood was collected in a Microtainer® tube containing lithium heparin. Samples were tested immediately with all five BGMSs using blood from the Microtainer tube. Up to two additional capillary blood samples were then collected from each subject, and each blood sample was glycolyzed to lower the glucose concentration. For glycolysis, capped tubes were placed in a water bath (32 °C) to lower the blood glucose level for a maximum of 10 h to achieve a glucose concentration <70 mg/dl.

The testing order of the various BGMSs was randomized. One test strip lot for each BGMS was tested, and 10 meters from each BGMS were used in the study. The EZ meters and test strips were selected randomly from the Bayer commercial inventory, and the other four BGMSs were purchased commercially. All fresh (natural) and glycolyzed capillary blood samples were tested directly when received by the operator with each BGMS to avoid evaporation or concentration of the glucose in the samples. After each blood sample was tested on the five BGMSs, the remaining blood sample was centrifuged to obtain the plasma, which was analyzed on the Yellow Springs Instruments (YSI) laboratory reference analyzer (YSI 2300 STAT Plus™, YSI Life Sciences Inc., Yellow Springs, OH). Single blood glucose test results from each of the five BGMSs were compared with the same blood sample tested on the YSI analyzer. The YSI result was an average of four measurements taken on the same sample. Evaluability criterion required that the elapsed time between the first BGMS test and centrifugation of the sample for the YSI be no greater than 15 min for BGMSs from all manufacturers. The reference method specified by the manufacturer of each BGMS is hexokinase for the ACAP and glucose oxidase (GOx; YSI) for the other four BGMSs.

The precision and accuracy of the YSI analyzer was monitored throughout the study by assaying six traceability control sera (range, 24–605 mg/dl). Target glucose levels for the controls had been determined previously using a reference method traceable to the National Institute of Standards and Technology (NIST) Standard Reference Material 965a Glucose in Frozen Human Serum (aqueous New England Reagents Laboratory glucose standards).[16]

Hematocrit was measured for each subject, in duplicate, using a HemataSTAT II® Microhematocrit Centrifuge (Separation Technology Inc., Sanford, FL).

Assessment and Analyses

The objective of this study was to determine if there were differences in accuracy between the five BGMSs, which was evaluated through a number of preplanned analyses. Accuracy of the BGMSs was assessed by comparing the MARD of the blood glucose meter readings to the laboratory reference values for each system. These analyses included determining the ARD of the BGMS value from the laboratory value for all five BGMSs. The mean of the ARD values was calculated to obtain the MARD for each BGMS (ARD = 100*|meter result - reference result|/reference result). MARD refers to the average percentage deviation of the blood glucose meter results from the laboratory reference results. Lower MARD values indicate greater accuracy (i.e., smaller difference between reference value and meter value). For the primary objective, data for samples across the entire tested glucose range (24–386 mg/dl) were used to perform an analysis of variance, from which least squares means estimates of the MARD were generated. For the secondary objective, data for samples with glucose concentrations <70 mg/dl (i.e., 24–69 mg/dl) were used in the analysis. Additional analyses were performed using three other data sets: samples with glucose concentrations ≥70 mg/dl, fresh (natural) samples only, and glycolyzed samples only.

Additional prespecified analyses included regression analyses of all BGMS results versus YSI results using weighted least squares, Parkes consensus error grid plots to determine the clinical accuracy of each BGMS[17] and difference plots to evaluate the difference between BGMS results and reference results. Difference plots were constructed with the YSI result on the *x* axis and signed difference from the YSI on the *y* axis. The plots included all evaluable samples. Plots were also constructed to show the middle 95% range of the relative difference distribution of BGMS results from the reference results (i.e., plots show the range of values from the 2.5th to 97.5th percentiles of the absolute value of relative difference [ARD = 100*|meter result - reference result|/reference result] distribution). The 95% ARD distribution is an indicator of variability, with a larger range indicating greater variability.

The study was intentionally designed to obtain the majority of blood glucose values in the low or hypoglycemic range in order to have sufficient power to perform the statistical comparisons for values <70 mg/dl.

The lower limit of the measurable glucose concentration range for all BGMSs used in this study was 20 mg/dl (as specified in the labeling materials for each system; **Table 1**). However, some samples with a blood glucose concentration of ≥20 mg/dl, as measured by the YSI analyzer, did not produce a numerical reading on some meter systems; rather, they displayed a "low" message. In order to include these "low" results in the numerical analyses, the results were censored by setting them to 20 mg/dl (i.e., the lowest value in the meter's reported glucose concentration range). Results were not used in the analysis when the YSI result was <20 mg/dl.

Adverse events (AEs) were monitored throughout the study.

Results

Subjects

Subject demographics and medical history information are summarized in **Table 2**. A total of 146 subjects (61 male; 85 female) were enrolled, with a median age of 62 years (range, 19–87 years). The majority of subjects had type 2 diabetes [80.1% (117/146)]; 7.5% (11/146) had type 1 diabetes, 8.2% (12/146) had diabetes of unknown type, and 4.1% (6/146) did not have diabetes.

All enrolled subjects (N = 146) completed the study and had evaluable capillary results. Of the 393 samples collected, five glycolyzed samples were not evaluable because of a YSI result of <20 mg/dl (two samples) or because glycolysis exceeded the 10 h limit (three samples). Thus, there were 388 evaluable results per BGMS.

Sample Characteristics

Glucose concentration ranged from 23.5 to 386 mg/dl for capillary blood samples (as measured on the YSI); 49% (190/388) of the samples were <70 mg/dl, and 51% (198/388) of samples were ≥70 mg/dl. A total of 146 fresh (natural) capillary samples and 242 glycolyzed capillary samples were tested with all five BGMSs. Of the 190 blood samples with glucose concentrations <70 mg/dl, 6 samples were fresh (natural) and 184 samples were glycolyzed. The number of censored results for each BGMS is shown in **Table 3**. The EZ and the ACAP had no censored results, indicating that all blood samples (>20 mg/dl by YSI) displayed a numerical result on the meter. The hematocrit had a mean of 38.7% (range, 30–50%). All values were within the hematocrit range for all systems (**Table 1**).

Table 2.
Subject Demographics and Baseline Characteristics

Characteristic	*N* = 146
Type of diabetes, *n* (%)[a]	
Type 1	11 (7.5)
Type 2	117 (80.1)
Unknown	12 (8.2)
No diabetes	6 (4.1)
Gender, n (%)	
Male	61 (41.8)
Female	85 (58.2)
Age, years (mean ± standard deviation)	60.6 ± 13.76
Median (range)	62 (19–87)
Ethnicity, *n* (%)[a]	
Caucasian	122 (83.6)
Black/African American	17 (11.6)
Native American	3 (2.1)
Other	2 (1.4)
No answer	2 (1.4)
Duration of diabetes, *n* (%)[b]	
4–6 months	3 (2.1)
7–12 months	6 (4.3)
13 months–2 years	11 (7.9)
3–5 years	29 (20.7)
6–10 years	25 (17.9)
>10 years	66 (47.1)
Frequency of daily blood glucose testing, *n* (%)[a,b]	
>4	24 (17.1)
4	12 (8.6)
3	21 (15.0)
2	39 (27.9)
1	33 (23.6)
<1	11 (7.9)

[a] Total percentages may not add up to 100% due to rounding.
[b] *N* = 140.

Accuracy

For the primary end point analysis for overall blood glucose results (range, 24–386 mg/dl), the EZ had the lowest MARD estimate of 4.7%, and the TT had the highest MARD estimate of 26.2% (**Table 4**).

For secondary end point analyses, the EZ had the lowest MARD estimate compared with the other BGMSs when tested with samples with glucose concentrations <70 and ≥70 mg/dl, fresh (natural) and glycolyzed samples (**Table 5**).

Table 3.
Censored Results for Blood Glucose Monitoring Systems Tested

Meter	*N*	Censored readings	Numeric readings
EZ	388	0	388 (100%)
ACAP	388	0	388 (100%)
FFL	388	11 (2.8%)	377 (97.1%)
OTU2	388	8 (2.1%)	380 (97.9%)
TT	388	60 (15.5%)	328 (84.5%)

Table 4. Overall MARD Results for the Five BGMSs for Overall Blood Glucose Results (Primary End Point)

Blood glucose meter	Overall MARD (*n* = 388)			
	%	95% Confidence interval	Standard error, %	*P* value[a]
EZ	4.7	−2.0 to 11.4	3.4	Not applicable
ACAP	6.3	−0.4 to 13.0	3.4	2.7×10^{-10}
FFL	18.3	11.6 to 25.0	3.4	3.0×10^{-13}
OTU2	23.4	16.7 to 30.1	3.4	3.0×10^{-13}
TT	26.2	19.5 to 32.9	3.4	3.0×10^{-13}

[a] Versus the EZ BGMS as determined using Tukey's honestly significant difference methodology.

Table 5.
Mean Absolute Relative Difference Results for All Samples (Secondary Analyses)

Blood glucose meter	Glucose concentration <70 mg/dl (n = 190)[a]				Glucose concentration ≥70 mg/dl (n = 198)				Overall glucose concentration (23.5–386 mg/dl)							
									Fresh (natural) samples (n = 146)				Glycolyzed samples (n = 242)			
	MARD, %	95% Confidence interval	Standard error, %	P value[b]	MARD, %	95% Confidence interval	Standard error, %	P value[b]	MARD, %	95% Confidence interval	Standard error, %	P value[b]	MARD, %	95% Confidence interval	Standard error, %	P value[b]
EZ	0.65	−5.5 to 6.8	3.1	Not applicable	5.5	0.7 to 10.3	2.4	Not applicable	8.9	4.5 to 13.3	2.2	Not applicable	11.2	4.8 to 17.5	3.3	Not applicable
ACAP	2.5	−3.6 to 8.7	3.1	3.1×10^{-9}	6.9	2.1 to 11.6	2.4	9.6×10^{-5}	10.3	5.9 to 14.7	2.2	4.8×10^{-4}	12.9	6.5 to 19.3	3.3	2.0×10^{-9}
FFL	18.3	12.1 to 24.4	3.1	8.0×10^{-11}	15.3	10.5 to 20.0	2.4	7.4×10^{-11}	18.5	14.1 to 22.9	2.2	9.7×10^{-11}	27.2	20.8 to 33.5	3.3	4.2×10^{-11}
OTU2	22.4	16.2 to 28.6	3.1	8.0×10^{-11}	21.3	16.5 to 26.1	2.4	7.4×10^{-11}	24.5	20.2 to 28.9	2.2	9.7×10^{-11}	31.6	25.3 to 38.0	3.3	4.2×10^{-11}
TT	33.2	27.1 to 39.4	3.1	8.0×10^{-11}	16.3	11.5 to 21.1	2.4	7.4×10^{-11}	17.7	13.3 to 22.1	2.2	9.7×10^{-11}	40.3	33.9 to 46.7	3.3	4.2×10^{-11}

[a] Of the 190 blood samples with glucose concentrations <70 mg/dl, 6 samples were fresh (natural) and 184 samples were glycolyzed.
[b] Versus the EZ BGMS as determined using Tukey's honestly significant difference methodology.

Regression analyses showed a high degree of correlation between the BGMS results and the YSI reference results for all BGMSs. The EZ had an adjusted R^2 of 99.6%. The adjusted R^2 for the ACAP, FFL, OTU2, and TT was 99.3%, 99.2%, 95.0%, 93.3%, respectively.

Difference plots are shown in **Figure 1**; the points are differentiated by unique symbols, denoting whether the samples were fresh (natural) or glycolyzed. The difference plots showed a slight negative bias of FFL and OTU2 results. Results for the TT were also generally biased in the negative direction; no such bias was observed for the EZ or the ACAP.

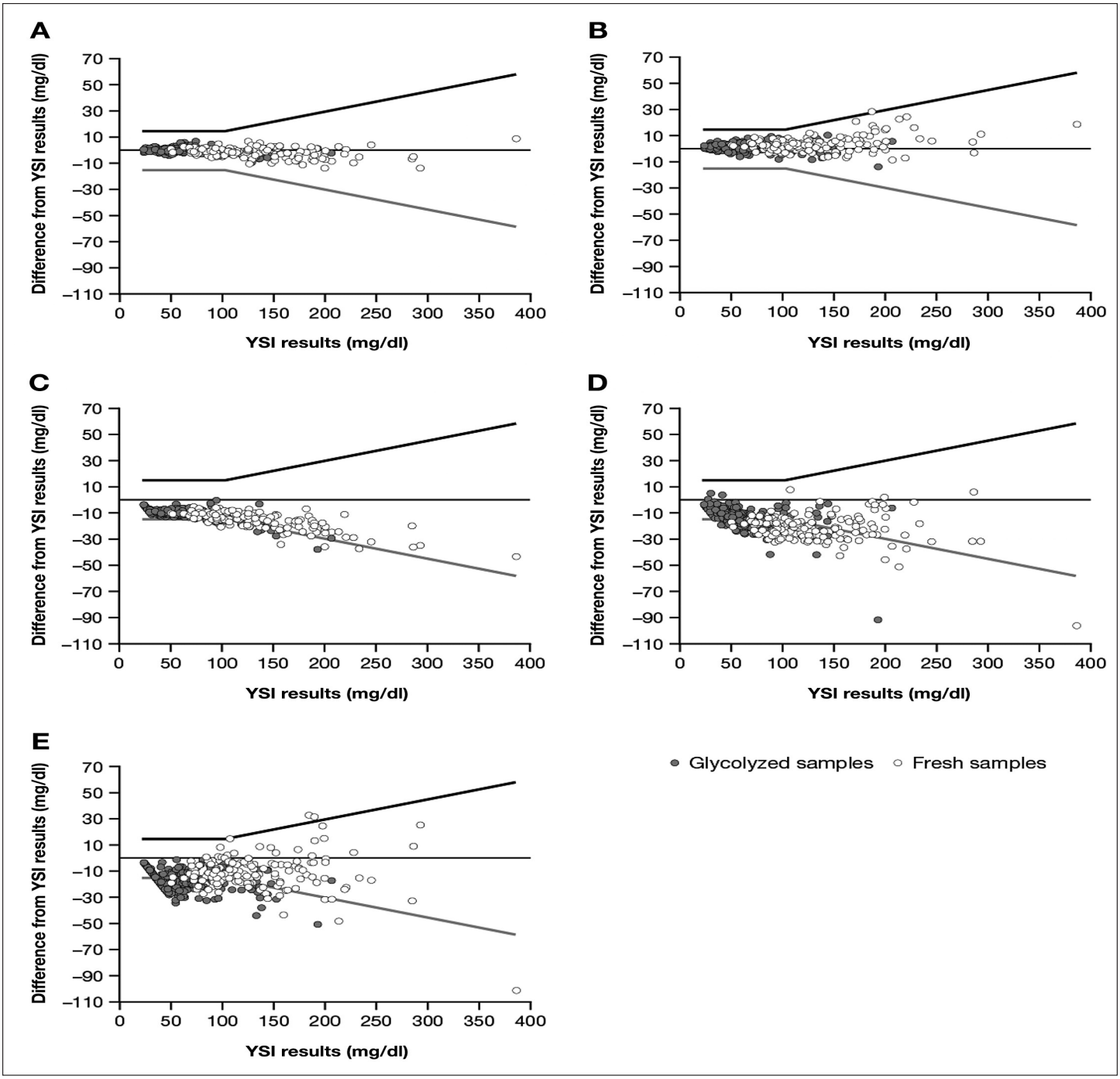

Figure 1. Difference plots of all BGMS results: **(A)** EZ, **(B)** ACAP, **(C)** FFL, **(D)** OTU2, and **(E)** TT. The lower limits and upper limits indicated on the plots are either ±15 mg/dl (YSI <100 mg/dl) or ±15% (YSI ≥100 mg/dl) of the YSI value. These limits are calculated per ISO15197:2013 criteria[5] and are expressed in mg/dl.

Parkes consensus error grid analyses are shown in **Figure 2**. Per error grid analysis, 100% of EZ and ACAP results were in zone A (**Figures 2A** and **2B**, respectively). For the FFL, 98% of results were in zone A and 2% in zone B (**Figure 2C**). For the OTU2, 79% of results were in zone A and 21% in Zone B (**Figure 2D**). For the TT, 84% of results were in zone A and 16% in Zone B (**Figure 2E**). There were no results in zones C, D, or E for any of the systems.

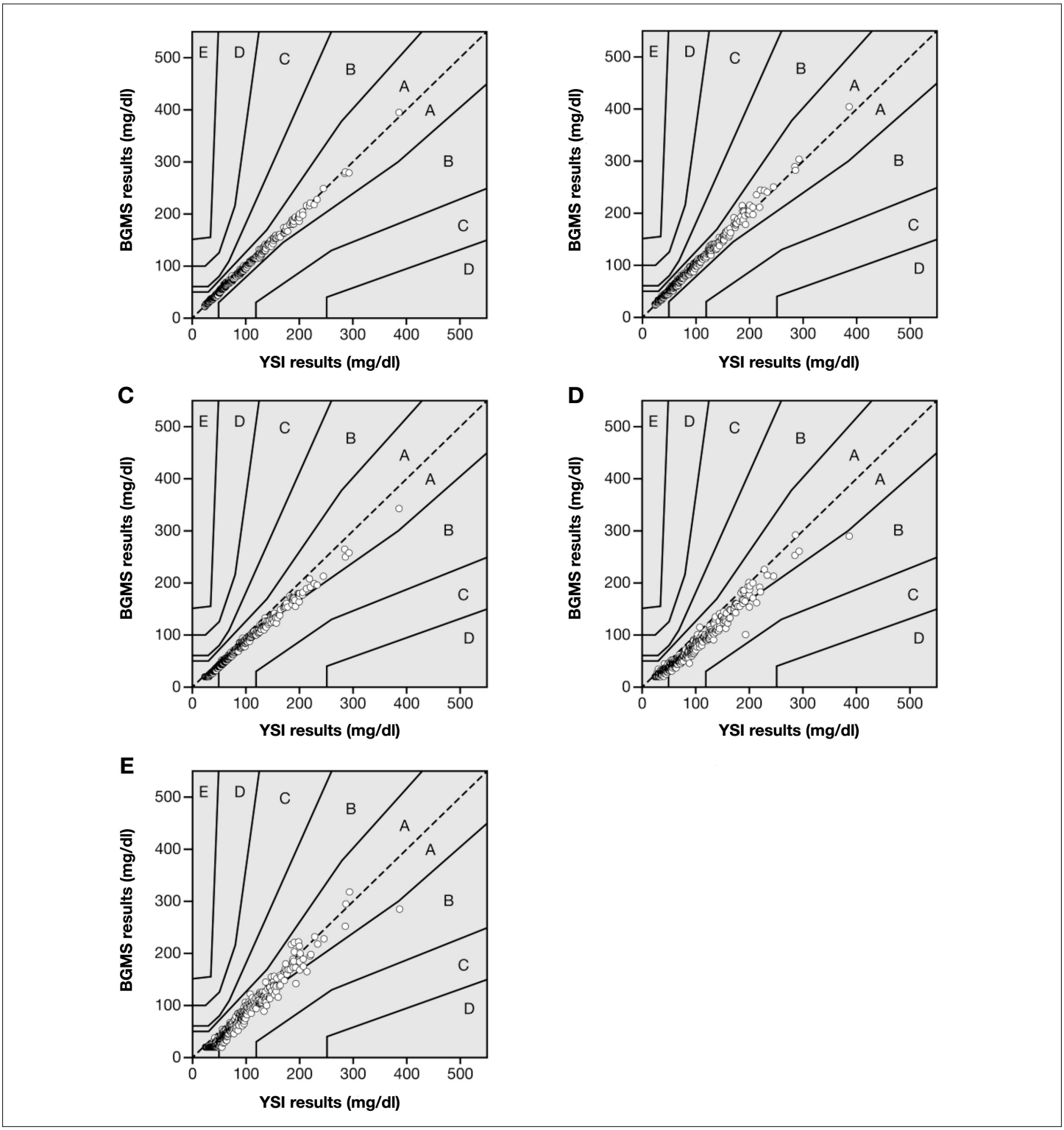

Figure 2. Parkes consensus error grid analysis of all BGMS results: **(A)** EZ, **(B)** ACAP, **(C)** FFL, **(D)** OTU2, and **(E)** TT.

The variability of blood glucose readings of the BGMSs, based on the middle 95% range of ARD distributions, is graphically represented in **Figure 3**. The EZ had the narrowest 95% range (from 0.10% to 7.49%), indicating that it had the least variability, while the TT had the largest (from 1.40% to 54.56%).

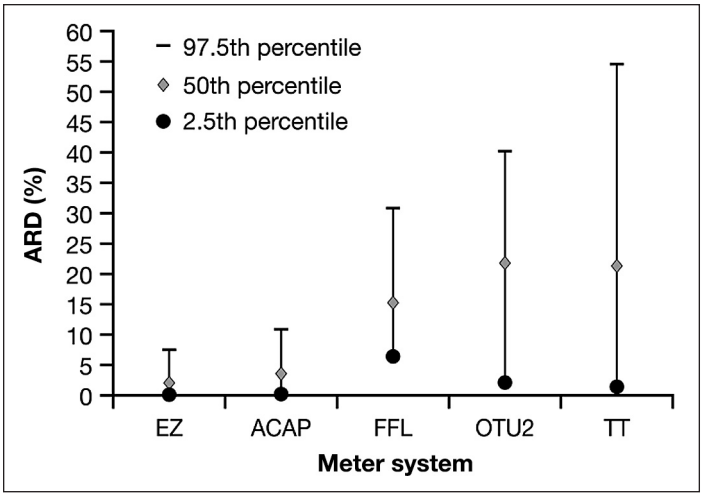

Figure 3. Middle 95% range of ARD distributions. The MARD value for overall blood glucose results was 4.7% for the EZ, 6.3% for the ACAP, 18.3% for the FFL, 23.4% for the OTU2, and 26.2% for the TT.

Adverse Events

Four nonserious, anticipated, non-device-related, mild AEs occurred. The four subjects had hypoglycemia (YSI-derived blood glucose level of <60 mg/dl). The AEs were documented and resolved before the subjects left the study site.

Discussion

Because the performance of a BGMS is an important factor in diabetes management, five BGMSs were tested to determine their relative analytical accuracy as assessed by MARD. The EZ had the lowest MARD value across the tested blood glucose range as well as for low blood glucose concentrations (<70 mg/dl) compared with four other BGMSs, showing that the EZ had the smallest average percentage deviation from the reference results of all BGMSs tested. This study was not performed according to the ISO15197:2013 protocol, as one of our objectives was to assess comparative accuracy in the low (<70 mg/dl) glucose range. According to the ISO protocol, 20% of the samples should be at 80 mg/dl or below (or 20 samples from 100 subjects).[5] This study included 190 samples below 70 mg/dl for sufficient statistical power for comparing MARD values across five different systems. Previous studies on the EZ were conducted that satisfy ISO15197:2013 criteria.[3,4,6,7]

Several characteristics of this study that may impact interpretation of results are as follows: (1) The study was designed to assess comparative analytical accuracy of BGMSs and thus does not address the performance of these systems in the hands of intended users. (2) In order to safely obtain sufficient capillary blood with glucose concentrations in the low range (<70 mg/dl) without subjects becoming hypoglycemic, up to two additional capillary samples collected into test tubes from each subject (n = 242 samples) were allowed to glycolyze *in vitro* prior to testing. Because glycolysis can alter oxygen concentration, caution must be taken when interpreting results, especially for the GOx-based BGMSs (OTU2 and TT), which can be affected by oxygen. To account for this potential bias, we repeated the MARD analysis on fresh (natural) samples only and found that the EZ still had the lowest average percent deviation from the reference results compared with the other systems tested. Therefore, when accounting for oxygen dependency of the GOx-based BGMSs by excluding glycolyzed samples, the EZ had the lowest MARD of all systems tested. (3) The ACAP is calibrated using a hexokinase-based reference method but was compared with a GOx-based reference method (YSI) in this study. The remaining BGMSs used in this study are calibrated to a YSI glucose analyzer. Therefore, it is possible that ACAP MARD values are even lower than reported in this study. In addition, the different BGMSs tested here were calibrated by their manufacturers, which may result in slightly higher or lower biases due to the inherent bias of the comparison method relative to the primary reference procedure. The YSI in the current study was tested with a set of serum controls with assigned values established with a secondary reference procedure, the NIST/Centers for Disease Control and Prevention reference method for plasma glucose (barium hydroxide/zinc sulfate deproteinized plasma, hexokinase). This secondary procedure is calibrated with NIST standard reference materials (SRM 965), and the assigned values of these materials were established with the primary reference procedure (isotope dilution/gas chromatography/mass spectrometry).

Previous studies have evaluated the comparative accuracy and precision of the other BGMSs used in this study (ACAP, FFL, OTU2, and TT), and in some cases, the FFL and the OTU2 performed better in these previous studies than in the current study,[8–10,12,13] while the performance of the TT was similarly poorer compared with other BGMSs evaluated.[11]

However, none of these studies included the EZ meter. Study design differences could account for the apparent discordant results reported in these studies compared with the current analysis. The current study was designed to test comparative accuracy in the overall and low glucose range, resulting in a sample distribution that was intentionally skewed toward low glucose concentrations. This study did not follow the DIN EN ISO15197:2003 (or 2013) bin distribution requirements for different glucose concentrations and included more samples <70 mg/dl than required in the ISO15197:2003 and 2013 standards. Therefore, if the performance of a given BGMS is not consistent across a wide glucose concentration range, this could be reflected in different results from studies focused on specific glucose ranges. Another possible explanation for these discordant results is test strip lot selection (i.e., prior studies may have used lots of test strips that performed much better than the test strip lots used in our study). Therefore, another potential question of the current study is whether the test strip lots included in the current study are representative of the overall populations of the competitive BGMSs. Test strip lots for the EZ meter were selected randomly from the Bayer commercial inventory, and test strips for the other four BGMSs were purchased commercially. Other factors that could have affected the results of this study and the other comparative studies include sample handling technique, reference method calibration, subject variability, and hematocrit.

Conclusions

The current study showed that the EZ BGMS had the lowest MARD value across the tested glucose range when compared with four other BGMSs. To account for potential effects of glycolysis on GOx-based systems, a separate analysis was conducted on fresh (natural) samples only. The MARD value for the EZ BGMS was also significantly lower than the MARD values of the other four systems when fresh (natural) samples were analyzed separately. Using an accurate BGMS is important for optimal diabetes management because BGMS results have the potential to affect the behaviors and outcomes of people with diabetes.

Funding:

This study was supported by Bayer HealthCare LLC, Diabetes Care, Tarrytown, NY. Medical writing assistance was provided by Allison Michaelis, Ph.D., of MedErgy, Yardley, PA, and was supported by Bayer HealthCare LLC, Diabetes Care, Tarrytown, NY.

Disclosures:

All authors are full-time employees of Bayer HealthCare LLC, Diabetes Care.

Acknowledgments:

Sally Robinson, Sherry Jamison, Nancy Kessler, Irene Janczyk, Denise Clay, Sandra Youngs, and Paula Sharp-Harris also contributed to the study.

References:

1. American Diabetes Association. Self-monitoring of blood glucose. Diabetes Care. 1994;17(1):81–6.
2. American Diabetes Association. Clinical practice recommendations. Diabetes Care. 2010;33 Suppl 1:S1–S99.
3. Pflug B, Warchal-Windham ME, Goldy A, Chu A. Analytical accuracy evaluation of the CONTOUR® XT blood glucose meter. J Diabetes Sci Technol. 2013;7(1):281–4,A107.
4. Warchal-Windham ME, Castro R, Chu A. Accuracy evaluation of the CONTOUR® XT blood glucose meter. Presented at: 5th Annual International Conference on Advanced Technologies and Treatments for Diabetes, February 8–11, 2012, Barcelona, Spain.
5. International Organization for Standardization. ISO15197:2013: *In vitro* diagnostic test systems -- requirements for blood-glucose monitoring systems for self-testing in managing diabetes mellitus. Geneva: International Organization for Standardization; 2013.
6. Bailey TS, Wallace JF, Parkes JL, Pardo S, Yu J, Schachner HC, Simmons DA, Chu A. Performance of a new blood glucose monitoring system in the hands of intended users. Diabetes Technol Ther. 2012;14(9):783–9.
7. Bailey T, Tideman A, Greene C, Viggiani M, Yu J, Pardo S, Parkes JL. User performance evaluation of a new blood glucose monitoring system. Diabetes. 2012;61 Suppl 1:A223. Abstract 880–P.
8. Freckmann G, Schmid C, Baumstark A, Pleus S, Link M, Haug C. System accuracy evaluation of 43 blood glucose monitoring systems for self-monitoring of blood glucose according to DIN EN ISO 15197. J Diabetes Sci Technol. 2012;6(5):1060–75.

9. Freckmann G, Baumstark A, Jendrike N, Zschornack E, Kocher S, Tshiananga J, Heister F, Haug C. System accuracy evaluation of 27 blood glucose monitoring systems according to DIN EN ISO 15197. Diabetes Technol Ther. 2010;12(3):221–31.

10. Pfützner A, Mitri M, Musholt PB, Sachsenheimer D, Borchert M, Yap A, Forst T. Clinical assessment of the accuracy of blood glucose measurement devices. Curr Med Res Opin. 2012;28(4):525–31.

11. Sheffield CA, Kane MP, Bakst G, Busch RS, Abelseth JM, Hamilton RA. Accuracy and precision of four value-added blood glucose meters: the Abbott Optium, the DDI Prodigy, the HDI True Track, and the HypoGuard Assure Pro. Diabetes Technol Ther. 2009;11(9):587–92.

12. Young JK, Ellison JM, Marshall R. Performance evaluation of a new blood glucose monitor that requires no coding: the OneTouch Vita System. J Diabetes Sci Technol. 2008;2(5):814–8.

13. Tack C, Pohlmeier H, Behnke T, Schmid V, Grenningloh M, Forst T, Pfützner A. Accuracy evaluation of five blood glucose monitoring systems obtained from the pharmacy: a European multicenter study with 453 subjects. Diabetes Technol Ther. 2012;14(4):330–7.

14. Luijf YM, Mader JK, Doll W, Pieber T, Farret A, Place J, Renard E, Bruttomesso D, Filippi A, Avogaro A, Arnolds S, Benesch C, Heinemann L, Devries H. On Behalf Of The Ap Home Consortium JH. Accuracy and reliability of continuous glucose monitoring systems: a head-to-head comparison. Diabetes Technol Ther. 2013. Epub ahead of print.

15. Damiano ER, El-Khatib FH, Zheng H, Nathan DM, Russell SJ. A comparative effectiveness analysis of three continuous glucose monitors. Diabetes Care. 2013;36(2):251–9.

16. Neese JW, Duncan P, Bayse D, Robinson M, Cooper T, Stewart C. Development and evaluation of a hexokinase/glucose-6-phosphate dehydrogenase procedure for use as a national glucose reference method. HEW Publication No. (CDC) 77-8330. Atlanta: Centers for Disease Control and Prevention; 1976.

17. Parkes JL, Slatin SL, Pardo S, Ginsberg BH. A new consensus error grid to evaluate the clinical significance of inaccuracies in the measurement of blood glucose. Diabetes Care. 2000;23(8):1143–8.