Evaluation of six portable blood glucose meters for measuring blood glucose concentration in dogs

Todd A. Cohen, DVM; Richard W. Nelson, DVM, DACVIM; Philip H. Kass, DVM, PhD, DACVPM; Mary M. Christopher, DVM, PhD; Edward C. Feldman, DVM, DACVIM

Objective—To evaluate accuracy of 6 portable blood glucose meters (PBGMs) by comparing results of these meters with results obtained with a reference chemistry analyzer.

Design—Evaluation study.

Animals—49 dogs (158 blood samples).

Procedures—Venous blood samples were tested with the 6 PBGMs, and results were compared with results of a commercially available analyzer that used a reference method based on the hexokinase reaction.

Results—Plasma glucose concentrations obtained with the reference analyzer ranged from 41 to 639 mg/dL. There were significant correlations between blood glucose concentrations obtained with the 6 PBGMs and plasma glucose concentrations obtained with the reference analyzer ($r \geq 0.96$). However, for all 6 PBGMs, results differed from results for the reference analyzer, with the difference increasing as plasma glucose concentration increased. Significant differences in bias were found among meters. For 142 samples classified as hypoglycemic, euglycemic, or hyperglycemic on the basis of results of the reference analyzer, the percentage of samples that were misclassified on the basis of results of the PBGMs ranged from 2.1% to 38.7%.

Conclusions and Clinical Relevance—Results of the present study suggested that there were substantial differences in the accuracy of currently available PBGMs when used to determine blood glucose concentration in dogs. (*J Am Vet Med Assoc* 2009;235:276–280)

Portable blood glucose meters are commonly used to measure venous and capillary blood glucose concentrations in dogs and cats.[1–5] However, results obtained with various PBGMs can differ among themselves and from results of chemistry analyzers that use a reference method based on the hexokinase reaction.[4–6] Blood glucose concentrations obtained with most PBGMs are lower than concentrations obtained with a hexokinase reference method, with the difference typically increasing as the true blood glucose concentration increases.[4] This raises concerns when blood glucose concentrations obtained from some PBGMs are used to make clinical decisions regarding diabetic control and adjustments to insulin dosage for dogs and cats with diabetes mellitus.[6]

Previous studies[4,6] have provided guidance on choosing a PBGM, but all of the meters evaluated in those studies have been replaced by newer and, presumably, more accurate devices. In addition, a PBGM[a] specifically designed for use in dogs and cats that purportedly accounts for differences in glucose bound to RBCs versus free in the plasma has recently become available. Thus, additional studies of the accuracy of the newer PBGMs, including the PBGM marketed for use in dogs and cats, are needed. The purposes of the study reported here were to evaluate the accuracy of 6 commercially available PBGMs by comparing results of these meters with results obtained with a chemistry analyzer that used a reference method based on the hexokinase reaction and to evaluate the concordance between results obtained with these meters and results obtained with the reference method with regard to whether blood samples were classified as hypoglycemic, euglycemic, or hyperglycemic.

Abbreviation

PBGM Portable blood glucose meter

Materials and Methods

Dogs—The study was conducted at the University of California Veterinary Medical Teaching Hospital between November 2006 and August 2007. Forty-nine dogs and 158 blood samples were used in the study. Several dogs were identified for inclusion in the study on the basis of a potential for hyper- or hypoglycemia, given their suspected condition. Multiple blood samples were obtained at various times from some dogs included in the study to obtain samples with a wide range of blood glucose concentrations. Individual blood samples were excluded from the study if the patient's inspired oxygen concentration was > 21%, as the resultant change in oxygen content of the blood has been reported to affect the results of PBGMs.[7] Five of the dogs (5 blood sam-

From the Veterinary Medical Teaching Hospital (Cohen) and the Departments of Medicine and Epidemiology (Nelson, Feldman), Population Health and Reproduction (Kass), and Pathology, Microbiology and Immunology (Christopher), School of Veterinary Medicine, University of California, Davis, CA 95616.

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Address correspondence to Dr. Nelson.

ples) included in the study were considered healthy, 18 (113 blood samples) had diabetes mellitus, and 26 (40 blood samples) had various other medical conditions, including 5 dogs with insulinoma. All owners provided informed consent for collection of blood samples from their dogs prior to enrollment in the study.

PBGMs—Six brands of PBGMs[a–f] were evaluated in the study, with a single meter of each brand used. All 6 meters and their respective test strips were purchased from a local pharmacy or directly from the distributor. For all 6 meters, the basic operation was the same, with blood drawn into the reaction chamber of the test strip by capillary action and blood glucose concentration determined by means of an electrochemical or photometric method (**Appendix**). Measurement ranges for each of the meters had been established by the manufacturer, and all 6 meters displayed a value of LO or HI when blood glucose concentration was less than or greater than these established limits. Any blood sample for which 1 or more of the meters provided a result of LO or HI was excluded from the study. The AlphaTrak meter was set to the code corresponding to a canine blood sample.

Experimental protocol—Blood samples were collected from the jugular or cephalic vein with a 20- or 22-gauge needle. A drop of blood was placed on the wrapper from a test strip for one of the PBGMs, and the end of a test strip for each of the 6 PBGMs was then touched to the drop of blood, and blood glucose concentration was measured with each of the 6 meters. Immediately afterward, 1 mL of blood was placed in a tube containing dry lithium heparin.[g] Heparinized samples were centrifuged, plasma was harvested, and plasma glucose concentration was determined within 15 minutes after blood sample collection with a chemistry analyzer[h,i] that used a reference method based on the hexokinase reaction and was operated by trained laboratory technicians.

All PBGMs were operated according to manufacturer directions, with the exception that venous rather than capillary blood was used. Each meter was calibrated as directed by the manufacturer, and all assays were performed by a single individual (TAC). The sequence for determination of blood glucose concentrations with the 6 PBGMs was randomized throughout the study by the use of statistical software.[j]

Quality control measures—Control solutions and calibration test strips supplied by each manufacturer were used for quality control of the 6 PBGMs. In accordance with manufacturer instructions, meters were calibrated whenever a new box of test strips was opened. For the reference analyzer, quality control procedures were performed daily or any time reagents were changed.

Effects of heparin—Twenty-seven of the 158 blood samples were used to assess the effects of heparin on glucose concentrations obtained with the reference analyzer. For these samples, after 1 mL of each sample had been placed in a tube containing lithium heparin, an additional 1 mL was placed in a plain glass tube without any additives. Serum was harvested within 15 minutes after blood sample collection, and serum and plasma glucose concentrations were determined with the reference analyzer.

Intra-assay coefficients of variation—For each of the 6 PBGMs, intra-assay coefficients of variation were assessed with 3 blood samples containing low (52 mg/dL), normal (103 mg/dL), and high (379 mg/dL) plasma glucose concentrations, as determined with the reference analyzer. Intra-assay coefficients of variation were calculated by measuring blood glucose concentration in each sample 10 times.

Data analysis—Data were summarized as median and range, unless otherwise indicated. Least-squares regression analysis with clustered robust SEs to account for repeated measurements within individuals was used to compare blood glucose concentrations obtained with each of the PBGMs with plasma glucose concentrations obtained with the reference analyzer (ie, reference concentrations). Wilcoxon signed rank tests with stratification on individual dogs to account for repeated measurements within individuals were used to compare median bias between PBGMs, with bias defined as the absolute value of the difference between blood glucose concentrations obtained with a PBGM and corresponding plasma glucose concentrations obtained with the reference analyzer. Scatterplots of the difference between glucose concentrations obtained with each PBGM and the reference analyzer versus mean concentration obtained with the 2 methods were assessed subjectively to evaluate agreement over the range of glucose concentrations obtained.

Concordance between results obtained with each of the 6 PBGMs and results obtained with the reference analyzer was examined. Plasma glucose concentrations determined by the reference analyzer were classified as hypoglycemic (glucose concentration < 70 mg/dL), euglycemic (glucose concentration between 70 and 120 mg/dL), or hyperglycemic (glucose concentration > 200 mg/dL). Classification of plasma glucose results measured from the corresponding blood sample by each of the 6 PBGMs was determined, and the percentage of results from each PBGM that were correctly classified on the basis of results from the reference analyzer was determined. Samples with plasma glucose concentrations > 120 mg/dL but ≤ 200 mg/dL were excluded from these analyses.

Statistical analyses were performed with standard software,[k–m] and values of $P < 0.05$ were considered significant.

Results

For the 158 samples included in the study, plasma glucose concentration, determined with the reference analyzer,

Table 1—Results of least-squares linear regression analysis of blood glucose concentrations obtained with 6 PBGMs versus plasma glucose concentrations obtained with a commercial analyzer that used a reference method based on the hexokinase reaction.

Meter	Slope	Intercept	Correlation coefficient	*P* value*
AlphaTrak[a]	1.115	–9.01	0.96	> 0.05
Precision[b]	1.323	5.08	0.96	< 0.05
Elite[c]	1.154	20.76	0.98	> 0.10
Contour[d]	1.106	53.64	0.97	< 0.01
Accu-Chek[e]	1.197	18.13	0.98	< 0.05
OneTouch[f]	1.022	17.87	0.98	> 0.05

Data represent results for 158 blood samples from 49 dogs.
*Represents the *P* value for a test for proportional error (ie, nonlinearity).

ranged from 41 to 639 mg/dL. Twenty-nine of the 158 samples had plasma glucose concentrations < 100 mg/dL, 31 had plasma glucose concentrations between 100 and 199 mg/dL, 36 had plasma glucose concentrations between 200 and 299 mg/dL, 36 had plasma glucose concentrations between 300 and 400 mg/dL, and 26 had plasma glucose concentrations > 400 mg/dL.

There were significant correlations between blood glucose concentrations obtained with each of the 6 PBGMs and plasma glucose concentrations obtained with the reference analyzer (**Table 1**). However, 86 (55%), 158 (100%), 154 (98%), 156 (99%), 156 (99%), and 134 (85%) of the blood glucose concentrations obtained with the AlphaTrak, Precision, Elite, Contour, Accu-Chek, and OneTouch meters, respectively, were low, compared with corresponding reference concentrations. On the other hand, 67 (43%) of the blood glucose concentrations obtained with the AlphaTrak meter were high, compared with corresponding reference concentrations.

For each of the 6 PBGMs, bias, defined as the absolute value of the difference in blood glucose concentration obtained with the meter versus plasma glucose concentration obtained with the reference analyzer, increased as plasma glucose concentration increased (**Table 2**). Bias varied among meters but was generally lowest for the AlphaTrak and OneTouch meters (**Figures 1 and 2**). Median bias varied significantly ($P < 0.05$) among all 6 PBGMs.

Overall, 20 of the samples were classified, on the basis of results of the reference analyzer, as hypoglycemic (glucose concentration < 70 mg/dL), 24 were classified as euglycemic (glucose concentration between 70 and 120 mg/dL), and 98 were classified as hyperglycemic (glucose concentration > 200 mg/dL). Of the 142 samples, 3 (2.1%) would have been misclassified with the AlphaTrak meter, 29 (20.4%) would have been misclassified with the Precision meter, 22 (15.5%)

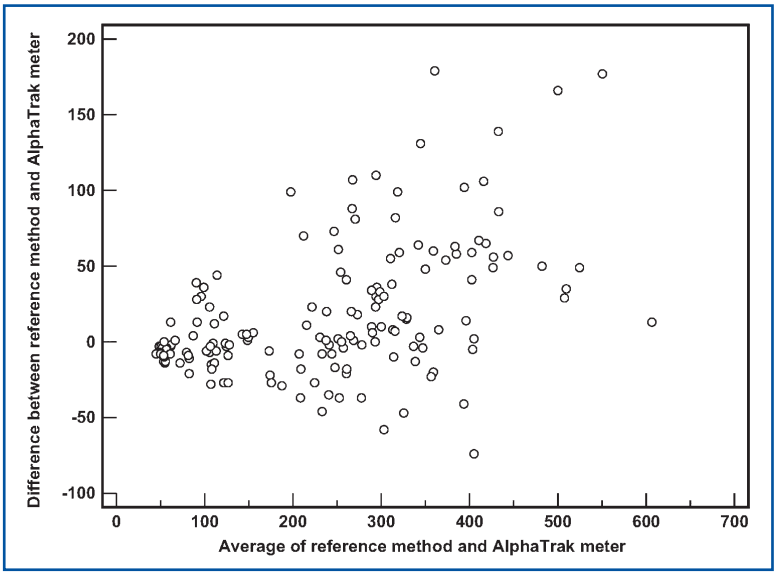

Figure 1—Scatterplot of glucose concentrations (mg/dL) measured with an AlphaTrak portable blood glucose meter and a reference analyzer in 158 blood samples from 49 dogs. Values are plotted as the mean of the results for the 2 methods versus the difference between results for the 2 methods.

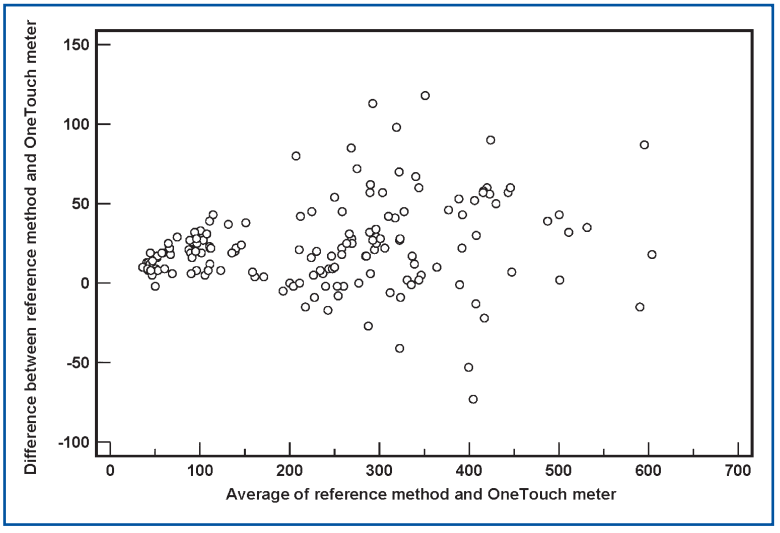

Figure 2—Scatterplot of glucose concentrations (mg/dL) measured with a OneTouch portable blood glucose meter and a reference analyzer in 158 blood samples from 49 dogs. *See* Figure 1 for key.

Table 2—Bias associated with blood glucose concentrations obtained with 6 PBGMs versus plasma glucose concentrations obtained with a commercial analyzer that used a reference method based on the hexokinase reaction.

	Glucose concentration obtained with reference analyzer (mg/dL)				
Meter	**< 100 (n = 29)**	**100–199 (n = 31)**	**200–299 (n = 36)**	**300–400 (n = 36)**	**> 400 (n = 26)**
AlphaTrak[a]	8 (0–28)	12 (1–44)	18 (0–99)	31.5 (3–110)	57.5 (2–179)
Precision[b]	22 (2–37)	30 (6–53)	52 (4–112)	85 (24–152)	133.5 (48–234)
Elite[c]	20 (12–32)	34 (18–50)	46 (0–97)	64 (1–144)	82 (30–155)
Contour[d]	30 (22–52)	54 (38–76)	81 (7–141)	94.5 (5–182)	101.5 (5–197)
Accu-Chek[e]	21 (10–52)	34 (20–54)	47 (9–104)	71.5 (1–136)	120.5 (44–196)
OneTouch[f]	13 (2–29)	22 (4–43)	16.5 (0–80)	30.5 (1–113)	44.5 (2–118)

Data are given as median bias (range) and represent results for 158 blood samples from 49 dogs. For each meter, bias was defined as the absolute value of the difference between blood glucose concentrations obtained with the meter and the corresponding plasma glucose concentrations obtained with the reference analyzer. n = No. of blood samples.

would have been misclassified with the Elite meter, 55 (38.7%) would have been misclassified with the Contour meter, 23 (16.2%) would have been misclassified with the Accu-Chek meter, and 6 (4.2%) would have been misclassified with the OneTouch meter. None of the 24 euglycemic samples were misclassified by the AlphaTrak meter, but 6, 8, 20, 8, and 5, respectively, of the 24 euglycemic samples were misclassified by the Precision, Elite, Contour, Accu-Chek, and OneTouch meters as hypoglycemic. Of the 98 hyperglycemic samples, 2, 23, 14, 35, 15, and 1, respectively, were misclassified by the AlphaTrak, Precision, Elite, Contour, Accu-Chek, and OneTouch meters as having glucose concentrations < 200 mg/dL. One hypoglycemic sample (65 mg/dL) was misclassified by the AlphaTrak meter as euglycemic (79 mg/dL).

Effect of heparin—For the 27 samples in which both plasma and serum glucose concentrations were measured, median plasma glucose concentration was 267 mg/dL (range, 77 to 527 mg/dL) and median serum glucose concentration was 275 mg/dL (range, 77 to 546 mg/dL). There was a significant ($r = 0.998$; $P < 0.001$) correlation between plasma and serum glucose concentrations.

Intra-assay coefficients of variation—Intra-assay coefficients of variation, calculated for blood samples with low, normal, and high plasma glucose concentrations were 4.6%, 4.4%, and 2.6%, respectively, for the AlphaTrak meter; 7.2%, 9.1%, and 5.0% for the Precision meter; 3.0%, 4.6%, and 5.4% for the Elite meter; 4.3%, 4.2%, and 3.7% for the Contour meter; 5.4%, 3.5%, and 2.9% for the Accu-Chek meter; and 2.3%, 3.9%, and 3.1% for the OneTouch meter.

Discussion

For all 6 PBGMs in the present study, a high proportion of samples yielded blood glucose concentrations that were low compared with the plasma glucose concentration determined with a reference analyzer. This was similar to findings of previous studies.[4,6] Importantly, for 4 of the meters, ≥ 98% of samples yielded results that were lower than the reference concentration, and for 1 meter (OneTouch), 85% of samples yielded results that were lower than the reference concentration. The fact that blood glucose concentrations obtained with these meters were generally lower than the reference concentration is an advantage when interpreting results obtained with these meters, in that clinicians can generally assume that the true glucose concentration is higher than the value obtained with any of these meters. Not surprisingly, misclassification errors for all 5 of these meters were a result of misclassifying euglycemic samples as hypoglycemic or misclassifying hyperglycemic samples as having glucose concentrations < 200 mg/dL.

In contrast, the AlphaTrak meter used in the present study did not provide results that were consistently lower or higher than the reference glucose concentration, with 67 (43%) of the samples yielding blood glucose concentrations higher than the reference concentration. High and low blood glucose concentrations were obtained throughout the range of glucose concentrations used. Because of this lack of consistency, one should use caution in interpreting results obtained with the AlphaTrak meter and should not assume that they are consistently inaccurately low.

Because of these inconsistencies among PBGMs, blood glucose concentrations obtained with any newly purchased PBGM should be compared with values obtained with a reference method to determine whether the meter tends to provide values that are low, high, or both. In addition, any animal identified by a PBGM as being hypoglycemic should be retested with a reference analyzer before diagnostic testing to identify an underlying cause is initiated.

Results of previous studies evaluating the impact of PBGM bias on clinical decision making have been conflicting. In 1 study,[4] the authors concluded that the error in glucose concentrations obtained from PBGMs had little to no impact on the accuracy of clinical decisions. In another study,[6] the authors concluded that PBGM bias altered clinical decisions, especially when blood glucose concentrations were < 100 mg/dL. In the present study, we evaluated the impact of meter bias on clinical decision making by determining the percentages of samples that would be misclassified, with results of the reference analyzer used as the gold standard, and found that percentage of misclassified samples ranged from 2.1% to 38.7%. The AlphaTrak and OneTouch meters generally had the lowest bias and the lowest percentages of samples that were misclassified, whereas the Contour meter generally had the highest bias and the highest percentage of samples that were misclassified.

Although it had the lowest misclassification percentage, the AlphaTrak meter used in the present study did misclassify 1 hypoglycemic sample as being euglycemic. Although the discrepancy in glucose concentration probably would not have changed the clinical management of this dog, the potential for failure to identify hypoglycemia with the AlphaTrak meter exists and emphasizes the importance of interpreting test results in conjunction with history and physical examination findings.

There were several limitations of the present study, including the time lag between testing of samples with the PBGMs and the reference analyzer, the use of venous blood, and the use of only a single device from each manufacturer. Glucose concentration in blood samples may decrease over time because of utilization; however, all samples in the present study were tested within 15 minutes of blood sample collection. Thus, any impact of glucose utilization over time on results of the study should have been minimal.

All of the PBGMs used in the present study are labeled for evaluation of blood glucose concentrations in capillary blood samples. In the present study, we used venous blood samples because it would not have been possible to obtain a large enough capillary blood sample for testing with all 6 meters. In a previous study,[8] glucose concentrations measured with a PBGM were similar for blood samples obtained from the saphenous vein, from a catheter placed in the cephalic vein, and following pricking of the marginal ear vein in diabetic cats, suggesting that the origin of blood samples (eg, capillary vs venous) may not be critical when assessing blood glucose concentrations with these devices.

In the present study, we used a single meter from each manufacturer to remove variability associated with

differences among meters from the same manufacturer. Thus, it is possible that the bias detected for 1 or more of the PBGMs used in the present study was a result of a defect in the device. However, all of the PBGMs and glucose test strips were purchased from a local pharmacy or distributor, and presumably, all of these meters were tested by the manufacturer prior to their sale. In addition, problems with calibration were not identified for any of the PBGMs used in the present study.

In addition to overall accuracy, the cost and availability of meters should be taken into account when deciding which PBGM to purchase. All meters and test strips used in the present study, with the exception of the AlphaTrak meter and test strips, are widely available at most commercial pharmacies and are priced similarly. In contrast, the AlphaTrak meter and test strips must be ordered from a veterinary distributor or directly from the manufacturer. The cost of the AlphaTrak meter and test strips was similar to the cost for other meters and test strips used in the present study.

Portable blood glucose meters are popular because of their small size, portability, relatively low cost, ability to quickly provide blood glucose concentrations, and usefulness for monitoring diabetic dogs and cats at home. Results of the present study suggested that there were substantial differences in the accuracy of currently available PBGMs when used to determine blood glucose concentration in dogs. Overall, results obtained with the AlphaTrak and OneTouch meters were closest to results obtained with our reference analyzer and were associated with the lowest percentages of misclassification errors.

a. AlphaTrak, Abbott Laboratories, Abbott Park, Ill.
b. Precision Xtra, Abbott Laboratories, Abbott Park, Ill.
c. Ascensia Elite XL, Bayer Diagnostics Inc, Tarrytown, NY.
d. Ascensia Contour, Bayer Diagnostics Inc, Tarrytown, NY.
e. Accu-Chek Advantage, Roche Diagnostics Inc, Indianapolis, Ind.
f. OneTouch Ultra2, LifeScan Inc, Milpitas, Calif.
g. Monoject, Tyco Healthcare, Mansfield, Mass.
h. Roche/Hitachi 917 chemistry analyzer, F Hoffmann-La Roche Ltd, Basel, Switzerland.
i. Roche/Hitachi Gluco-quant Glucose/HK (catalog No. 11876899), F Hoffmann-La Roche Ltd, Basel, Switzerland.
j. Microsoft Excel 2001, Microsoft Corp, Seattle, Wash.
k. StatXact 8, Cytel Software Corp, Cambridge, Mass.
l. MedCalc for Windows, version 9.2.0.0, MedCalc Software, Mariakerke, Belgium.
m. Stata/IC 10.1, StataCorp LP, College Station, Tex.

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Appendix

Specifications of 6 PBGMs used in a study evaluating their accuracy in measuring blood glucose concentration in dogs.

Meter	Measurement range (mg/dL)	Measurement method	Minimum sample volume (μL)	Measurement time (s)	Calibration method
AlphaTrak[a]	20–500	Electrochemical	0.3	15 (approx)	Control solutions
Precision[b]	20–500	Electrochemical (amperometry)	0.6	5	Lot-specific calibration strip
Elite[c]	20–600	Electrochemical	2.0	30	Lot-specific calibration strip
Contour[d]	10–600	Electrochemical	0.6	15	Programmed into each strip
Accu-Chek[e]	10–600	Electrochemical (glucose dehydrogenase)	4.0	40	Lot-specific code
OneTouch[f]	20–600	Electrochemical (glucose oxidase)	1.0	5	Lot-specific code