

# Comparison of three point-of-care blood glucose meters for use in adult and juvenile alpacas

Brett S. Tennent-Brown, BVSc, DACVIM, DACVECC; Amie Koenig, DVM, DACVIM, DACVECC;  
Lisa H. Williamson, DVM, MS, DACVIM; Raymond C. Boston, PhD

**Objective**—To compare the performance of 3 point-of-care glucose meters in adult and juvenile alpacas with that of a laboratory-based analyzer.

**Design**—Evaluation study.

**Animals**—35 adult alpacas and 21 juvenile alpacas.

**Procedures**—Whole blood samples obtained via jugular venipuncture were tested with all 3 point-of-care glucose meters; plasma samples were also tested with 1 of those meters. Glucose concentrations determined by use of the point-of-care meters were compared with results from the laboratory-based analyzer.

**Results**—Plasma glucose concentrations determined by use of the laboratory-based analyzer ranged from 36 to 693 mg/dL. Over the entire range of glucose concentrations tested, the Lin concordance correlation coefficient (agreement) was significant and excellent for all comparisons. Concordance decreased for 1 glucometer when testing whole blood samples over a narrower range of glucose concentrations (50 to 200 mg/dL). Bias was typically small (< 10 mg/dL) for 3 of the 4 comparisons but considerable for 1 meter with the use of whole blood. The limits of agreement were wide for all comparisons over the entire range of glucose concentrations tested but decreased to within acceptable limits when the narrower glucose range (50 to 200 mg/dL) was analyzed for 3 of the comparisons. For samples with a PCV < 25%, bias and the limits of agreement were greater for one of the meters tested.

**Conclusions and Clinical Relevance**—Discrepancies between point-of-care glucose meters and reference techniques can be considerable in alpacas, emphasizing the importance of assessing individual meter performance in a target population. (*J Am Vet Med Assoc* 2011;239:380–386)

Because of their increasing popularity and economic value, South American camelids comprise a considerable part of the caseload of many large animal veterinary practices. Glucose dyshomeostasis appears to occur commonly in ill South American camelids and can be exacerbated by administration of dextrose-containing solutions.<sup>1–5</sup> Persistent hyperglycemia has detrimental effects, including disruption of fluid and electrolyte balances. Conversely, severe hypoglycemia can occur in neonatal South American camelids, requiring high rates of dextrose infusion to maintain euglycemia. Evidence in human medicine suggests that tight regulation of glucose concentrations improves outcome in critically ill patients, and it is reasonable to assume that appropriate control of blood glucose concentrations would be important in hospitalized South American camelids.<sup>6,7</sup>

From the Departments of Large Animal Medicine (Tennent-Brown, Williamson) and Small Animal Medicine (Koenig), College of Veterinary Medicine, University of Georgia, Athens, GA 30602; and the Department of Clinical Studies, New Bolton Center, School of Veterinary Medicine, University of Pennsylvania, Kennett Square, PA 19348 (Boston).

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Address correspondence to Dr. Tennent-Brown (tennentb@uga.edu).

## ABBREVIATIONS

AC	AccuChek
ACPL	AccuChek with plasma sample
ACWB	AccuChek with whole blood sample
AT	AlphaTrak
HITA	Hitachi
iST	i-Stat
POC	Point of care

Point-of-care meters have become invaluable in the management of critically ill patients in human and veterinary medicine.<sup>8–11</sup> Appropriately validated meters provide inexpensive, accurate, and rapid results that allow treatment decisions to be made in real time.<sup>8–11</sup> However, experience in other veterinary species indicates that results obtained with POC glucose meters and laboratory-based analyzers can differ considerably.<sup>9,10,12</sup> In particular, the use of whole blood samples in some meters appears to impair performance in the measurement of blood lactate and glucose concentrations in horses.<sup>9,10</sup> Therefore, it is important that measurement techniques be validated in each target population.

The purpose of the study reported here was to compare the performance of 3 POC analyzers in adult and juvenile alpacas with that of a laboratory-based analyzer in the measurement of glucose concentration. We hypoth-

esized that correlation between measurement techniques would be substantial to excellent but that there could be clinically important biases between the assay techniques.

## Materials and Methods

**Study population**—Blood samples were collected from privately owned alpacas at a single farm on 3 occasions. Depending on availability of the alpacas, 1 to 3 blood samples were collected from adult (> 1 year of age) and juvenile (< 7 weeks of age) alpacas. Alpacas were determined to be healthy on the basis of history and physical examination findings. All procedures were approved by the University of Georgia's Institutional Clinical Research Committee and performed with informed consent of the clients.

**Sample handling**—Blood samples obtained via jugular venipuncture from each alpaca were collected into 3 heparinized blood collection tubes.<sup>a</sup> One of the 3 samples was analyzed with each of 3 POC analyzers (ie, AC,<sup>b</sup> AT,<sup>c</sup> and iST<sup>d</sup>) shortly after collection. Initially, this blood sample was analyzed within 10 minutes after collection. However, afterward, it was determined that blood glucose concentration did not change in blood samples stored on ice for up to 2 hours; therefore, subsequent samples were stored in that manner until analyzed within 2 hours after collection. This allowed analysis to be conducted more conveniently in a laboratory under controlled ambient conditions rather than in the field. To create a range of blood glucose concentrations, the second blood sample was stored at 42°C for between 2 and 6 hours to facilitate glucose metabolism and the third blood sample was spiked with 3 to 5 drops of 50% dextrose<sup>e</sup> diluted to a 10% solution with sterile water.<sup>f</sup> Whole blood samples were analyzed with each of the 3 POC analyzers. Immediately after analysis of whole blood, the samples were centrifuged and the plasma harvested. Plasma samples were analyzed with the AC meter<sup>b</sup> and then stored frozen at -80°C for batch analysis with a laboratory-based biochemistry analyzer, HITA.<sup>g</sup> All measurements were performed with a single meter of each type; however, several lots of test strips or cartridges were used for each meter throughout the study. Where applicable, reference samples containing a known glucose concentration were analyzed with the POC analyzers prior to use; in each case, results were within acceptable limits as outlined by the manufacturer. For the HITA analyzer, reference range values have been established for individual species. A 2-point calibration procedure was performed by laboratory staff for each new lot of test reagents with solutions of known glucose concentration supplied by the manufacturer.<sup>13</sup> The coefficient of variance for glucose calibration samples ranged between 1.7% and 3.2%.

**The HITA analyzer**—Plasma glucose concentrations were measured with the HITA analyzer<sup>g</sup> by use of the hexokinase method, a recognized reference technique. The manufacturer's reported range for plasma glucose concentration measurements was 2 to 750 mg/dL.

**The iST meter**—Single-use cartridges that draw the whole blood sample into a reaction chamber by cap-

illary action were used in the iST meter.<sup>c</sup> Whole blood glucose concentration was measured with the iST meter amperometrically. The iST meter provided results in approximately 1 minute, and the manufacturer's reported range for whole blood glucose concentration measurements was 20 to 700 mg/dL.

**The AC meter**—Single-use test strips that draw the sample (plasma or whole blood) into a reaction chamber by capillary action were used in the AC meter.<sup>b</sup> Glucose concentration was measured by use of a glucose dehydrogenase-based sensor and an oxygen insensitive technique. The AC meter provided results in approximately 5 seconds, and the manufacturer's reported range for whole blood glucose concentration measurements was 10 to 600 mg/dL.

**The AT meter**—Single-use test strips that draw the whole blood sample into a reaction chamber by capillary action were used in the AT meter, a glucometer designed specifically for veterinary use.<sup>d</sup> Whole blood glucose concentration was determined colorimetrically by use of a glucose dehydrogenase catalyzed reaction that is insensitive to the oxygen content of the blood sample. In a pilot study, whole blood samples from adult ( $n = 19$ ) and juvenile (4) alpacas were analyzed and compared with results from the laboratory-based analyzer, HITA. The raw data from this pilot study were then used by the manufacturer to generate a calibration code for this meter by use of a proprietary algorithm. All subsequent measurements with this meter used that calibration code. Data collected during the pilot study were not used in evaluating meter performance. The AT meter provided results in approximately 15 seconds, and the manufacturer's reported range for whole blood glucose concentration measurements was 20 to 750 mg/dL.

**Data analysis**—Comparisons were made between glucose measurements from the laboratory-based biochemistry analyzer (ie, HITA) and each of the 3 POC analyzers. These comparisons are designated by the following: HITA-iST, HITA-ACWB, HITA-ACPL, and HITA-AT.

Data were analyzed by use of the Lin concordance correlation coefficient ( $\rho_c$ ), which compares 2 techniques measuring the same variable without the inherent bias of establishing a gold standard.<sup>14,15</sup> The concordance correlation coefficient indicates overall agreement between 2 measurements, across all paired observations, by use of the 2 techniques, with a value of 1 indicating perfect concordance. However, the Lin concordance correlation analysis does not accommodate the use of repeated measures.<sup>16</sup> To account for repeated measures, data pairs were randomly selected by use of statistics software<sup>h</sup> and tested once; the data set created from the random selection of data pairs was then used to derive an estimate of  $\rho_c$ . This process was repeated until the mean concordance based on all the randomly selected data pairs ceased to change with increases in the sample size. The mean of the data from the resultant concordance postprocessing file was calculated to yield estimates of the final concordance correlation coefficients and their errors.<sup>16</sup> Two hundred runs were required to produce consistent estimates of the concordance. A value for  $\rho_c$  of 0.41 to 0.60 cor-

responded to moderate concordance, 0.61 to 0.80 corresponded to substantial concordance, and 0.81 to 1.00 corresponded to excellent concordance.<sup>14</sup>

The bias (mean difference between 2 techniques) and limits of agreement were analyzed by use of the method described by Bland and Altman,<sup>17,18</sup> which has recently been modified for use with multiple observations per individual.<sup>16,19</sup> The bias represents the systematic departure between the 2 measurement techniques. The upper and lower limits of agreement are calculated as bias  $\pm$  2 SD and define the range in which 95% of the differences between 2 techniques are found. The relative (ie, percentage) difference between glucose concentrations determined by use of each POC analyzer and the laboratory-based analyzer (ie, HITA) was calculated as  $(\text{POC} - \text{HITA}/\text{HITA}) \times 100\%$ , for each paired observation. The mean of the absolute relative differences was calculated and reported. The percentage of POC analyzer results that were within 20%, 15%, 10%, or 5% of the result obtained by use of the HITA was determined.

To determine whether extreme glucose concentrations affected concordance, bias, and the limits of agreement between glucose measurement methods, the Lin concordance correlation and Bland-Altman analyses were performed for samples with a blood glucose concentration between 50 and 200 mg/dL (as determined by use of the laboratory-based analyzer, HITA). To determine whether age (adult or juvenile) would affect concordance, bias, and the limits of agreement between methods, the Lin concordance correlation and Bland-Altman analyses were repeated for each age group. Similarly, to determine whether anemia would influence concordance, bias, and the limits of agreement between methods, the Lin concordance correlation and Bland-Altman analyses were performed for samples from alpacas with a PCV  $\geq$  25% and compared with those from alpacas with a PCV  $<$  25%.

Values of  $P \leq 0.05$  were considered significant. All analyses were performed with a commercially available statistical software package.<sup>h</sup>

## Results

Blood samples were collected from 35 female adult alpacas; blood samples were collected from 2 adult alpacas on 3 occasions, from 3 adult alpacas on 2 occasions, and from 30 alpacas on 1 occasion. The mean age of adult alpacas in which age was known was 7.7 years (range, 1.8 to 18.7 years); age was unknown for 3 adult alpacas. Blood samples were collected from 21 juvenile alpacas of both sexes; blood samples were collected from 3 juveniles on 2 occasions and from the remainder of the juveniles on 1 occasion. The mean age of juvenile alpacas in which age was known was 18 days (range, 2 to 43 days); age was either unknown or not recorded for 4 juveniles. The mean PCV of the adult alpacas was 25.9% (range, 12% to 35%), and the mean total solids concentration was 6.1 g/dL (range, 4.8 to 7.5 g/dL). The mean PCV of the juvenile alpacas was 28.7% (range, 18% to 39%), and the mean total solids concentration was 5.2 g/dL (range, 4.3 to 6.4 g/dL).

Plasma glucose concentration was measured in 190 plasma samples with the laboratory-based analyzer,

HITA; the number of whole blood or plasma samples analyzed with each of the POC analyzers was as follows: iST, 83 (29 stored at 42°C, 29 stored on ice, and 25 spiked with glucose) whole blood samples from adults and 43 (18 stored at 42°C, 14 stored on ice, and 11 spiked with glucose) from juveniles; AC, 68 (23 stored at 42°C, 23 stored on ice, and 22 spiked with glucose) whole blood samples from adults and 50 (20 stored at 42°C, 18 stored on ice, and 12 spiked with glucose) from juveniles; AC, 66 (23 stored at 42°C, 23 stored on ice, and 20 spiked with glucose) plasma samples from adults and 48 (20 stored at 42°C, 18 stored on ice, and 10 spiked with glucose) from juveniles; and AT, 64 (23 stored at 42°C, 23 stored on ice, and 18 spiked with glucose) whole blood samples from adults and 48 (20 stored at 42°C, 18 stored on ice, and 10 spiked with glucose) from juveniles. Plasma glucose concentrations from unaltered blood samples as determined by use of the HITA ranged from 92 to 203 mg/dL. Following either blood sample storage at 42°C for 2 to 6 hours to facilitate glucose metabolism or addition of glucose to samples, plasma glucose concentrations ranged from 36 to 693 mg/dL. Of the 190 samples analyzed, 141 had a PCV  $\geq$  25% and 49 had a PCV  $<$  25%.

For the entire range of glucose concentrations examined, concordance ( $\rho_c$ ) was significant ( $P < 0.001$ ) and excellent for all comparisons, although concordance for the HITA-ACWB comparison was consistently lower than that for other comparisons (Tables 1 and 2). When examined by age group (adult or juvenile) and PCV ( $<$  25% or  $\geq$  25%), concordance remained excellent for all comparisons. When concordance correlation analysis was performed solely for observations with glucose concentrations (as determined with the laboratory-based analyzer, HITA) between 50 and 200 mg/dL, concordance decreased for all comparisons. However, concordance remained excellent the HITA-iST comparison, HITA-AT comparison, and HITA-ACPL comparison; for the HITA-ACWB comparison, concordance was substantial.

The absolute mean  $\pm$  SD difference in measurements between POC analyzers, compared with that of the HITA, determined by use of the Bland-Altman analysis for the entire range of glucose concentrations examined was as follows (listed from smallest to greatest): HITA-AT ( $5.2 \pm 26.5$  mg/dL), HITA-ACPL ( $5.5 \pm 10.2$  mg/dL), HITA-iST ( $9.2 \pm 11.1$  mg/dL), and HITA-ACWB ( $41.2 \pm 38.2$ ). For all glucose concentrations examined, the AT meter tended to overestimate glucose concentration, compared with that of the HITA, whereas the other POC analyzers tended to underestimate glucose concentrations (Tables 1 and 2). When subsets of observations based on either age or PCV and glucose concentrations between 50 and 200 mg/dL as measured by use of the HITA were examined, the iST and AC meters consistently underestimated the glucose concentration. In contrast, the relationship between the mean difference of values determined by use of the AT meter and laboratory-based analyzer (HITA) was somewhat inconsistent (ie, the blood glucose meter would underestimate the glucose concentration in some circumstances and overestimate it in others). Bland-Altman plots for glucose concentrations between 50 and 200 mg/dL as measured by use of the HITA for each of the POC analyzers were developed (Figure 1).

Table 1—Results from the Lin concordance correlation and Bland-Altman analyses comparing 3 POC glucose meters (iST, AC, and AT) with a laboratory-based chemistry analyzer (HITA) in blood samples from alpacas for the entire range of glucose concentrations tested (36 to 693 mg/dL).

Comparison	All alpacas		Juveniles*		Adults*	
	$\rho_c$ (95% CI)	MD (95% LOA)	$\rho_c$ (95% CI)	MD (95% LOA)	$\rho_c$ (95% CI)	MD (95% LOA)
HITA-iST	1.00 (0.99–1.00)	-9.2 (-30.8 to 12.5)	0.99 (0.98–1.00)	-13.9 (-42.9 to 15.2)	1.00 (0.99–1.00)	-7.0 (-21.2 to 7.1)
HITA-ACWB	0.93 (0.91–0.94)	-41.2 (-116.2 to 33.7)	0.91 (0.84–0.95)	-40.7 (-109.4 to 27.9)	0.93 (0.87–0.96)	-40.3 (-111.3 to 30.3)
HITA-ACPL	1.00 (0.99–1.00)	-5.5 (-25.5 to 14.5)	1.00 (0.99–1.00)	-2.7 (-22.5 to 17.2)	1.00 (0.99–1.00)	-8.0 (-25.7 to 9.6)
HITA-AT	0.98 (0.98–0.99)	5.2 (-46.6 to 57.1)	0.98 (0.97–0.99)	-3.0 (-43.3 to 37.3)	0.98 (0.97–0.99)	9.7 (-40.4 to 59.8)

\*Adult alpacas were > 1 year of age; juveniles were < approximately 6 weeks of age.  
 CI = Confidence interval. LOA = Limits of agreement. MD = Mean difference in glucose concentration (mg/dL).

Table 2—Results from the Lin concordance correlation and Bland-Altman analyses comparing 3 POC glucose meters (iST, AC, and AT) with a laboratory-based chemistry analyzer (HITA) in blood samples from alpacas with glucose concentrations between 50 and 200 mg/dL or with a PCV < 25% or ≥ 25%.

Comparison	Glucose concentration between 50 and 200 mg/dL†		PCV < 25%‡		PCV ≥ 25%‡	
	$\rho_c$ (95% CI)	MD (95% LOA)	$\rho_c$ (95% CI)	MD (95% LOA)	$\rho_c$ (95% CI)	MD (95% LOA)
HITA-iST	0.97 (0.95–0.98)	-4.8 (-11.3 to 1.7)	1.00 (0.99–1.00)	-7.8 (-23.9 to 8.3)	0.99 (0.99–1.00)	-10.3 (-34.5 to 14.0)
HITA-ACWB	0.70 (0.58–0.79)	-23.4 (-41.4 to -5.3)	0.95 (0.90–0.98)	-32.7 (-87.9 to 22.5)	0.90 (0.85–0.95)	-42.9 (-111.6 to 25.8)
HITA-ACPL	0.97 (0.95–0.98)	-3.3 (-16.1 to 9.4)	0.99 (0.98–1.00)	-8.1 (-23.0 to 6.9)	1.00 (0.99–1.00)	-4.8 (-25.1 to 15.5)
HITA-AT	0.95 (0.91–0.97)	-3.9 (-20.7 to 13.0)	0.97 (0.95–0.99)	17.3 (-40.2 to 74.6)	0.99 (0.98–0.99)	-1.3 (-44.3 to 42.2)

†As determined by use of the laboratory based chemistry analyzer (HITA). ‡Entire glucose range tested.  
 See Table 1 for remainder of key.

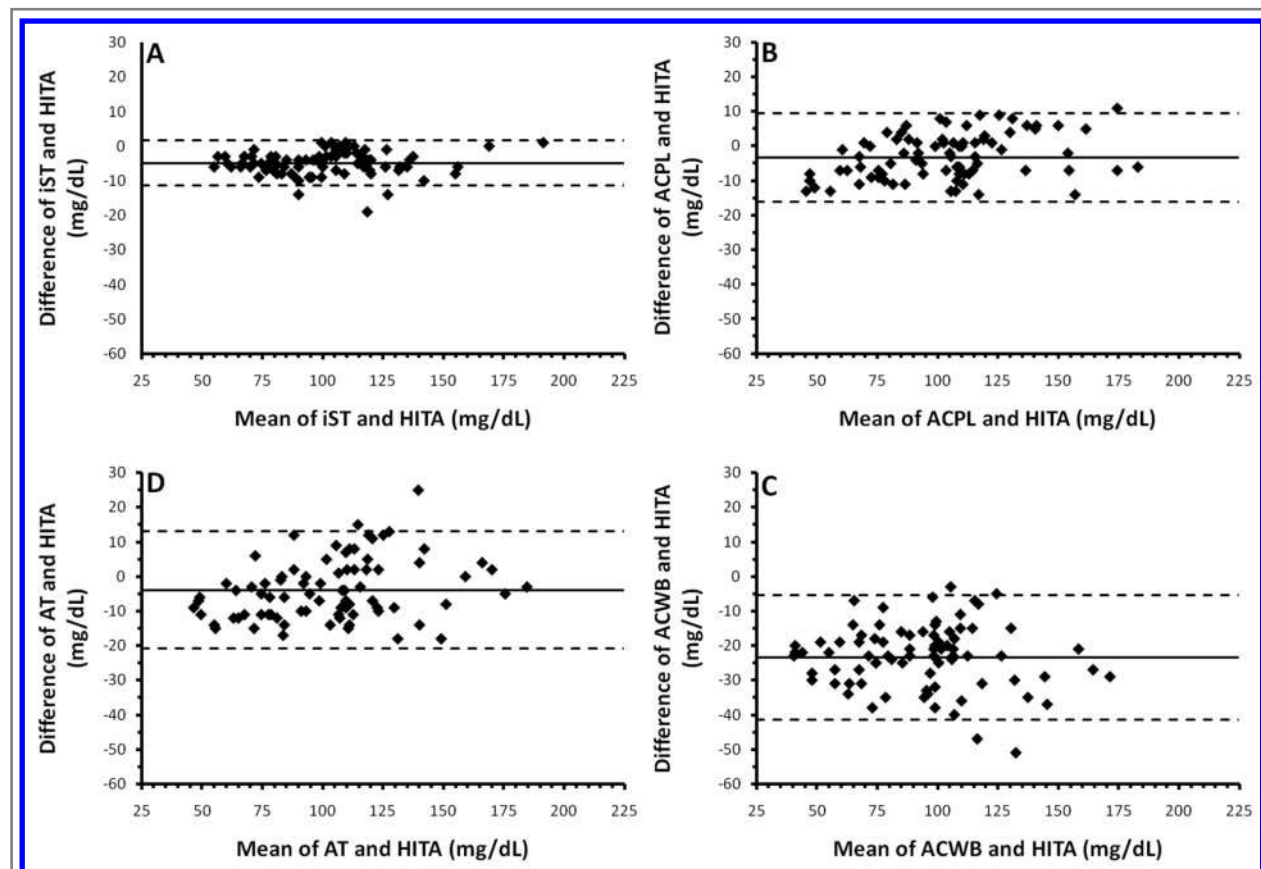


Figure 1—Bland-Altman plots of the mean difference (solid line) and 95% limits of agreement (dashed lines) between glucose concentrations determined by use of a laboratory-based chemistry analyzer (HITA) and 3 POC analyzers in blood samples of alpacas for glucose concentrations between 50 and 200 mg/dL (as determined by use of the HITA analyzer). Notice that whole blood and plasma samples were assessed with the AC meter, but only whole blood samples were assessed the iST and AT meters. A—Comparison for HITA-iST. B—Comparison for HITA-ACPL. C—Comparison for HITA-ACWB. D—Comparison for HITA-AT.

Table 3—Percentage of results determined by use of the POC meters that were within 20%, 15%, 10%, or 5% of the result determined with the laboratory-based chemistry analyzer.

Variable	20%	15%	10%	5%
Glucose concentration between 36 and 693 mg/dL*				
iST	100	100	92.9	57.1
ACPL	95.6	92.1	82.5	49.1
ACWB	45.8	18.6	6.8	2.5
AT	93.8	83.0	61.6	31.3
Glucose concentration between 50 and 200 mg/dL*				
iST	100	100	93.1	51.7
ACPL	96.3	92.5	78.8	46.3
ACWB	42.5	18.8	7.5	2.5
AT	96.3	86.3	62.5	30.0

\*As determined by use of the laboratory-based chemistry analyzer (HITA).

The upper and lower limits of agreement indicate the range within which 95% of the values for mean difference can be expected to fall. For the entire range of glucose concentrations examined, compared with that of the HITA, the difference between the upper and lower limits of agreement for each comparison was as follows (listed from smallest to greatest): HITA-ACPL, 40.0 mg/dL; HITA-iST, 43.3 mg/dL; HITA-AT, 103.7 mg/dL; and HITA-ACWB, 149.9 mg/dL. The difference between the upper and lower limits of agreement decreased for each comparison when a narrower glucose concentration was examined. For a glucose concentration between 50 and 200 mg/dL as measured by use of the HITA, the differences between the upper and lower limits of agreement were as follows (listed from smallest to greatest): HITA-iST, 13.0 mg/dL; HITA-ACPL, 25.5 mg/dL; HITA-AT, 33.7 mg/dL; HITA-ACWB, 46.7 mg/dL (Figure 1). Over the entire range of glucose concentrations, compared with that measured with the HITA, the mean  $\pm$  SD relative difference between the analyzers (ie, the mean percentage difference between results determined by 2 analyzers) was as follows (listed from smallest to greatest): HITA-iST,  $5.2 \pm 3.1\%$ ; HITA-ACPL,  $6.3 \pm 5.5\%$ ; HITA-AT,  $9.0 \pm 6.4\%$ ; and HITA-ACWB,  $22.9 \pm 10.0\%$ . The percentage of POC analyzer results that were within 20%, 15%, 10%, or 5% of the result determined by use of the HITA for the entire glucose concentration range tested and also for glucose concentrations between 50 and 200 mg/dL was determined (Table 3).

## Discussion

Measurements of blood glucose concentration have prognostic value in critically ill humans<sup>20,21</sup> and horses,<sup>22-24</sup> and tight regulation of blood glucose concentration improves outcome in some populations of hospitalized human patients.<sup>6,7</sup> Abnormalities in blood glucose concentrations occur commonly in adult and neonatal South American camelids, requiring frequent monitoring and often requiring intervention.<sup>1-5</sup> The use of POC glucose meters in human intensive care units has facilitated rapid and inexpensive glucose concentration measurement in patients that require frequent assessment.<sup>8</sup> However, in patients with severe systemic

derangements, meter performance can be insufficiently accurate to safely direct treatment.<sup>25</sup> It is often assumed that the inexpensive POC glucose meters widely used by human diabetics will provide reliable results when used in veterinary patients. However, experience with POC glucose and lactate meters in other species suggests that meter accuracy cannot be assumed and their performance should be assessed in the target animal population.<sup>9,10,12</sup> In the present study, concordance between the 3 POC analyzers and a laboratory-based chemistry analyzer was excellent across a wide range of blood glucose concentrations in samples collected from healthy alpacas. Although bias of the POC analyzers was typically small ( $< 10$  mg/dL), compared with measurements from the HITA, the limits of agreement were extremely wide in some instances. For the one POC analyzer (ie, AC) in which the use of whole blood versus plasma was assessed, concordance increased and bias and the limits of agreement decreased when plasma rather than whole blood samples were analyzed; however, the use of plasma samples limits the usefulness of this meter in the field.

The Lin concordance correlation analysis is used to compare the results obtained by 2 techniques without specifying which technique is preferred.<sup>14,15</sup> A concordance correlation coefficient ( $\rho_c$ ) with a value of 1 indicates perfect agreement between 2 techniques. In contrast, it becomes less likely that 2 techniques are measuring the same variable as the value for  $\rho_c$  deviates further from 1. Over the entire range of glucose concentrations tested, concordance correlation analysis revealed excellent agreement between the laboratory-based chemistry analyzer (HITA) and all 3 POC analyzers (Table 1). The accuracy of any meter measuring values outside the reference interval should be sufficient so that trends can be followed reliably. However, it is critical for a technique to be accurate for values within the reference range, particularly if one is attempting to regulate blood glucose concentrations within narrow limits. To address this in the present study, analyses were performed for a range of glucose concentrations that might be targeted in clinical practice (ie, between 50 and 200 mg/dL). Within this range, agreement remained excellent for the iST and AT meter with whole blood samples and for the AC meter with plasma samples (Table 2). However, with whole blood samples, agreement between the AC meter and the laboratory-based analyzer (HITA) decreased for the narrower range of glucose concentrations. The cause of the decrease in the concordance coefficient for the HITA-ACWB comparison (ie, when whole blood samples were analyzed instead of plasma samples) is unknown but has also been described in a study<sup>10</sup> in horses. Concordance correlation analysis can be influenced by extreme values within a data set, and these might have artifactually improved agreement for the HITA-ACWB comparison when the wider range of glucose concentrations was assessed.<sup>26</sup>

In the present study, bias between measurement techniques was calculated as the mean difference between values determined via the 2 techniques being compared.<sup>17,18</sup> A certain amount of bias is acceptable if it is predictable and consistent. All meters investigated had some degree of bias, compared with measurements made from the HITA, and tended to over- or underesti-

mate glucose concentration. In most instances, this bias was small ( $< 10$  mg/dL) and unlikely to affect clinical decisions. However, when glucose concentrations were measured in whole blood samples by use of the AC meter, absolute bias was substantial (23.4 to 42.9 mg/dL) and could lead to differences in treatment decisions (Tables 1 and 2). Although absolute bias was smaller for the HITA-ACWB comparison at glucose concentrations between 50 and 200 mg/dL, it remained considerable (23.4 mg/dL; Figure 1). Under most conditions assessed, the AT meter had minimal bias ( $< 10$  mg/dL), although this meter would underestimate blood glucose concentrations under some circumstances and overestimate it under others and bias was greater in samples with a PCV  $< 25\%$ .

In contrast to the agreement and bias, the limits of agreement were extremely wide for many comparisons (Tables 1 and 2). The upper and lower limits of agreement are the values between which 95% of values can be expected to fall.<sup>17,18</sup> The narrower the limits of agreement, the more confident one can be that the reported value of a variable approximates its true value. In human medicine, POC meters often become less reliable at extreme glucose concentrations; however, at extreme values, even large errors typically make little difference in terms of case management. For glucose concentrations between 50 and 200 mg/dL as measured by use of the HITA, the limits of agreement for the HITA-iST, HITA-ACPL, and HITA-AT comparisons decreased to within acceptable limits (Figure 1).

The National Committee for Clinical Laboratory Standards has recommended error tolerances for POC glucose meters of  $\pm 15$  mg/dL for glucose concentrations  $< 100$  mg/dL and  $\pm 15\%$  to  $20\%$  for glucose concentrations  $> 100$  mg/dL.<sup>27</sup> As technology has improved, the American Diabetes Association has steadily tightened its recommendations and has suggested that glucose measurements determined with POC glucose meters should be within  $\pm 5\%$  of the value reported by laboratory reference techniques.<sup>27</sup> The error grid analysis method for validation of blood glucose assays assumes that results are clinically accurate and will not adversely affect treatment decisions if they are within  $20\%$  of the value determined by a reference technique.<sup>28</sup> Most of the values determined by use of the iST, AT, and ACPL are within the less rigorous requirements for performance suggested by the National Committee for Clinical Laboratory Standards, but few meet the stringent requirements of the American Diabetes Association (Table 3). Factors that have been reported to adversely affect glucose meter performance include changes in PCV,<sup>11,29-31</sup> acid-base disturbances,<sup>25</sup> abnormal blood gas tensions,<sup>11</sup> systemic hypoperfusion,<sup>25</sup> hemolysis,<sup>32</sup> and ambient temperature.<sup>33</sup> Because healthy alpacas were used in the present study, many of these factors could be eliminated. There were 3 alpacas that were moderately to markedly anemic (PCVs of 18%, 17%, and 12%); however, data for 2 of these alpacas (those with PCVs of 17% and 12%) were used only for the HITA-iST comparison, so that would not have affected results for other comparisons. In this study, the bias and limits of agreement were greater for the HITA-AT comparison for samples with a PCV  $< 25\%$ , compared with

samples with a PCV  $\geq 25\%$  (Table 2). In contrast, concordance was greater, bias was smaller, and the limits of agreement were narrower for the HITA-ACPL comparison (ie, when plasma samples rather than whole blood samples were used; Table 3).

Changes in PCV have been shown to impair the performance of some POC glucose meters in human studies.<sup>11,29-31</sup> The effect of PCV in human studies<sup>27,29</sup> is variable, with extreme glucose concentrations typically more affected than glucose concentrations closer to the reference interval. Changes in PCV might influence glucose measurements by altering the viscosity of the blood sample, the volume of plasma that reaches the reaction surface of the test strip, and glucose diffusion kinetics.<sup>11</sup> Many POC glucose meters use a standard factor to convert whole blood glucose concentration to plasma glucose concentration; the conversion becomes inaccurate in samples with a PCV outside of the reference range. Based on earlier experience<sup>9</sup> and a report<sup>10</sup> evaluating the AC glucose meter in horses, plasma and whole blood samples were evaluated with this meter in the present study. In agreement with 1 report<sup>10</sup> in horses, performance of the AC meter used in the present study improved considerably (reduced bias and limits of agreement) when plasma rather than whole blood samples were used. The use of equine plasma samples also improved performance of a POC lactate meter,<sup>9</sup> although PCV had little effect on the differences between the POC glucose meter and a laboratory-based analyzer. It was suggested that this might be due to the way that equine erythrocytes packed onto the test strips of the POC glucose meter and trapped plasma or interfered with reflectance of the meter's light source. However, the lactate test strips in that study<sup>9</sup> used a glass fiber layer to separate erythrocytes from plasma and a colorimetric assay to determine lactate concentration within the resultant plasma. In contrast, each of the 3 meters used in the present study operates by drawing the sample into a chamber in which a chemical reaction occurs, generating an electrical current proportional to the glucose concentration of the sample. Results for the HITA-iST comparisons were similar for samples with a PCV  $\geq 25\%$ , compared with samples with a PCV  $< 25\%$ , and as expected, PCV made little difference in the HITA-ACPL comparison (ie, when plasma samples were used; Table 2). For the AT meter, the bias was closer to zero and the difference between the upper and lower limits of agreement was smaller in samples with a PCV  $\geq 25\%$ , compared with samples with a PCV  $< 25\%$ ; this might reflect the use of an algorithm for the conversion of whole blood glucose concentrations to plasma concentrations that uses a typical PCV value. Regression analyses would be required to better delineate the relationship between PCV and meter performance but was not performed in this study. Although several alpacas in this study were anemic, the PCVs of most alpacas fell within a narrow range and a relationship between PCV and meter performance might be difficult to accurately discern. There was no measurable effect of PCV on the accuracy of the AC meter in a recent study<sup>10</sup> evaluating that meter in equine emergency patients.

The present study has some limitations, the most important of which is that samples were obtained from

healthy alpacas. Monitoring of blood glucose concentrations is most likely to be performed in diseased alpacas in which changes in blood composition might further affect meter performance.<sup>11,25,29–31</sup> Although meter performance is unlikely to improve in diseased alpacas in the authors' opinion, this remains to be tested. A further limitation is that the age range of the juvenile alpacas included was broad. Physiologic development in the first few days after birth can be quite different from that at even a few weeks of age, and this too might influence meter performance; however, we were unable to determine that in the present study.

In conclusion, of the 3 POC analyzers assessed, the iST meter performed best under all the conditions evaluated. The cartridges used by the iST meter are also the most expensive and approximately 3 to 4 times the cost of the test strips used by the other 2 meters. However, the iST meter can measure a wide range of other variables depending on the cartridge selected and that might offset the cost. This meter was the slowest of the 3, although this is probably only of minor inconvenience. The AT meter performed well on whole blood samples within a clinically relevant range of glucose concentrations (ie, 50 to 200 mg/dL). Over a wider range of glucose concentrations, the limits of agreement are broad for this meter; however, it is probably sufficiently accurate to track changes. This meter might also be less accurate in alpacas with a PCV < 25%, as evidenced by increases in the bias and limits of agreement in this study. Despite an excellent concordance coefficient, overall performance of the AC meter was poor with whole blood samples. However, the meter performed well with plasma samples, although use of plasma samples limits its usefulness in the field. The results of this study emphasize the importance of assessing the performance of individual meters in their target population.

- a. BD Vacutainer, Becton Dickinson & Co, Franklin Lakes, NJ.
- b. Accu-Chek Aviva, Roche Diagnostics, Indianapolis, Ind.
- c. i-Stat, Abbott Point of Care Inc, Princeton, NJ.
- d. AlphaTrak, Abbott Animal Health, Abbott Park, Ill.
- e. 50% dextrose, Hospira Inc, Lake Forrest, Ill.
- f. Sterile water, Baxter Healthcare Corp, Deerfield, Ill.
- g. Hitachi 912, Roche Diagnostics, Indianapolis, Ind.
- h. Stata, version 9.2, Stata Corp, College Station, Tex.

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