Accuracy of Four Blood Glucose Monitoring Systems

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Background: The minimum acceptable accuracy for results produced by a blood glucose monitoring system according to the current version of ISO 15197, created in 2003, is: 95% of the individual glucose results shall fall within ±15 mg/dL (0.83 mmol/L) of the results of the manufacturer's measurement procedure at glucose concentrations < 75 mg/dL (< 4.2 mmol/L) and within ±20% at glucose concentrations ≥ 75 mg/dL (≥ 4.2 mmol/L). The ISO Standard is undergoing revision and tighter accuracy requirements are expected. In this report, we compare the accuracy of four latest models of blood glucose monitoring systems using the current standard and tighter criteria.

Method: Accuracy of the four blood glucose monitoring systems for fingertip capillary blood testing was assessed at a diabetes clinic. A total of 150 diabetic subjects were included in the study. At the study site, the trained operator tested the subject's fingertip blood with the four systems and a YSI glucose analyzer, which served as the reference. Accuracy was evaluated using ISO 15197:2003, and by calculating the percentage of meter results falling within ±5%, ±10% and ±15% of the reference value for glucose concentrations 100 mg/dL (5.6 mmol/L) or higher, and within ±5, ±10 and ±15 mg/dL (±0.28, ±0.56 and ±0.83 mmol/L) of the reference value for glucose concentrations below 100 mg/dL (5.6 mmol/L).

Results: All four blood glucose monitoring systems in this study met the minimum acceptable accuracy required by ISO 15197:2003. When evaluated with tighter accuracy criteria, the FreeStyle Freedom Lite® system had 99.7% of its results agreeing within ±15% of the reference, and 95.5% of the results agreeing with ±10% of the reference—a performance significantly ($p<0.002$) better than those of OneTouch® Ultra®2 and Ascencia® Contour®. The FreeStyle Freedom Lite system had 72.3% of its results agreeing within ±5% of the reference, significantly ($p<0.002$) better than the Contour, OneTouch Ultra2 and Accu-Chek® Aviva.

Conclusions: Of the four latest models of blood glucose monitoring systems evaluated, the FreeStyle Freedom Lite system showed the highest level of accuracy. More accurate glucose results may help patients maintain their blood glucose levels with a higher degree of accuracy, and the more accurate glucose monitoring systems are more likely to meet any new ISO Standard and local regulatory requirements.

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Self-monitoring of blood glucose with an accurate device is an integral component of effective diabetes management. ISO 15197,[1] the international standard that specifies accuracy requirements of blood-glucose monitoring systems for self-testing, was created in 2003. Some professional organizations and regulatory agencies are now proposing a tightening of the accuracy standard. Using ISO 15197:2003 and tighter criteria, we compared the accuracy of four latest models of blood glucose monitoring systems based on different measurement technologies.

MATERIALS AND METHODS

GLUCOSE MONITORING SYSTEMS

The technologies and features of the four systems evaluated in this study are shown in Table 1. Accu-Chek® Aviva and OneTouch® Ultra®2 meters require coding by the user, and they were properly coded by the trained operators at the study site before use. Control solution testing was performed on all four systems to verify proper functioning before the start of the study. All systems and supplies were stored, handled and operated according to the manufacturer's instructions.

Table 1. Technologies and features of the four monitoring systems

	FreeStyle Freedom® Lite	Accu-Chek® Aviva	OneTouch® Ultra®2	Ascensia® Contour®
Manufacturer	Abbott Diabetes Care	Roche Diagnostics	LifeScan	Bayer Diabetes Care
Methodology	Coulometry, with the new FreeStyle Lite test strip with ZipWik™ tabs	Amperometry	Amperometry, with the new OneTouch Ultra Blue test strip	Amperometry
Enzyme	GDH-FAD	GDH-PQQ	GOD	GDH-FAD
Coding	No	Yes	Yes	No
Sample Size, µL	0.3	0.6	1.0	0.6
May apply second blood drop	Yes, within 60 sec.	Yes, within 5 sec.	No	No
Test Time, sec	≥ 4*	5	5	5
Referenced to plasma glucose values	Yes	Yes	Yes	Yes

*High glucose levels can take longer than 4 seconds.

REFERENCE GLUCOSE MEASUREMENT

The YSI 2300 Stat Plus Glucose Analyzer (YSI Inc., Yellow Springs, OH) was used as the reference. The calibration accuracy of the YSI analyzer at the study site was validated by testing National Institute of Standards and Technology (NIST)[1] standard reference material SRM 965b, which consists of four levels of glucose concentrations.

ACCURACY EVALUATION

The accuracy of the four monitoring systems for finger blood testing was evaluated at a diabetes clinic using three different lots of test strips tested in duplicate with each system. One lot of test strips was used with each group of 50 diabetic subjects. The order of testing the four systems was rotated after each subject. With each subject, immediately after applying blood to the four systems, additional blood was collected from the finger into a heparin tube for testing in duplicate on the YSI analyzer. The protocol specifies that the first YSI test must be completed within 15 minutes of the first meter test, and the duplicate YSI results must agree within ±4 mg/dL (±0.2 mmol/L) at glucose concentrations up to 100 mg/dL (5.6 mmol/L) or within ±4% at glucose concentrations above 100 mg/dL (5.6 mmol/L). Before testing the blood sample of each subject on the YSI, the YSI standard (180 mg/dL; 10.0 mmol/L) was tested and the result must be within the range of 176-184 mg/dL (9.8-10.2 mmol/L). To ensure sufficient number of finger blood samples with glucose concentrations below 50 mg/dL (2.8 mmol/L) and above 400 mg/dL (22.2 mmol/L) were tested, eight samples were modified to lower the glucose concentration below 50 mg/dL (2.8 mmol/L) and another eight samples were modified to elevate above 400 mg/dL (22.2 mmol/L). Finger blood glucose results obtained with the four monitoring systems were compared to results obtained on the YSI.

RESULTS

A total of 150 diabetic subjects were enrolled at the study site. An institutional review board approved the study, and all subjects gave their informed consent before participation. There were no protocol deviations, and no subjects were excluded from the study or data analysis. However, one subject obtained one result, instead of two, on the Contour® meter due to an error code 'E2', which indicates the test started with insufficient blood. One of the eight modified blood samples supplemented with glucose provided only one result on the OneTouch® Ultra®2 meter while the duplicate test gave an error message.

Based on the YSI results, blood glucose concentrations of the 150 subjects and the 16 modified samples ranged from 23 to 460 mg/dL (1.3 – 25.6 mmol/L), with a mean value of 175 mg/dL (9.7 mmol/L) and a median of 155 mg/dL (8.6 mmol/L). The hematocrits of the 150 subjects ranged from 32% to 54% (mean and median, 42%).

As shown in Table 2, results of all four systems met the minimum acceptable accuracy requirement of ISO 15197:2003—At least 95% of the individual glucose results shall fall within ±15 mg/dL (0.83 mmol/L) of the results of the manufacturer's measurement procedure at glucose concentrations < 75 mg/dL (< 4.2 mmol/L) and within ± 20% at glucose concentrations ≥ 75 mg/dL (≥ 4.2 mmol/L).

When the accuracy criterion was tightened to ±15% of the reference value, or ±15 mg/dL (±0.83 mmol/L) at glucose concentrations below 100 mg/dL (5.6 mmol/L), less than 90% of the Contour results fell within these limits, whereas the other three systems had ≥ 95% of the results within the tighter limits.

When the accuracy criterion was tightened to ±10% of the reference value, or ±10 mg/dL (±0.56 mmol/L) at glucose concentrations below 100 mg/dL (5.6 mmol/L), only the FreeStyle Freedom Lite® system had 95% of the results falling within the limits. The Accu-Chek® Aviva, OneTouch Ultra2 and Contour had 91.9%, 80.4% and 59.5% of the results within these limits.

When the accuracy criterion was tightened to ±5% of the reference value, or ±5 mg/dL (±0.28 mmol/L) at glucose concentrations below 100 mg/dL (5.6 mmol/L), roughly three quarters of the FreeStyle Freedom Lite results, half of the Accu-Chek Aviva and OneTouch Ultra2 results, and one quarter of the Contour results fell within these very tight limits.

The FreeStyle Freedom Lite system had significantly ($p < 0.002$) more results falling within each set of limits in Table 2 than OneTouch Ultra2 and Contour. The FreeStyle Freedom Lite system also had significantly ($p < 0.002$) more results falling within ±5% of the reference value, or ±5 mg/dL (±0.28 mmol/L) at glucose concentrations below 100 mg/dL (5.6 mmol/L), than Accu-Chek Aviva.

Table 2. Percentage of meter results falling within various intervals of the reference glucose value

System	Within ±5 mg/dL (±0.28 mmol/L) or ±5%*	Within ±10 mg/dL ±0.56 mmol/L or ±10%*	Within ±15 mg/dL (±0.83 mmol/L) or ±15%*	Within ±15 mg/dL (±0.83 mmol/L) or ±20%**
FreeStyle Freedom Lite®	72.3%	95.5%	99.7%	100%
Accu-Chek® Aviva	60.5%	91.9%	99.1%	100%
One Touch® Ultra®2	49.2%	80.4%	95.2%	97.0%
Ascensia® Contour®	27.2%	59.5%	85.8%	97.3%

N = 331-332 tests on each glucose monitoring system with 166 blood samples from 150 patients.

*For glucose concentrations <100 mg/dL (< 5.6 mmol/L), the % meter results within ± the specified mg/dL of the reference glucose values are tabulated. For glucose concentrations ≥ 100 mg/dL (≥ 5.6 mmol/L), the % meter results within ± the specified % of the reference glucose values are tabulated.

**ISO 15197:2003: For glucose concentrations < 75mg/dL (< 4.2 mmol/L), the % meter results within ± 15 mg/dL of the reference glucose values are tabulated. For glucose concentrations ≥ 75mg/dL (≥ 4.2 mmol/L), the % meter results within ± 20 % of the reference glucose values are tabulated.

*Shaded areas indicate significant difference from the FreeStyle Freedom Lite system ($p < 0.002$).

DISCUSSION

Self monitoring of blood glucose (SMBG) is an important component of the treatment plan of patients with diabetes. It allows patients to achieve and maintain specific glycemic goals.

The minimum acceptable accuracy for results produced by a blood glucose monitoring system according to ISO 15197:2003, is: 95 % of the individual glucose results shall fall within ±15 mg/dL (0.83 mmol/L) of the results of the manufacturer's measurement procedure at glucose concentrations < 75 mg/dL (< 4.2 mmol/L) and within ±20% at glucose concentrations ≥ 75 mg/dL (≥ 4.2 mmol/L). As expected, all four blood glucose monitoring systems in this study met the minimum acceptable accuracy required by ISO 15197:2003.

Although there are no outcome studies that substantiate improved patient benefits from greater accuracy of blood glucose monitoring systems, it is logical to suggest that patients would be able to maintain their blood glucose levels with a higher degree of accuracy if their meters were more accurate. Some professional organizations (such as the American Diabetes Association and the American Association of Clinical Endocrinologists) and regulatory agencies (such as the FDA in the US) have come out in strong support for standards stricter than the ISO 15197:2003. The ISO Standard is now undergoing revision and tighter accuracy requirements are expected.

The 1986 consensus conference,[2] organized by the American Diabetes Association (ADA), led to the following recommendations: (1) With current systems, SMBG measurements should be within 15% of the results of the reference measurement; (2) The goal of all future SMBG systems should be to achieve variability (system plus user) of < 10% at glucose concentrations of 30-400 mg/dL (1.7-22.2 mmol/L) 100% of the time. In this study, the FreeStyle Freedom Lite® system had 99.7% of its results agreeing within ±15% of the reference, and 95.5% of the results agreeing with ±10% of the reference. This performance is significantly better than those of OneTouch® Ultra®2 and Contour®.

The 1993 ADA consensus conference[3] provided the following recommendation: The goal of SMBG device manufacturers should be to make future SMBG systems with an analytical error of ±5%. It has been suggested that reducing the total analytical error of the glucose monitoring system from 10-15% toward 5% may significantly reduce the frequency and magnitude of insulin dosage errors.[4] The FreeStyle Freedom Lite system had 72.3% of its results agreeing within ±5% of the reference, significantly better than Contour, OneTouch Ultra2 and Accu-Chek® Aviva.

In conclusion, of the four latest models of blood glucose monitoring systems evaluated, the FreeStyle Freedom Lite system showed the highest level of accuracy. More accurate glucose results may help patients maintain their blood glucose levels with a higher degree of accuracy, and the more accurate glucose monitoring systems are more likely to meet any new ISO Standard and local regulatory requirements.

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