**Journal of Diabetes Science and Technology**
Volume 1, Issue 2, March 2007


SYMPOSIUM

# Quality Control of Self-Monitoring of Blood Glucose: Why and How?

Bogdan Solnica, M.D., Ph.D. and Jerzy W. Naskalski, Ph.D., D.Sc.

## Abstract

The control of analytical quality of self-monitoring of blood glucose (SMBG) is recommended as a routine procedure in diabetes management. This control procedure should be easily accessible to patients, convenient, not time-consuming, and provide a reliable assessment of glucose meter performance. Optimally it should be located in the diabetes outpatient clinic. Presently there are two approaches to carrying out SMBG quality control. The first is based on the comparison of results obtained by a controlled glucose meter and use of the laboratory method or point-of-care testing device as a surrogate reference analyzer. The second one is a traditionally organized external quality assessment scheme with use of a dedicated control material, which is distributed to all participants. The recommended allowable meter error in SMBG can be realistically set at 10%.

*J Diabetes Sci Technol 2007;1(2):164-168*

## Introduction

Glycemic-guided treatment of diabetes is presently a basis for optimal diabetes metabolic control and maintenance in patients near normoglycemia. This type of therapy requires frequent measurements of patient's blood glucose concentrations and tentative therapeutic intervention, taken up, if necessary, by the educated patient. Thus, self-monitoring of blood glucose (SMBG) is considered an integral part of the current strategy of diabetes treatment.[1,2] According to American Diabetes Association (ADA) recommendations for patients using multiple insulin injections, blood glucose measurements should be performed three or more times a day. Patients treated with less frequent insulin injections, oral glucose-lowering drugs, or diet alone are also encouraged to use SMBG as an aid in achieving target glycemia.[1] In effect, blood glucose self-monitoring, with frequency depending on patients clinical status and the applied treatment, has become a common regimen required for all people with diabetes.

**Author Affiliation:** Department of Clinical Biochemistry, Jagiellonian University Medical College, Krakow, Poland

**Abbreviations:** (ADA) American Diabetes Association, (CV) coefficient of variation, (EQAS) external quality assessment scheme, (INSTAND) Institute of Standardization and Documentation, (ISO) International Organization for Standardization, (NCCLS) National Committee of Clinical Laboratory Standards, (POCT) point-of-care testing, (SMBG) self-monitoring of blood glucose

**Keywords:** analytical quality, diabetes mellitus, glucose meter, glycemia, imprecision

**Corresponding Author:** Bogdan Solnica, Ph.D., Department of Clinical Biochemistry, Jagiellonian University Medical College, ul. Kopernika 15b, 31-501 Krakow, Poland; email address mbsolnic@cyf-kr.edu.pl

Implementation of SMBG as an effective glycemic control tool requires that three crucial conditions are met:

- To convince the patient to carry out SMBG
- To educate patients in SMBG technique and proper use of the results to adjust therapy
- To assure adequate analytical quality of the SMBG process

The quality of patient's glycemic self-assessment has significant impact on the effectiveness of diabetes control. Therefore, validation of analytical quality of glucose assays should be considered as a part of management of patients with diabetes. Poor performance of SMBG leads to results conflicting with $HbA_{1c}$ levels and implies inadequate treatment adjustments or omissions of hypoglycemia episodes.

## Quality of SMBG Information

The quality of SMBG depends on the analytical performance of a glucose meter and the skill of its user. ADA and other diabetes societies recommend evaluation of the monitoring technique of all patients at regular intervals. However, because patients using glucose meters do not have means for assessment of SMBG quality, SMBG quality assurance and quality control require the involvement of various professionals able to carry out this task. The process of glycemic monitoring involves patients, nurses, and producers of glucose meters and strips. Manufacturers of glucose meters provide glucose control solutions with properties mimicking fresh human blood. These solutions, however, do not meet criteria of control material. Glucose target concentration is given only as "meter acceptable readouts range," which is too wide for the assessment of meter analytical quality. In turn, special electronic control strips are designed to check the meter measurement system, omitting information about performance of the reagent strips.

The two main prerequisites of a quality assessment plan for SMBG are the establishment of:

- Analytical quality goals for glucose meters
- A structured program to implement the plan's goals

## Establishing Analytical Quality Goals

Adequate control material, e.g., whole blood with stable glucose concentrations given as nominal values for various meters, is not available for widespread routine use, and solutions (suspensions) offered by manufacturers are not suitable for quality control. Thus the assessment of analytical accuracy, as in the case of quality control routinely carried out in the laboratory, is not possible for glucose meters. For this reason the reference value of glucose concentration used for the calculation of analytical error is the result obtained in the same material using a well-standardized and controlled laboratory method. Thus, glucose meter error is calculated as the difference between the glucose concentration measured by a controlled meter and the concentration obtained in the same material using a laboratory method, expressed as a percentage of the reference laboratory value:

$$\text{Meter error} = ([\text{Gluc}]_{\text{meter}} - [\text{Gluc}]_{\text{lab}})/[\text{Gluc}]_{\text{lab}} \times 100\%$$

The SMBG allowable analytical error is still the subject of debate. ADA recommends the total error of glucose meter assays be less than 5%.[3,4] Other recommendations are less stringent. According to the National Committee of and Laboratory Standards Institute), the allowable error for blood glucose >100 mg/dl is ±20% and for glycemia ≤100 mg/dl is ±10 mg/dl.[2] The International Organization for Standardization (ISO) stated in 2003 that for blood glucose >76 mg/dl, 95% of results should fall in the ±20% range, whereas concentrations ≤76 mg/dl should fall in the ±15-mg/dl range.[5] NCCLS and ISO recommendations and error grid analysis,[6] evaluating the effect of analytical inaccuracy on the interpretation of results obtained using glucose meters, allow an error up to 20%.

## Performance of Glucose Meters

The ADA recommended performance was met only by a few evaluated glucose meters. Our own experience, found the analytical error of glucose meters in the range of 10%.[7–13] Thus it seems reasonable to propose 10% as the upper limit of allowable SMBG error. This proposal is consistent with the analytical quality of the majority of currently used glucose meters, as well as the target set by NCCLS and ISO recommendations. Moreover, it is only slightly higher than the allowable total error of glucose assays performed in the laboratory, amounting to 7.9%.[2]

Employing a computer simulation, Boyd and Bruns[14] estimated that an allowable glucose meter bias and imprecision coefficient of variation (CV) only in the range 1 to 2% can assure the proper insulin dosage. Skeie and colleagues,[15] analyzing patient-derived quality specifications for glucose meters, reported that imprecision CV <5% and bias <5% meet the expectations of >75% of patients in situations other than hypoglycemia. Such analytical quality targets, however, are not achievable at present. Moreover, one should remember that the total error of glycemia measurement also includes sampling error and other factors of uncertainty, additionally contributing to the glucose meter error. Furthermore, further improvement of glucose meters' construction and methodology of testing is not the sole prerequisite for improving the medical value of SMBG. Thus education and training of patients in proper SMBG execution are the next pivotal factors for the achievement of analytical quality goals.

Evaluation of various glucose meters disclosed a significant difference among the individual devices.[8] In this study, One Touch II, One Touch Basic, and One Touch Profile yielded results 10.7 to 16.9% higher than GX, Medisense Card Sensor, Exact Tech, and Esprit. The latter glucose meters yielded results that conformed to glucose laboratory assay results in the range of 2%. The observed differences were apparently related to device factory calibration, as all glucose meters belonging to the One Touch family yielded glucose results higher by 14% than the laboratory method and other glucose meters studied.[8] This suggests that a uniform calibration of all glucose meters is of crucial importance. Ideally, glucose meters should be plasma calibrated and the results should be traceable to the standard reference values. This would bring SMBG data in line with results obtained in the laboratory. The recommendation to use plasma glucose concentrations in the diagnosis of diabetes and prediabetic states provides additional rationale for glucose meters' plasma calibration.[16]

The quality control of SMBG is based on the calculation of glucose meters' error in relation to the laboratory method. Thus, quality control of glucose meters should be performed in cooperation with a clinical laboratory. However, patients do not have direct access to the laboratory but usually remain in permanent contact with the selected diabetes outpatient clinic. Therefore, patients' glucose meter control should be carried out by the comparison with the dedicated glucose analyzer used in the clinic. The glucose analyzer used for the validation of patients' glucose meters must be subjected to systematic quality control by the local clinical laboratory. This procedure meets the requirement of comparing the controlled patients' meters with the laboratory method and combines it with professional care of the clinic staff.

## Establishing a Structured Program

The optimal setting of SMBG quality control is the diabetes outpatient clinic, where assessment of the patient's clinical status can be carried out together with the quality control of his/her glucose meter. This quality control assessment should be performed by a trained nurse or a diabetes educator. The assessment should adhere to a five-step standardized schedule,[17] which consists of the following.

1. Inspecting the glucose meter and reagent strips.
2. Observing the patient's performance of SMBG conducted on the patient's own glucose meter.
3. Measuring blood glucose by a point-of-care testing (POCT) analyzer used in the clinic, performed on a sample of capillary blood from the same finger prick.
4. Calculating the glucose meter error and the discussion of possible causes for discrepant measurement results due to preanalytical and analytical factors (i.e., sampling errors, device inaccuracy, drug interferences).
5. Recording all measured results and explanatory comments into a control log.

The patient must be instructed on how to carry out the detailed inspection of the meter and the reagent strips and detect mechanical damage or contamination of the measurement system. Any damage detected should be corrected if possible. The expiration date and code of reagent strips should be checked, with the latter being compared with the code entered into the glucose meter. Once the meter and reagent strips are suitable for use, a patient measures glucose concentration in his/her capillary blood using his/her own glucose meter. The blood sampling and glucose measurement are supervised by a nurse or diabetes educator to assess the patient's skill. The obtained result is recorded.

Simultaneously, the glucose concentration in capillary blood from the same finger prick is measured by a POCT analyzer, used routinely in the clinic. The POCT glucose analyzer used for SMBG quality control must be subjected to everyday quality control based on comparison with the laboratory method, using fresh capillary blood or dedicated control blood if available. Analytical quality specifications for this analyzer should be the same as for laboratory instruments, i.e., imprecision CV <2.0% and total error <7.9%.[2] Such an indirect, two-step mode of comparison of SMBG data with the laboratory method is necessary for patient convenience. Direct comparison eliminates analytical variability of the POCT device, but requires locating a SMBG control in the laboratory with all organizational problems. A POCT device regularly controlled in the laboratory seems to provide an adequate surrogate reference glucose analyzer for SMBG control purposes. Such analyzers, e.g., HemoCue B-Glucose, YSI, and Biosen, can be used for meter quality control.[18]

When comparing glucose meter and POCT analyzer data, one should keep in mind how the results are expressed. Glucose meters can be whole blood or plasma calibrated. Similarly, POCT analyzers can measure whole blood or plasma glucose concentrations. In case of discrepancy, whole blood and plasma glucose concentrations can be converted using the following formula:[19]

$$[\text{Gluc}]_{\text{plasma}} = [\text{Gluc}]_{\text{whole blood}} \times 1.11$$

Results obtained using the patient's glucose meter and POCT device are used to calculate meter error according to the formula:

$$\text{Meter error} = ([\text{Gluc}]_{\text{meter}} - [\text{Gluc}]_{\text{POCT}})/[\text{Gluc}]_{\text{POCT}}) \times 100\%$$

As mentioned earlier, taking into account published data from evaluations of glucose meters and quality control programs, an allowable meter error in SMBG up to 10% can be recommended. In case of an error higher than 10%, corrective action should be taken, including changing reagent strip lots or even changing the glucose meter. Finally, obtained results and remarks should be recorded in the control log.

The quality control of SMBG should be recognized as an integral part of diabetes treatment, such as SMBG itself. Yet, the majority of people with diabetes use their glucose meters without any quality control. Some of them use available control solutions of poor quality or unsuitable control strips. There is still much to be done to make SMBG quality control more broadly available.

## External Quality Assessment

The procedure of quality control of SMBG described here and verified in practice can be applied easily in an outpatient clinic.[17] According to recommendations of ADA and other scientific associations, physicians and nurses are responsible for this control. However, the quality control of SMBG, when based on a POCT glucose analyzer, also requires cooperation with the clinical laboratory, providing a reference method and control of POCT device results. The procedure of quality control of SMBG can be simplified when appropriate control material is available. Meter error can be calculated in relation to the target value in control material, i.e., without the use of a POCT or laboratory analyzer. Control material can be used for SMBG control purposes in outpatient clinics or for traditionally organized external quality assessment schemes (EQAS). Kristensen *et al.*[20] reported results of an EQAS for SMBG based on control samples sent by mail to patients twice a year. The analytical performance was recognized as "good" with deviation from target value less than 5% and "acceptable" with deviation up to 10%. The authors concluded that implementing such a traditional EQAS among diabetic patients may improve the analytical quality of SMBG and could be convenient for its participants. However, the group of patients included in the EQAS consisted of highly motivated volunteers responding to the announcement about the program in the *Journal of Norwegian Diabetes Association*, website, and pharmacies' information materials.

Wood[21] published the results of implementation of the EQAS for SMBG by the German Institute of Standardization and Documentation (INSTAND). The INSTAND program employed commercially available conserved whole blood control samples designed for the quality control of POCT devices, serum samples, and specific artificial control samples. The obtained results depended on the control material employed and were less favorable than the results of Kristensen and colleagues.[20] Imprecision CV across various glucose meters ranged from 2.2 to 12.9% for artificial control samples, 3.66 to 12.9% for plasma control samples, and 4.74 to 12.8% for conserved blood. The author concludes that, at present, EQA surveys are suitable for checking the imprecision of POCT glucose analyzers only.[21]

The clinical usefulness of quality control of SMBG is widely accepted and reflected in clinical recommendations.[22,23] Quality control will increase the cost of SMBG, but it could also decrease the overall costs of diabetes treatment, thereby making it more effective and safer by improving SMBG data. SMBG quality control as part of an outpatient clinic activity and traditionally organized EQAS based on control blood samples sent to glucose meter users can be considered as two alternative approaches. Further evaluation, including overall costs of these two models and outcome studies, is needed. The disadvantage of SMBG control employing EQAS is that patients perform control glucose tests on their own, without assistance of health care professionals, which is desired in case of patient's poor technical skill and the uncertainty about the meter's performance. Our two-step indirect mode of SMBG quality control under the supervision and assistance of health care professionals offers more reliable procedure. However, the growing availability of control materials for glucose meters favors using EQAS for SMBG and it may be used in nationwide evaluation studies, which are needed for outcome studies.

**References:**


1. American Diabetes Association Position Statement Standards of Medical Care in Diabetes–2006. Diabetes Care. 2006;29:S4-42.
2. Sacks DB, Bruns DE, Goldstein DE, Maclaren NK, McDonald JM, Parrott M. Guidelines and recommendations for laboratory analysis in the diagnosis and management of diabetes mellitus. Clin Chem. 2002 Mar;48(3):436-72.
3. American Diabetes Association. Consensus statement on self-monitoring of blood glucose. Diabetes Care. 1987;10:95-9.
4. American Diabetes Asociation. Self-monitoring of blood glucose. Diabetes Care. 1994;17:81-6.
5. International Organization for Standardization. In vitro diagnostic test systems–Requirements for blood glucose monitoring systems for self-testing in managing diabetes mellitus. ISO/FDIS 15197 2003.
6. Clarke WL, Cox D, Gonder-Frederick LA, Carter W, Pohl SL. Evaluating clinical accuracy of systems for self-monitoring of blood glucose. Diabetes Care. 1987 Sep-Oct;10(5):622-8.
7. Solnica B, Naskalski JW, Sieradzki J. The evaluation of analytical performance of the Precision G point-of-care glucometer. Clin Chem Lab Med. 2001 Dec;39(12):1283-6.
8. Solnica B, Naskalski JW, Sieradzki J. Analytical performance of glucometers used for routine glucose self-monitoring of diabetic patients. Clin Chim Acta. 2003 May;331(1-2):29-35.
9. Greffkin G, Winter WE. Hardware and software in diabetes mellitus: performance characteristics of hand-held glucose testing devices and the application of glycemic testing to patients' daily diabetes management. Clin Chem. 2001 Jan;47(1):11-2.
10. Skeie S, Thue G, Nerhus K, Sandberg S. Instruments for self-monitoring of blood glucose: comparisons of testing quality achieved by patients and a technician. Clin Chem. 2002 Jul;48(7):994-1003.
11. Singh Dhatt G, Agarwal M, Bishawi B. Evaluation of a glucose meter against analytical quality specifications for hospital use. Clin Chim Acta. 2004 May;343(1-2):217-21.
12. Hawkins RC. Evaluation of Roche Accu-Chek Go and Medisense Optium blood glucose meters. Clin Chim Acta. 2005 Mar;353(1-2):127-31.
13. Dai KS, Tai DY, Ho P, Chen CC, Peng WC, Chen ST, Hsu CC, Liu YP, Hsieh HC, Yang CC, Tsai MC, Mao SJ. Accuracy of the EasyTouch blood glucose self-monitoring system: a study of 516 cases. Clin Chim Acta. 2004 Nov;349(1-2):135-41.
14. Boyd JC, Bruns DE. Quality specifications for glucose meters: assessment by simulation modeling of errors in insulin dose. Clin Chem. 2001 Feb;47(2):209-14.
15. Skeie S, Thue G, Sandberg S. Patient-derived quality specifications for instruments used in self-monitoring of blood glucose. Clin Chem. 2001 Jan;47(1):67-73.
16. American Diabetes Association Position Statement. Diagnosis and classification of diabetes mellitus. 2004. Diabetes Care. 2006;29: S43-8.
17. Solnica B, Naskalski JW. Quality control of SMBG in clinical practice. Scand J Clin Lab Invest Suppl. 2005;240:80-5.
18. Lefevre G, Girardot-Dubois S, Chevallier G, Cohen C, Couderc R, Etienne J. Evaluation of the quality of blood glucose meters using the HemoCue B glucose system. Diabetes Metab. 1999 Sep;25(4):350-5.
19. International Federation of Clinical Chemistry and Laboratory Medicine, Scientific Division, Working Group on Selective Electrodes. IFCC recommendation on reporting results for blood glucose. Clin Chim Acta. 2001;307:205-9.
20. Kristensen GB, Nerhus K, Thue G, Sandberg S. Results and feasibility of an external quality assessment scheme for self-monitoring of blood glucose. Clin Chem. 2006 Jul;52(7):1311-7.
21. Wood WG. Problems with the external quality assessment of accuracy of point of care devices (POCD) for blood glucose are independent of sample composition. Clin Lab. 2006;52(7-8):345-51.
22. Guerci B, Drouin P, Grange V, Bougneres P, Fontaine P, Kerlan V, Passa P, Thivolet Ch, Vialettes B, Charbonnel B; ASIAGroup. Self-monitoring of blood glucose significantly improves metabolic control in patients with type 2 diabetes mellitus: the Auto-Surveillance Intervention Active (ASIA) study. Diabetes Metab. 2003 Dec;29(6):587-94.
23. Winter WE. A Rosetta stone for insulin treatment: self-monitoring of blood glucose. Clin Chem. 2004 Jun;50(6):985-7.