Comparison of glucose concentrations in serum, plasma, and blood measured by a point-of-care glucometer with serum glucose concentration measured by an automated biochemical analyzer for canine and feline blood samples

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Received March 7, 2019.
Accepted June 13, 2019.

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OBJECTIVE
To determine the correlation between glucose concentrations in serum, plasma, and blood measured by a point-of-care glucometer (POCG) and serum glucose concentration measured by an automated biochemical analyzer (ABA; gold standard).

SAMPLE
152 canine and 111 feline blood samples.

PROCEDURES
For each sample, the glucose concentration in serum, plasma, and blood was measured by a POCG and compared with the ABA-measured glucose concentration by means of the Lin concordance correlation coefficient. Results were summarized by species for all samples and subsets of samples with hyperglycemia (ABA-measured glucose concentration > 112 mg/dL for dogs and > 168 mg/dL for cats) and pronounced hyperglycemia (ABA-measured glucose concentration > 250 mg/dL for both species). The effect of PCV on correlations between POCG and ABA measurements was also assessed.

RESULTS
Hyperglycemia and pronounced hyperglycemia were identified in 69 and 36 canine samples and 44 and 29 feline samples, respectively. The POCG-measured glucose concentrations in serum, plasma, and blood were strongly and positively correlated with the gold standard concentration. The PCV was positively associated with the correlation between the POCG-measured blood glucose concentration and the gold standard concentration but was not associated with the correlations between the POCG-measured glucose concentrations in serum and plasma and the gold standard concentration.

CONCLUSIONS AND CLINICAL RELEVANCE
Results indicated that POCG-measured glucose concentrations in serum, plasma, and blood were strongly correlated with the ABA-measured serum glucose concentration, even in hyperglycemic samples. Given the time and labor required to harvest serum or plasma from blood samples, we concluded that blood was the preferred sample type for use with this POCG.
Am J Vet Res (2019;80:1074–1081)

Point-of-care glucometers are widely used for quick and easy measurement of blood glucose concentration in veterinary patients, particularly dogs and cats with diabetes mellitus.[1-7] In a 2015 study by Tauk et al,[1] glucose concentrations in serum and plasma measured by a specific POCG[a] (POCG1) were strongly and positively correlated with the serum glucose concentration measured by an ABA (gold standard) for canine and feline blood samples; however, the correlation was not as strong between the POCG1-measured glucose concentration in blood and the ABA-measured serum glucose concentration, especially for canine blood samples. In that study,[1] the POCG1-measured blood glucose concentration was consistently lower than the ABA-measured serum glucose concentration, and it was hypothesized that the RBCs present in blood samples interfered with measurement of the glucose concentration by the POCG1. The same problem is not observed in serum and plasma samples because the RBCs have been removed.[1] Although RBC interference with measurement of glucose concentration is well recognized,

ABBREVIATIONS

ABA	Automated biochemical analyzer
CCC	Concordance correlation coefficient
CI	Confidence interval
POCG	Point-of-care glucometer

the mechanism by which RBCs impair measurement of the glucose concentration by the POCG1 is unknown. Suggested mechanisms include altered blood viscosity, mechanical obstruction of plasma flow to the test strip by RBCs, changes in diffusion kinetics, and a relative decrease in the available plasma volume available for testing owing to the presence of RBCs.[8]

The POCG1 used in the Tauk et al[1] study and the POCG[b] (POCG2) assessed in the study reported here are similar in that they use test strips in which pyrroloquinoline quinone glucose dehydrogenase is the primary reaction enzyme. Pyrroloquinoline quinone glucose dehydrogenase converts glucose to gluconic acid and creates an electric current that is quantified and is proportional to the glucose concentration.[9] Pyrroloquinoline quinone glucose dehydrogenase has a high catalytic efficiency and is not affected by changes in blood oxygen concentration, but it is not substrate specific, and in addition to glucose, it also catalyzes the oxidation of allose, 3-O-methyl-glucose, lactose, cellobiose, and maltose.[10] Therefore, a modified pyrroloquinoline quinone glucose dehydrogenase that is more substrate specific has been engineered for use in the POCG test strips. The POCG1 evaluated in the Tauk et al[1] study uses test strips with unmodified pyrroloquinoline quinone glucose dehydrogenase, whereas the POCG2 assessed in the study reported here uses test strips with a glucose-specific modified pyrroloquinoline quinone glucose dehydrogenase.[10]

Consequent to the results of the Tauk et al[1] study, the protocols for use of the POCG1 with canine and feline blood samples were changed at the University of Pennsylvania Ryan Veterinary Hospital. Specifically, measurement of glucose concentration by the POCG1 was limited to serum samples. Soon after implementation of the new protocol, a new POCG2 was introduced to the hospital, and use of the POCG1 evaluated in the Tauk et al[1] study was discontinued.

The purpose of the study reported here was to determine the correlation between glucose concentrations in serum, plasma, and blood measured by the POCG2 and the serum glucose concentration measured by an ABA (gold standard) for canine and feline blood samples. The blood samples evaluated included samples with glucose concentrations within the reference interval as well as hyperglycemic samples because results of other studies[2–7] indicate that hyperglycemia can significantly affect POCG measurements. The effect of PCV on the correlations between POCG2 and ABA measurements was also assessed. It was hypothesized that the respective correlations between the POCG2-measured glucose concentrations in serum and plasma and the ABA-measured serum glucose concentration would be greater than the correlation between the POCG2-measured blood glucose concentration and ABA-measured serum glucose concentration and that hyperglycemia and polycythemia would adversely affect glucose concentrations measured by the POCG2.[1–7,11–13]

Materials and Methods

Animals

All study protocols were reviewed and approved by the University of Pennsylvania Institutional Animal Care and Use Committee. Any dog or cat examined at the University of Pennsylvania Ryan Veterinary Hospital that underwent venipuncture was eligible for study enrollment. None of the animals underwent additional venipuncture owing to study enrollment. All blood samples were obtained between September 2016 and December 2018 during a designated research period for one of the investigators (MJL).

Sample size calculation

A sample size calculation was performed as described.[1] Briefly, a 2-sided paired *t* test was used to determine the number of samples required to detect a difference of at least 15 mg/dL between the glucose concentrations determined by the POCG2 and ABA with a power of 0.8 and type I error rate (α) of 0.05. The calculation was made on the basis of the mean ± SD serum glucose concentration (117 ± 25 mg/dL) used to establish the reference interval for the ABA. Other assumptions included a correlation of 0.7 and a ratio of 1 between POCG2 and ABA measurements. Results of the calculation indicated that 44 blood samples were required from both dogs and cats; however, samples continued to be obtained from eligible animals until the end of the allocated research time. Additionally, 44 blood samples from hyperglycemic dogs and cats were obtained to ensure that the study had sufficient power to detect a glucose concentration difference of at least 15 mg/dL between the POCG2 and ABA measurements for such animals.

Experimental protocol

The experimental protocol was performed as described.[1] Briefly, for each blood sample obtained, 1 drop of blood was analyzed by the POCG2 immediately after collection, and the remainder of the sample was placed into 2 heparinized microhematocrit tubes,[c] 2 nonheparinized microhematocrit tubes,[d] and an evacuated serum separator tube.[e] Two microhematocrit tubes of each type were filled in case 1 of the 2 was damaged during centrifugation. Immediately after the microhematocrit tubes were filled, they were centrifuged for 3 minutes, after which the PCV was measured and plasma and serum were harvested from the heparinized and nonheparinized microhematocrit tubes, respectively, for measurement of the glucose concentration by the POCG2. Blood samples placed in serum separator tubes were submitted to the on-site clinical pathology laboratory, and serum was harvested from each sample within 15 minutes after blood sample collection for measurement of the glucose concentration by an ABA. Serum samples that were not harvested within 15 minutes after blood sample collection were excluded from the study.

POCG2

One POCG2[b] was used for all measurements. Manufacturer-provided control solutions, test strips, and code chips were used for all calibrations and measurements. The POCG2 was calibrated and used in accordance with the manufacturer's directions except that serum, plasma, and venous blood (rather than capillary blood) were used for measurement of glucose concentration. The code chip was changed, and control and calibration tests were performed once monthly and each time a new box of 50 test strips was opened. For each measurement, a test strip was inserted in the POCG2, and 1 drop (approx 0.6 μL) of plasma, serum, or blood was placed on the test strip. The POCG2 provided an automated reading of the measured glucose concentration after 5 seconds. Blood samples for which 1 or more POCG2 glucose concentration measurements were > 600 mg/dL were excluded from analyses. All POCG2 measurements were performed by the same investigator (MJL).

ABA

The ABA[f] measured the glucose concentration in serum by means of hexokinase-mediated conversion of glucose to glucose-6-phosphate that was further oxidized by glucose-6-phosphate dehydrogenase to the reduced form of nicotinamide adenine dinucleotide, which was then quantified spectrophotometrically. The analyzer required 10 μL of serum for analysis and was operated by trained laboratory technologists. Reference intervals established by the clinical pathology laboratory for the ABA were used to categorize samples as hypoglycemic, euglycemic, and hyperglycemic. The serum glucose concentration reference interval was 65 to 112 mg/dL for dogs and 67 to 168 mg/dL for cats. Hypoglycemia was defined as an ABA-measured serum glucose concentration < 65 mg/dL for dogs and < 67 mg/dL for cats. Hyperglycemia was defined as an ABA-measured serum glucose concentration > 112 mg/dL for dogs and > 168 mg/dL for cats. Pronounced hyperglycemia was defined as an ABA-measured serum glucose concentration > 250 mg/dL for both dogs and cats. The serum glucose concentration determined by the ABA was considered the gold standard against which all POCG2 measurements were compared.

Statistical analysis

Multiple blood samples were analyzed for some animals, and all blood samples included in the study were considered independent observations. Dog and cat data were analyzed separately. For each species, descriptive statistics were calculated to summarize glucose concentrations in serum, plasma, and blood measured by the POCG2 and the serum glucose concentrations measured by the ABA. For each sample, the respective differences between the POCG2-measured glucose concentrations in serum, plasma, and blood and ABA-measured serum glucose concentration were calculated. The data distributions for those differences were then assessed for normality visually and by calculation of the skewness and kurtosis. None of the differences were normally distributed; therefore, the Mann-Whitney test was used to compare median differences among the 3 sample types (serum, plasma, and blood).

The Lin CCCs (ρ_c) and associated 95% CIs were computed and used to quantify the respective levels of agreement between the POCG2-measured glucose concentrations in serum, plasma, and blood and the ABA-measured serum glucose concentration. The bias correction factor, which measures how far the best-fit line deviates from the identify line (ie, the 45° line, or line through the origin where y = x), was also calculated. The Lin CCC and bias correction factor were calculated for all samples evaluated and for the subsets of samples with hyperglycemia and pronounced hyperglycemia. Bland-Altman plots were generated to graphically evaluate those correlations.

Linear regression models were created to evaluate the respective effects of PCV, lipemia, hemolysis, and icterus on the correlation between POCG2 and ABA measurements. For each linear regression model, fixed effects included the POCG2-measured glucose concentration in a given sample type (serum, plasma, or blood) and the other independent variable of interest (PCV, lipemia, hemolysis, or icterus), and the dependent (outcome) variable was the ABA-measured serum glucose concentration. Anemia was defined as a PCV < 40% for dogs and < 32% for cats, and polycythemia was defined as PCV > 60% for dogs and > 48% for cats. The data distribution for PCV was assessed for normality visually and by calculation of the skewness and kurtosis. Data for PCV were not normally distributed; therefore, descriptive results for that variable were reported as the median and range. Lipemia, hemolysis, and icterus were analyzed as dichotomous (present or absent) variables. All analyses were performed with a statistical software program,[g] and values of $P < 0.05$ were considered significant.

Results

Blood samples

A total of 277 blood samples were analyzed during the study period. Results from 13 samples were excluded from statistical analyses because the duration between sample collection and serum harvest for the ABA measurement was > 15 minutes. Results from another sample were excluded from statistical analyses because one of the POCG2-measured glucose concentrations was > 600 mg/dL. Thus, 263 blood samples were included in the analyses. There were 152 samples obtained from 106 dogs and 111 samples obtained from 79 cats. The blood sample collection interval was at least 2 hours for dogs and cats from which multiple samples were obtained.

Sixty-nine of 152 (45%) samples from dogs and 44 of 111 (40%) samples from cats were classified as hyperglycemic. Pronounced hyperglycemia (ABA-

measured glucose concentration > 250 mg/dL) was identified in 36 (24%) and 29 (26%) canine and feline samples, respectively; samples with pronounced hyperglycemia represented a subset of all hyperglycemic samples. Hypoglycemia was identified in 2 (1%) canine samples (ABA-measured glucose concentration, 36 and 55 mg/dL) and 5 (5%) feline samples (median ABA-measured glucose concentration, 59 mg/dL; range, 49 to 64 mg/dL). Sixty of the 106 (57%) dogs and 57 of the 79 (72%) cats from which blood samples were analyzed had diabetes mellitus.

Anemia was identified for 39 of 152 (26%) canine samples (median PCV, 36%; range, 14% to 39%) and 39 of 111 (35%) feline samples (median PCV, 26%; range, 20% to 31%). Polycythemia was not identified in any of the samples evaluated. Lipemia, hemolysis, and icterus were reported for 62 (41%), 50 (33%), and 8 (5%) canine samples and for 26 (23%), 12 (11%), and 6 (5%) feline samples, respectively.

Glucose concentration measurements

The glucose concentrations in serum, plasma, and blood measured by the POCG2 and serum glucose concentration measured by the ABA were summarized for all 263 samples analyzed **(Table 1)** and the subset of 65 samples with pronounced hyperglycemia **(Table 2)**. The median difference between the POCG2-measured serum glucose concentration and ABA-measured serum glucose concentration for the subset of samples with pronounced hyperglycemia was significantly greater than that for all samples analyzed for dogs ($P < 0.001$) but not for cats ($P = 0.10$). The respective median differences between the POCG2-measured glucose concentrations in plasma and blood and the ABA-measured serum glucose concentration were significantly ($P < 0.001$ for all comparisons) greater for the subset of samples with pronounced hyperglycemia, compared with those for all samples analyzed for both dogs and cats. For all sample types, the absolute value of the magnitude of the difference between POCG2 and ABA measurements was greater for dogs than for cats. In general for both dogs and cats, the POCG2-measured glucose concentrations in serum and plasma were higher and the POCG2-measured glucose concentration in blood was lower than the ABA-measured serum glucose concentration.

Results of the Lin CCC analyses for all samples analyzed **(Table 3)**, hyperglycemic samples **(Table 4)**, and samples with pronounced hyperglycemia **(Table 5)** were summarized. The Lin CCCs indicated that there was a significant very good to excellent (ie, almost perfect) positive correlation for all comparisons between POCG2 and ABA measurements. Additionally, the Lin CCCs were similar for all 3 sample types within a species, and the Lin CCCs for cats were numerically greater than the corresponding values for dogs.

Bland-Altman plots indicated that the respective levels of agreement between the ABA-measured se-

Table 1—Descriptive statistics for glucose concentrations (mg/dL) in serum, plasma, and blood measured by a POCG2 and serum glucose concentration measured by an ABA for 152 samples from 106 dogs and 111 samples from 79 cats.

Species	Analyzer	Sample type	Mean ± SD	Median (range)	Median (range) difference between POCG2 measurement and referent
Dog	POCG2	Serum	198 ± 131	127 (41 to 597)	19 (–28 to 77)
	POCG2	Plasma	196 ± 130	126 (40 to 581)	16 (–44 to 71)
	POCG2	Blood	158 ± 115	99 (30 to 535)	–16 (–96 to 33)
	ABA	Serum	177 ± 124	110 (36 to 625)	Referent
Cat	POCG2	Serum	208 ± 119	169 (52 to 536)	14 (–21 to 65)
	POCG2	Plasma	208 ± 119	170 (56 to 517)	14 (–13 to 51)
	POCG2	Blood	181 ± 113	139 (50 to 488)	–11 (–78 to 15)
	ABA	Serum	193 ± 116	151 (49 to 528)	Referent

Table 2—Descriptive statistics for glucose concentrations (mg/dL) in serum, plasma, and blood measured by a POCG2 and serum glucose concentration measured by an ABA for a subset of 36 canine samples and 29 feline samples from Table 1 with pronounced hyperglycemia (ABA-measured serum glucose concentration > 250 mg/dL).

Species	Analyzer	Sample type	Mean ± SD	Median (range)	Median (range) difference between POCG2 measurement and referent
Dog	POCG2	Serum	412 ± 76	403 (291 to 597)	37 (–28 to 77)
	POCG2	Plasma	408 ± 75	395 (291 to 581)	35 (–44 to 71)
	POCG2	Blood	343 ± 83	334 (218 to 535)	–31 (–96 to 33)
	ABA	Serum	377 ± 89	357 (258 to 625)	Referent
Cat	POCG2	Serum	388 ± 57	402 (294 to 536)	23 (–21 to 65)
	POCG2	Plasma	390 ± 58	397 (295 to 517)	21 (–13 to 51)
	POCG2	Blood	354 ± 59	356 (243 to 488)	–17 (–50 to 15)
	ABA	Serum	370 ± 64	371 (260 to 528)	Referent

Table 3—Results of Lin CCC (ρ_c) analyses in which glucose concentrations in serum, plasma, and blood measured by a POCG2 were compared with serum glucose concentrations measured by an ABA for the 152 canine samples and 111 feline samples of Table 1.

Species	Sample type analyzed by POCG2	ρ_c (95% CI)	Bias correction factor	Mean ± SD (95% limits of agreement) difference between POCG2 measurement and referent (mg/dL)
Dog	Serum	0.978 (0.972 to 0.984)	0.984	21 ± 16 (–10 to 53)
	Plasma	0.981 (0.976 to 0.986)	0.987	20 ± 14 (–8 to 48)
	Blood	0.978 (0.973 to 0.984)	0.985	–18 ± 17 (–51 to 15)
Cat	Serum	0.986 (0.982 to 0.991)	0.992	15 ± 13 (–10 to 40)
	Plasma	0.988 (0.984 to 0.992)	0.992	15 ± 11 (–6 to 36)
	Blood	0.989 (0.985 to 0.993)	0.994	–12 ± 12 (–36 to 13)

For all comparisons, the referent (gold standard) was the ABA-measured serum glucose concentration. All ρ_cs were significantly ($P < 0.001$) different from 0.

Table 4—Results of Lin CCC analyses in which glucose concentrations in serum, plasma, and blood measured by a POCG2 were compared with serum glucose concentrations measured by an ABA for 69 canine samples and 44 feline samples with hyperglycemia.

Species	Sample type analyzed by POCG2	ρ_c (95% CI)	Bias correction factor	Mean ± SD (95% limits of agreement) difference between POCG2 measurement and referent (mg/dL)
Dog	Serum	0.964 (0.950 to 0.978)	0.974	30 ± 19 (–8 to 68)
	Plasma	0.969 (0.957 to 0.982)	0.978	28 ± 18 (–7 to 62)
	Blood	0.966 (0.953 to 0.979)	0.976	–26 ± 21 (–67 to 14)
Cat	Serum	0.967 (0.948 to 0.985)	0.981	18 ± 17 (–15 to 51)
	Plasma	0.970 (0.954 to 0.986)	0.979	20 ± 13 (–6 to 45)
	Blood	0.969 (0.952 to 0.987)	0.986	–16 ± 18 (–51 to 19)

Hyperglycemia was defined as an ABA-measured serum glucose concentration > 112 mg/dL for dogs and > 168 mg/dL for cats.

See Table 3 for remainder of key.

Table 5—Results of Lin CCC analyses in which glucose concentrations in serum, plasma, and blood measured by a POCG2 were compared with serum glucose concentrations measured by an ABA for 36 canine samples and 29 feline samples with pronounced hyperglycemia.

Species	Sample type analyzed by POCG2	ρ_c (95% CI)	Bias correction factor	Mean ± SD (95% limits of agreement) difference between POCG2 measurement and referent (mg/dL)
Dog	Serum	0.882 (0.825 to 0.939)	0.903	36 ± 22 (–7 to 78)
	Plasma	0.899 (0.851 to 0.948)	0.917	32 ± 21 (–10 to 73)
	Blood	0.891 (0.833 to 0.948)	0.922	–34 ± 23 (–80 to 12)
Cat	Serum	0.909 (0.851 to 0.968)	0.953	17 ± 19 (–21 to 56)
	Plasma	0.920 (0.871 to 0.969)	0.947	19 ± 15 (–11 to 50)
	Blood	0.932 (0.887 to 0.976)	0.963	–16 ± 16 (–48 to 16)

The canine and feline samples represented in this table were a subset of the samples represented in Table 4.

See Tables 2 and 3 for remainder of key.

rum glucose concentration and POCG2-measured glucose concentrations in serum, plasma, or blood were similar for both dogs **(Figure 1)** and cats **(Figure 2)**. Also, relative to the ABA-measured serum glucose concentration, the POCG2 tended to overestimate the glucose concentration when serum or plasma was used as the test sample and underestimate the glucose concentration when blood was used as the test sample.

Effect of PCV, lipemia, hemolysis, and icterus on the correlation between POCG2 and ABA measurements

The PCV had a significant ($P < 0.001$) effect on the correlation between POCG2-measured blood glucose concentration and the ABA-measured serum glucose concentration in both dogs and cats. In dogs, the ABA-measured serum glucose concentration was estimated to increase by 1.06 mg/dL for every 1-mg/dL increase in the POCG2-measured blood glucose concentration (mean slope ± SE, 1.06 ± 0.009 mg/dL; 95% CI, 1.042 to 1.078 mg/dL; $P <$ .001) and by 1.08 mg/dL for every 1% increase in PCV (mean slope ± SE, 1.08 ± 0.136 mg/dL; 95% CI, 0.808 to 1.346 mg/dL; $P < 0.001$) when all samples were included in the regression analysis. When only samples with pronounced hyperglycemia were included in the regression analysis, the ABA-measured serum glucose concentration was estimated to increase by 1.07 mg/dL for every 1-mg/dL in-

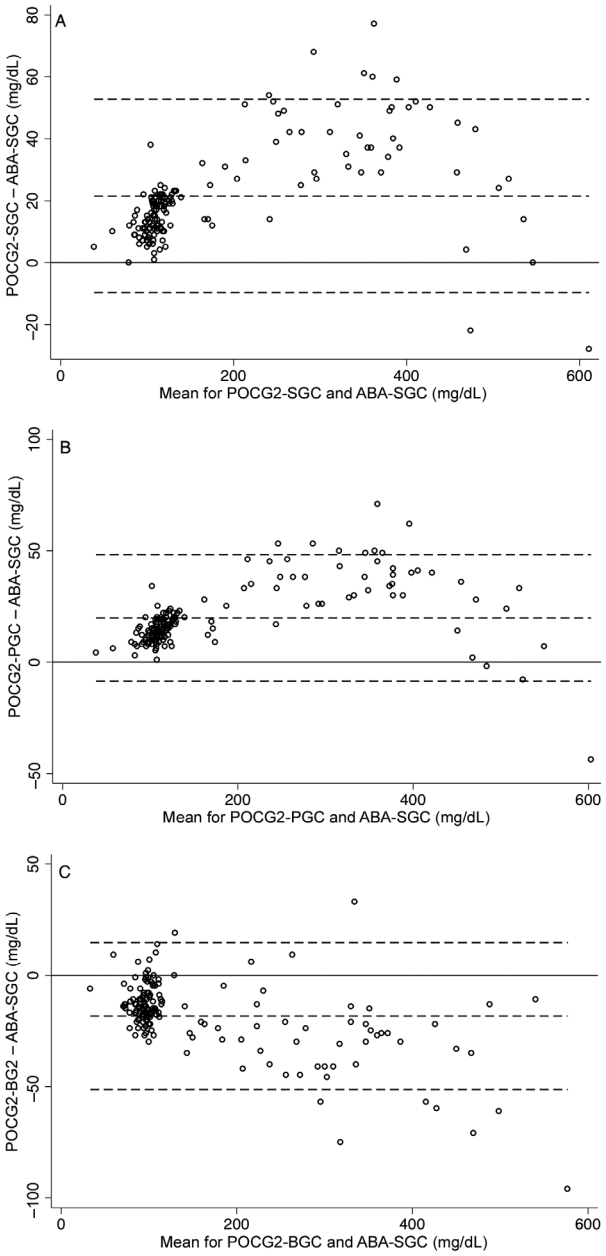

Figure 1—Bland-Altman plots of the respective differences between the glucose concentrations in serum (POCG2-SGC; A), plasma (POCG2-PGC; B), and blood (POCG2-BGC; C) measured by a POCG2 and the serum glucose concentration measured by an ABA (ABA-SGC) for 152 samples obtained from 106 dogs. For each plot, circles represent the difference between the glucose concentrations being compared for individual samples, the solid horizontal line represents a mean difference of 0, the middle dashed line represents the mean difference between the glucose concentrations being compared, and the outer dashed lines represent the 95% limits of agreement for that difference (mean difference ± 1.96 SD). The closer the middle dashed line is to the solid horizontal line, the greater the agreement between the 2 glucose concentrations being compared.

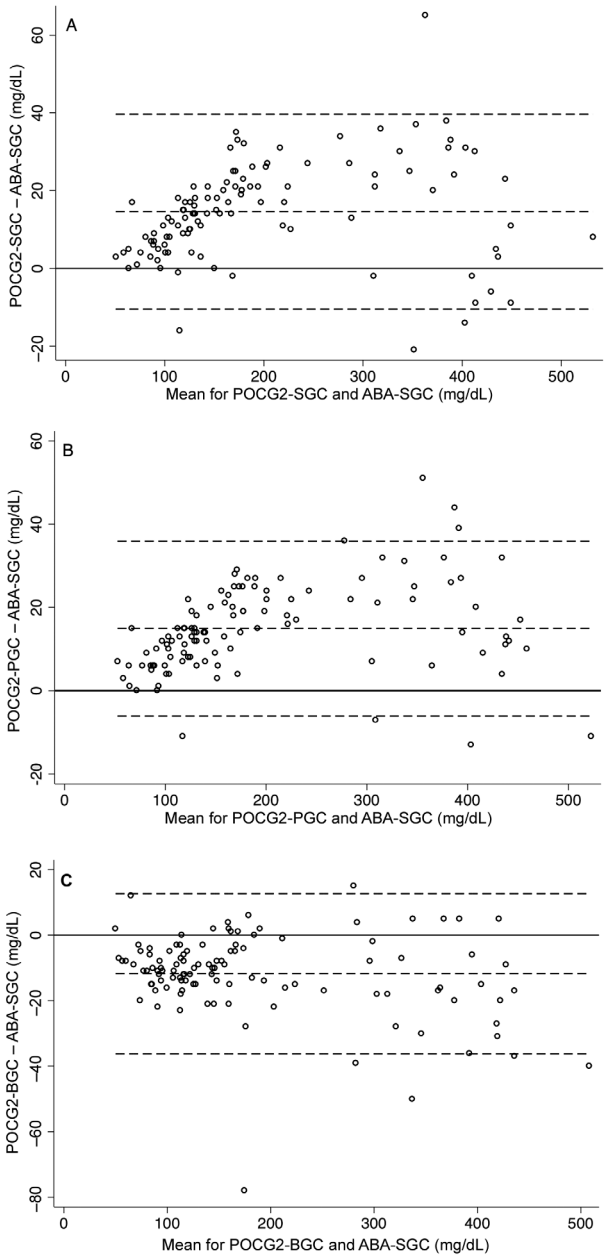

Figure 2—Bland-Altman plots of the respective differences between the glucose concentrations in serum (POCG2-SGC; A), plasma (POCG2-PGC; B), and blood (POCG2-BGC; C) measured by a POCG2 and the serum glucose concentration measured by an ABA (ABA-SGC) for 111 samples obtained from 79 cats. ***See*** Figure 1 for remainder of key.

crease in the POCG2-measured blood glucose concentration and by 2.04 mg/dL for every 1% increase in PCV. In cats, the ABA-measured serum glucose concentration was estimated to increase by 1.03 mg/dL for every 1-mg/dL increase in the POCG2-measured blood glucose concentration (mean slope ± SE, 1.03 ± 0.011 mg/dL; 95% CI, 1.009 to 1.053 mg/dL; $P < 0.001$) and by 0.66 mg/dL for every 1% increase in PCV (mean slope ± SE, 0.66 ± 0.170 mg/dL; 95% CI, 0.321 to 0.995 mg/dL; $P < 0.001$) when all samples were included in the regression analysis. When only samples with pronounced hyperglycemia were included in the regression analysis, the ABA-measured serum glucose concentration was estimated to increase by 1.05 mg/dL for every 1-mg/

dL increase in the POCG2-measured blood glucose concentration and by 1.07 mg/dL for every 1% increase in PCV. Thus, the effect of PCV on the correlation between POCG2-measured blood glucose concentration and ABA-measured serum glucose concentration appeared to be more profound at extremely high glucose concentrations. The PCV was not significantly associated with the respective correlations between the POCG2-measured glucose concentrations in serum and plasma and the ABA-measured serum glucose concentration in either dogs or cats. Lipemia, hemolysis, and icterus were not significantly associated with any of the correlations between the POCG2 and ABA measurements in either dogs or cats.

Discussion

Results of the present study suggested that, for both dogs and cats, there were very strong to almost perfect positive correlations between glucose concentrations in serum, plasma, and blood measured by a POCG2 and the serum glucose concentration measured by an ABA (gold standard), even for samples with pronounced hyperglycemia (ABA-measured glucose concentration > 250 mg/dL). In dogs with pronounced hyperglycemia, the absolute value of the mean difference between the POCG2-measured glucose concentration in blood and ABA-measured serum glucose concentration (–34 ± 23 mg/dL) was only slightly greater than the mean difference between the POCG2-measured glucose concentration in plasma and ABA-measured serum glucose concentration (32 ± 21 mg/dL). That difference of 2 mg/dL was not clinically significant and would not change treatment recommendations. Given the additional time, labor, and cost required to harvest serum or plasma from blood samples, we concluded that blood was the preferred sample type for use with the POCG2.

In a similar study[1] conducted at our institution with a different POCG (POCG1), it was concluded that use of serum or plasma with the POCG1 resulted in more accurate and reliable measurement of glucose concentration than did use of blood. Those findings led to a change in the standard operating procedure for the POCG1 in our hospital. The POCG1 is produced by the same manufacturer as the POCG2. The contrasting results regarding the optimum sample type for use with the POCG1 and POCG2 underscore the importance of validating POCG models individually, even when they are produced by the same manufacturer and are from the same product line.[2,4,5,7]

In the present study, the positive correlation between the POCG2 and ABA measurements was very good to excellent, regardless of sample type evaluated, even in samples with pronounced hyperglycemia. Within a species and sample type, the Lin CCC decreased as the sample population was parsed into subsets of samples with hyperglycemia and pronounced hyperglycemia. However, the decrease in the Lin CCC was < 10% for all comparisons within a species and sample type, and the lowest Lin CCC calculated (0.882) was still indicative of a very good positive correlation. The clinical relevance of the small numeric fluctuations in the correlation coefficients is unknown. For cats, the Lin CCC was greatest between the POCG2-measured blood glucose concentration and the gold standard concentration regardless of the sample subset, which suggested that blood was the preferred sample type. Moreover, for both dogs and cats, the magnitude of the mean difference between the POCG2-measured glucose concentration and the gold standard concentration was generally lower for blood than for serum and plasma, which provided further evidence that blood was the optimal sample type for use with the POCG2.

Results of the linear regression analyses indicated that the relationship between the POCG2-measured blood glucose concentration and ABA-measured serum glucose concentration was significantly and positively affected by PCV. The magnitude of the effect of PCV on that relationship was greater for dogs than for cats. The reason for the difference in the PCV effect magnitude between dogs and cats was unknown. In human patients with a clinically normal PCV and hydration status, the glucose concentration in plasma is approximately 11% greater than that in blood because of the higher water content of plasma relative to blood.[9] It is possible that the water content of feline blood is greater than that of canine blood, and that might have contributed to the difference in the PCV effect magnitude observed between the 2 species. It might also explain why the absolute value of the mean difference between the POCG2-measured blood glucose concentration and ABA-measured serum glucose concentration was greater for dogs than cats. The PCV was not significantly associated with the respective relationships between the POCG2-measured glucose concentrations in serum and plasma and ABA-measured serum glucose concentration.

If there is a positive association between sample water content and glucose concentration in dogs and cats, as there is in humans,[9] that may explain why mean glucose concentrations in serum and plasma were consistently greater than the corresponding mean glucose concentration in blood. Alternatively, higher mean glucose concentrations in serum and plasma relative to the mean glucose concentration in blood might be attributable to centrifugation-induced lysing of RBCs, which release glucose into the surrounding fluid.[14]

In the present study, lipemia, hemolysis, and icterus were not significantly associated with the respective relationships between the POCG2-measured glucose concentrations in serum, plasma, and blood and ABA-measured glucose concentration for either dogs or cats. However, the number of icteric samples was small, and analysis of more icteric samples is necessary to validate that finding.

The present study had several limitations. The number of hypoglycemic samples was small, which precluded separate analysis of hypoglycemic samples. The small number of hypoglycemic samples analyzed might have been a reflection of the study protocol, which mandated that the in-house clinical pathology laboratory be open so that the serum samples for measurement of glucose concentration by the ABA could be processed within 15 minutes after blood sample collection. It is possible that dogs and cats with severe hypoglycemia were examined by the emergency service after normal business hours when the in-house clinical pathology laboratory was closed and that the hypoglycemia in those patients had resolved by the time the laboratory reopened. It is also possible that hypoglycemia is not as prevalent as hyperglycemia and euglycemia in dogs and cats and that the samples analyzed in this study were reflective of that phenomenon. Only 1 POCG model was evaluated in this study, and the conclusions are limited to that model. Finally, it is important to point out that the establishment of reference intervals for the POCG2-measured glucose concentration in dogs and cats was beyond the scope of this study; additional studies are required for that purpose.

Findings of the present study indicated that, for dogs and cats, glucose concentrations in serum, plasma, and blood measured by a POCG2 were strongly correlated with the serum glucose concentration measured by an ABA (gold standard), even for samples with pronounced hyperglycemia. Because of the additional time, labor, and costs associated with harvesting serum and plasma from blood samples, we recommend that blood be used for measurement of the glucose concentration by the POCG2. Owing to the accuracy of the glucose concentrations measured by the POCG2 and its ease of use, we believe that the POCG2 is appropriate for use by pet owners to monitor the blood glucose concentrations of their pets at home. However, pet owners should be informed that the blood glucose concentration measured by the POCG2 is generally lower than the serum glucose concentration (gold standard). In dogs, the POCG2-measured blood glucose concentration is approximately 20 and 30 mg/dL lower than the gold standard in general and for hyperglycemic samples, respectively. In cats, the POCG2-measured blood glucose concentration is 10 and 15 mg/dL lower than the gold standard in general and for hyperglycemic samples, respectively. Those trends were observed for blood samples with PCVs within and below the reference interval, but we cannot comment on whether those trends are applicable for polycythemic samples because such samples were not evaluated in this study. Further research is necessary to assess the accuracy of POCG2-measured glucose concentrations in polycythemic blood samples.

Acknowledgments

Supported by a gift from Ms. Catharine Adler.

Footnotes

a. Accu-Chek Aviva, Roche Diagnostics Corp, Indianapolis, Ind.
b. Accu-Chek Performa, Roche Diagnostics Corp, Indianapolis, Ind.
c. Heparinized capillary tubes, Thermo Fisher Scientific, Waltham, Mass.
d. Nonheparinized capillary tubes, Thermo Fisher Scientific, Waltham, Mass.
e. Monoject blood collection tubes, Covidien, Mansfield, Mass.
f. Vitros 4600 Chemistry System, Ortho-Clinical Diagnostics, Rochester, NY.
g. Stata, version 14.0 for Mac, Stata Corp, College Station, Tex.

References

1. Tauk BS, Drobatz KJ, Wallace KA, et al. Correlation between glucose concentrations in serum, plasma, and whole blood measured by a point-of-care glucometer and serum glucose concentration measured by an automated biochemical analyzer for canine and feline blood samples. *J Am Vet Med Assoc* 2015;246:1327–1333.
2. Cohen TA, Nelson RW, Kass PH, et al. Evaluation of six portable blood glucose meters for measuring blood glucose concentration in dogs. *J Am Vet Med Assoc* 2009;235:276–280.
3. Johnson BM, Fry MM, Flatland B, et al. Comparison of a human portable blood glucose meter, veterinary portable blood glucose meter, and automated chemistry analyzer for measurement of blood glucose concentrations in dogs. *J Am Vet Med Assoc* 2009;235:1309–1313.
4. Wess G, Reusch C. Assessment of five portable blood glucose meters for use in cats. *Am J Vet Res* 2000;61:1587–1592.
5. Wess G, Reusch C. Evaluation of five portable blood glucose meters for use in dogs. *J Am Vet Med Assoc* 2000;216:203–209.
6. Kang MH, Kim DH, Jeong IS, et al. Evaluation of four portable blood glucose meters in diabetic and non-diabetic dogs and cats. *Vet Q* 2016;36:2–9.
7. Cohn LA, McCaw DL, Tate DJ, et al. Assessment of five portable blood glucose meters, a point-of-care analyzer, and color test strips for measuring blood glucose concentration in dogs. *J Am Vet Med Assoc* 2000;216:198–202.
8. Ramljak S, Lock JP, Schipper C, et al. Hematocrit interference of blood glucose meters for patient self-measurement. *J Diabetes Sci Technol* 2013;7:179–189.
9. Dimeski G, Jones BW, Tilley V, et al. Glucose meters: evaluation of the new formulation measuring strips from Roche (Accu-chek) and Abbott (MediSense). *Ann Clin Biochem* 2010;47:358–365.
10. Ferri S, Kojima K, Sode K. Review of glucose oxidases and glucose dehydrogenases: a bird's eye view of glucose sensing enzymes. *J Diabetes Sci Technol* 2011;5:1068–1076.
11. Daves M, Cemin R, Fattor B, et al. Evaluation of hematocrit bias on blood glucose measurements with six different portable glucose meters. *Biochem Med (Zagreb)* 2011;21:306–311.
12. Paul AE, Shiel RE, Juvet F, et al. Effect of hematocrit on accuracy of two point-of-care glucometers for use in dogs. *Am J Vet Res* 2011;72:1204–1208.
13. Lane SL, Koenig A, Brainard BM. Formulation and validation of a predictive model to correct blood glucose concentrations obtained with a veterinary point-of-care glucometer in hemodiluted and hemoconcentrated canine blood samples. *J Am Vet Med Assoc* 2015;246:307–312.
14. Viskupicova J, Blaskovic D, Galiniak S, et al. Effect of high glucose concentrations on human erythrocytes in vitro. *Redox Biol* 2015;5:381–387.