

Clinical Evaluation of Bionime Rightest GM310 Biosensors with a Simplified Electrode Fabrication for Alternative-Site Blood Glucose Tests

Ming-Hsun Wu,¹ Mei-Yen Fang,² Lin-Ni Jen,² Hung-Chan Hsiao,² Andreas Müller,³ and Cheng-Teng Hsu^{2*}

BACKGROUND: Most processes for fabricating biosensors applied to screen-printed carbon electrodes (SPCEs) are complex. This study presents a novel one-step process for manufacturing electrodes for injection-molding biosensors.

METHODS: During the sensor-fabrication process, barrel-plated gold electrodes were inserted into an injection-molded base. The electrode directly touched the electrical contact of a meter. We analyzed technical measurements for this biosensor, including tests of the measurement range, within-run imprecision, and between-meter imprecision. In clinical trials, experienced technicians tested 3 alternative sites (finger-tip, palm, and arm). The results were simultaneously compared with plasma values obtained with the hexokinase method on the Olympus AU640 instrument. Analytical results were evaluated according to International Standards Organization 15197 (ISO 15197:2003) criteria and by Clarke error grid analysis (EGA), and CVs were calculated to evaluate within-run imprecision.

RESULTS: The glucose measurement range was 0.6–33.3 mmol/L ($y = 0.96x + 0.07$ mmol/L; $r^2 = 0.9977$). The CVs in the within-run imprecision test were 1.7%–3.5%, and the overall CV was 2.1%, indicating good reproducibility of results. The Student *t*-tests of mean values from 5 meters revealed statistically insignificant differences ($P > 0.05$). In clinical trials, the agreement of the Rightest GM310 meter results with those of a laboratory method complied with ISO 15197:2003 criteria. In the EGA, 100% of the values were within the acceptable zones (A + B), and the proportion of values within zone A exceeded 95%.

CONCLUSIONS: The Bionime Rightest GM310 meter applied a simplified process for biosensor fabrication and displayed acceptable performance for monitoring glucose concentrations at alternative test sites.

© 2008 American Association for Clinical Chemistry

Meters for self-monitoring of blood glucose (SMBG)⁴ are indispensable home-use devices for effective control of glycemia levels by diabetes patients (1). Monitoring blood glucose concentrations requires a reliable and affordable measurement system, and many improvements have been made in the last few decades to enhance SMBG meter performance (2–8). These enhancements include an improved methodology, use of a redox mediator, and simplified processes for manufacturing electrodes. For instance, glucose dehydrogenases, such as quinoprotein glucose dehydrogenase, and flavoprotein glucose dehydrogenase, were introduced to improve the accuracy of glucose measurement and make it O₂-insensitive. Various screen-printed carbon electrodes (SPCEs) have been developed, and these electrodes have the advantages of simplicity, low cost, and the potential for mass production (9, 10). Major problems can still occur with SPCE techniques, however, as when polymers in the ink increase electron-transfer resistance, for example. In addition, inconsistency of the electrochemical area of SPCEs may produce imprecise measurements of blood glucose concentrations (4, 11).

Pretreating SPCEs can enhance the electrochemical properties of carbon electrodes, including electrochemical response, response time, cyclical voltammetric behavior, and mechanical stability (4, 12). Therefore, such processes as electroplating of copper (13) and sputtering of palladium and gold (11, 14)

¹ Department of Laboratory Medicine, Min-Sheng General Hospital, Taoyuan, Taiwan; ² Department of Core Technical Research, Bionime Corporation, Taichung, Taiwan; ³ IMCARMED GmbH, Saalfeld, Germany.

* Address correspondence to this author at: Department of Core Technical Research, Bionime Corporation, Taichung, Taiwan. Fax +886-4-24952568; e-mail brown.hsu@bionime.com.

Received March 12, 2008; accepted July 2, 2008.

Previously published online at DOI: 10.1373/clinchem.2008.106328

⁴ Nonstandard abbreviations: SMBG, self-monitoring of blood glucose; SPCE, screen-printed carbon electrode; ISO, International Standards Organization; EGA, error grid analysis.

have frequently been used to modify electrodes and thereby accelerate electron-transfer kinetics and reduce the potential required. Fabrication processes applied to most SPCE-based devices are extremely complex, however, and thus a simple process is required. This study investigated a novel technique for fabricating amperometric glucose biosensors that involved inserting barrel-plated gold electrodes into hollow holes in the injection-molded base, followed by immobilization of chemical reagents on a U-shaped furrow. This technique has the potential for producing manufacturing costs as low as those for the SPCE technique. Furthermore, gold particles generate large and specific areas that can immobilize most glucose oxidase molecules on the biosensing interface, and the excellent conductivity of gold accelerates electron transfer (14–16). This novel electrode-manufacturing technique for amperometric biosensors has been patented in the US (17).

Although commercially available glucose meters have been developed for alternative-site testing, the stability of measurements has been an ongoing topic of study in arm tests (18, 19). The aim of this study was to characterize and evaluate the clinical performance of the Bionime Rightest GM310 meter for alternative-site tests (e.g., fingertips, palms, and arms) with novel test strips fabricated by means of a one-step electrode-manufacturing process.

Materials and Methods

STUDY PARTICIPANTS

We enrolled 139 diabetic and nondiabetic patients in clinical trials at the outpatient clinic of Min-Sheng General Hospital (accredited by Joint Commission International), Taoyuan City, Taiwan. The clinical trial evaluated the performance of Bionime Rightest SMBG system GM310. The age range of the 139 volunteers (49 men and 90 women) was 21–84 years. The study participants were not necessarily users of Bionime Rightest meters. Informed consent was obtained from each participant, and the study protocol was reviewed and approved by the clinical trial committee of Min-Sheng General Hospital for experiments involving humans (MSEIRB Authority no. 951206).

BLOOD GLUCOSE METERS

This study used Rightest SMBG system GM310 (Bionime) and a new test strip. The meter used amperometric electrochemistry to measure capillary blood glucose concentrations. The meter required a 0.6- μ L blood sample and reported a venous plasma-equivalent glucose concentration in 5 s. The test strip was 40 mm long and 9 mm wide. The test strip consisted of

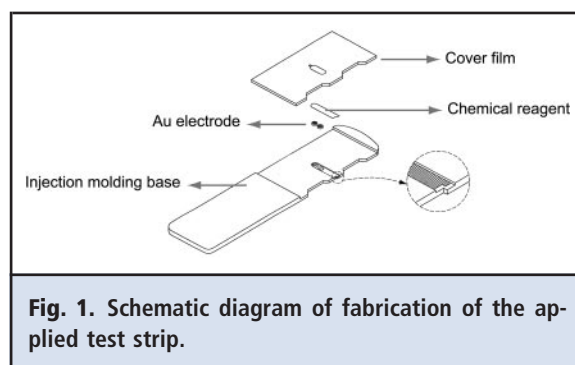


Fig. 1. Schematic diagram of fabrication of the applied test strip.

an injection-molded base, enzyme-modified gold-plated electrodes, chemical reagent, and a cover film (Fig. 1). The test strips were from the same batch (lot no. 1178062).

TEST PROCEDURES

The analytical measurement range was evaluated by assaying venous blood samples spiked with various glucose concentrations (range, 0.6–33.3 mmol/L) in heparin-containing tubes. Four replicates of each sample were tested with the meters. We centrifuged the samples, tested for the plasma glucose concentration in duplicate, and compared the results with those obtained with a glucose oxidase procedure on the YSI 2300 STAT Blood Glucose & Lactate Analyzer (Yellow Springs Instruments). Mean glucose values were calculated, and the meter results were plotted against the results obtained with the comparison method. We used 6 glucose concentrations (1.11–16.66 mmol/L) in venous blood samples with one meter to estimate within-run imprecision. The test procedure was designed on the basis of International Standards Organization (ISO) 15197:2003 criteria (20). In addition, we assessed between-meter imprecision with 5 meters; all meters measured the same venous blood sample (glucose concentration approximately 5 mmol/L) simultaneously in 10 replicates with the same batch of test strips. The imprecision in the mean values among the 5 meters was analyzed statistically with the paired Student *t*-test.

Supplementary Fig. 1 (see the Data Supplement that accompanies the online version of this article at <http://www.clinchem.org/content/vol54/issue10>) describes the clinical trial procedures. Trained technicians and nurses performed measurements according to the user manual with the meter at room temperature. Manufacturer-recommended methods were used to obtain blood samples from the fingertip, palm, and arm. We used the hexokinase method on an Olympus AU640 instrument (Olympus America) as a comparison method. The clinical trial was funded by Bionime Technology, Taiwan.

STATISTICAL AND CLINICAL ANALYSES

The clinical acceptability of the results obtained with the SMBG meter was evaluated by comparing them with those obtained with the Olympus AU640 method. We adopted 3 procedures for this analysis: (a) linear regression analysis, (b) Clarke error grid analysis (EGA), and (c) bias plots of accuracy criteria in accordance with ISO 15197:2003.

The EGA criteria specify that 95% of measurement results must fall in zone A and that 100% must fall in zones A plus B. The 5 zones in the EGA are based on their clinical acceptability. Measurements within zones A and B are clinically acceptable. Values in zone C lead to overcorrection of true glucose values. Values in zone D indicate the potential for dangerous treatments. Values in zone E may result in erroneous treatment. The EGA graph plots comparison-method values on the x axis and glucose values obtained with the meter on the y axis.

The primary objectives of the international standards (ISO 15197) are to establish requirements that result in acceptable performance. Performance criteria for blood glucose-monitoring systems were established on the basis of the accuracy (precision and trueness) required for individual glucose results. The accuracy determined by the degree of agreement between values obtained with blood glucose meters and laboratory plasma values was assessed further according to the criteria in ISO 15197:2003. The minimum acceptable performance for glucose-monitoring meters has been stipulated by ISO 15197:2003 (20): 95% of the individual glucose results must be within ± 0.83 mmol/L of the comparison-method results at glucose concentrations < 4.20 mmol/L and within $\pm 20\%$ of the comparison-method results at glucose concentrations ≥ 4.20 mmol/L.

Results

IMPRECISION TEST AND LINEARITY ANALYSIS

The Rightest GM310 method showed excellent linearity over the analytical measurement range of blood glucose concentrations (0.6–33.3 mmol/L), with the following meter results: $y = 0.96x + 0.07$ mmol/L; $r^2 = 0.9977$ (Fig. 2).

The imprecision results are shown in Table 1. Within-run CVs were 1.7%–3.5%, and the overall CV was 2.1%, excluding the SD value of 0.08 mmol/L for extra-low glucose concentrations (Table 1). For between-meter tests, differences in mean values were not statistically significant ($P > 0.05$, paired *t*-test). The maximum mean difference among the 5 meters was 0.08 mmol/L or a 1.6% variation (Table 1).

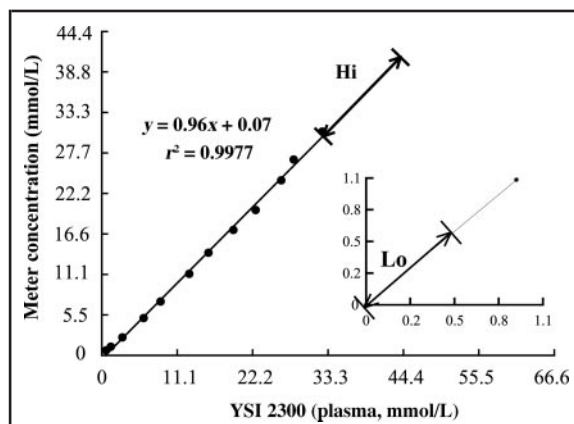


Fig. 2. The analytical range of glucose measurements obtained with Bionime Rightest GM310 glucose meters.

Plots of glucose values obtained with the meter vs plasma glucose values obtained with the YSI 2300 instrument. The meter displays the range of high values (Hi) in typical hyperglycemia (glucose > 33.33 mmol/L) and low values (Lo) in the hypoglycemia range (glucose < 0.60 mmol/L).

CLINICAL EVALUATION OF RIGHTEST BLOOD GLUCOSE-MONITORING SYSTEM GM310

The capillary blood glucose concentration was measured at the fingertip, the palm, and the arm. Within 5 min after values were obtained with the Rightest GM310, we drew a venous sample from the same individual, centrifuged the sample for 10 min, and analyzed it within 1 h at the Min-Sheng General Hospital

Table 1. CVs of imprecision tests.

	Mean, mmol/L	SD, mmol/L	CV, %
Within-run			
Extra-low (n = 20)	1.34	0.08	
Level I (n = 20)	2.32	0.08	3.5
Level II (n = 20)	4.55	0.10	2.4
Level III (n = 20)	8.31	0.15	1.8
Level IV (n = 20)	10.61	0.18	1.7
Level V (n = 20)	18.36	0.34	1.9
Total	8.83	0.19	2.1
Between-meter			
Meter A (n = 10)	5.02	0.08	1.6
Meter B (n = 10)	4.99	0.08	1.7
Meter C (n = 10)	5.07	0.09	1.8
Meter D (n = 10)	5.01	0.07	1.6
Meter E (n = 10)	5.03	0.08	1.7

Table 2. Comparison of blood glucose values obtained within the defined criteria for the laboratory method and for the Rightest GM310 method at the 3 alternative measurement sites.

Alternative site	Blood glucose measurements within the defined criteria (N = 139), n ^a							Values within measurement criteria, % ^b
	Difference (<4.20 mmol/L, n ₁ = 26)			Difference (≥4.20 mmol/L, n ₂ = 113)				
	≤0.27 mmol/L	≤0.55 mmol/L	≤0.83 mmol/L	≤5%	≤10%	≤15%	≤20%	
Finger	18	24	26	55	84	103	110	97.8
Palm	23	26	26	57	91	108	110	97.8
Arm	21	26	26	44	74	92	108	96.4

^a Defined criteria are blood glucose concentrations <4.20 mmol/L and ≥4.20 mmol/L.

^b Criteria of ISO 15197:2003.

^a Defined criteria are blood glucose concentrations <4.20 mmol/L and ≥4.20 mmol/L.

^b Criteria of ISO 15197:2003.

with an Olympus AU640 chemistry analyzer. Supplementary Fig. 1 in the online Data Supplement shows the flow chart of this clinical trial.

The range of blood glucose concentrations for the 139 study participants was 1.6–26.7 mmol/L, and hematocrits met the manufacturer's criteria (30%–55%). The agreement between the Rightest GM310 results and the comparison-method results (Olympus AU640) was clinically satisfactory (Table 2; Fig. 3).

In addition to fingertip tests, this study measured values from palm and arm sites. Although 139 measurements from the participants' arms produced 5 results that failed to fall within the ±20% interval of reference values, the agreement of the values for the Rightest GM310 and the comparison method was clinically acceptable.

An evaluation of subsets of measurements for the 3 alternative sites for the comparison interval of <4.20 mmol/L showed that 26 of 26 values were within the ±0.83-mmol/L interval of comparison values specified by ISO 15197:2003. For the comparison interval of ≥4.20 mmol/L, 110, 110, and 108 of 113 values fell within the ±20% interval of comparison values for the finger, palm, and arm tests, respectively, as specified by the ISO 15197:2003 criteria (Table 2). Thus, the ISO 15197:2003 requirements for SMBG meters were met. Fig. 4 shows the correlation coefficients for the comparison between the Rightest GM310 test and the comparison method for the 3 alternative sites. For the fingertip test (n = 139), $y = 0.99x - 0.08$ mmol/L, $r = 0.989$, and the SD of the residuals ($S_{y|x}$) = 0.90 mmol/L. For the palm test (n = 139), $y = 0.98x + 0.14$ mmol/L, $r = 0.990$, and $S_{y|x} = 0.85$ mmol/L. For the arm test (n = 139), $y = 0.97x - 0.21$ mmol/L, $r = 0.990$, and $S_{y|x} = 0.85$ mmol/L.

EGA results for the fingertip test (Fig. 4A) were within acceptable zone A in 97.8% of the cases. In the palm and arm tests, 100% of the values were within zones A plus B (97.8% and 96.4%, respectively, within

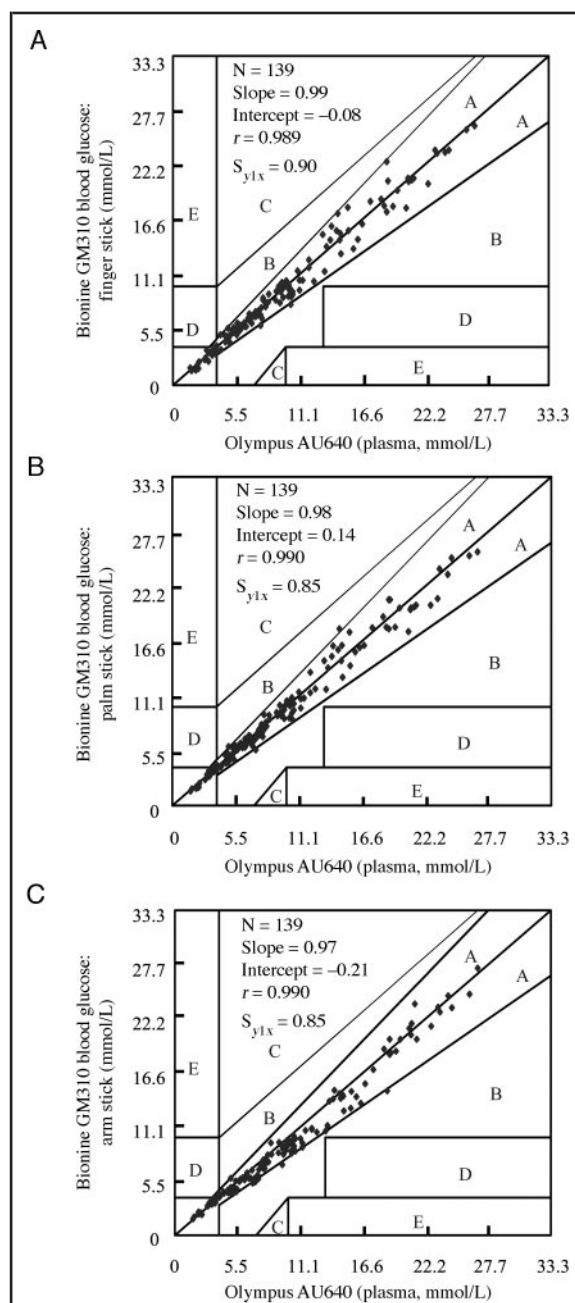
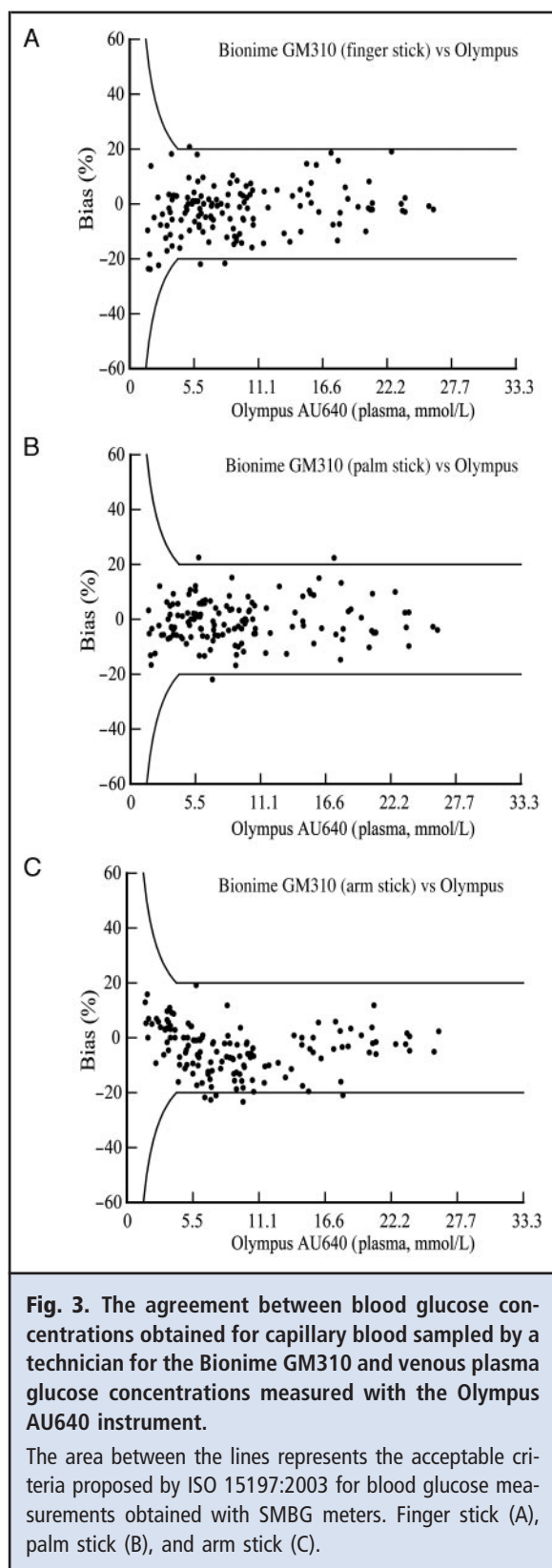
zone A; 2.2% and 3.6% within zone B; Fig. 4, B and C). The EGA results demonstrate that Rightest SMBG meter GM310 was clinically acceptable for use with alternative test sites.

Discussion

In this study, within-run imprecision tests demonstrated that the mean CV of the Bionime Rightest GM310 meter was 2.1%. Commercially available meters that apply the SPCE technique have CVs in the range of 3%–6% (21–23). The imprecision of glucose meter measurements has been attributed to inconsistency in the electrochemical response area (11). In the present study, efficient control of the electrochemical area seemed to effectively improve the imprecision. Additionally, gold electrodeposition during electrode manufacturing has better precision than the sputtering process because of the former's electrochemical reproducibility (11). We suggest that the superior precision of the GM310 may be attributed to its simplified fabrication technique (24).

The EGA results showed that 100% of the values fell within clinically acceptable zones A and B, suggesting that results obtained in alternative-site tests with the Rightest GM310 meter are clinically acceptable. According to ISO 15197:2003 criteria, the Bionime Rightest GM310 has met the requirements of SMBG systems for testing at alternative sites (fingertip, palm, and arm).

More than 50% of the values generated with the Bionime Rightest GM310 meet the alternative-site test criteria of the American Diabetes Association, which recommends that 100% of the values fall within the ±5% interval of comparison-method values (25, 26). Currently, only 15%–50% of values of most commercially available glucose meters meet this criterion (7, 22, 23, 26–28), and the performance of the Rightest meter is consistent with that of other meters.



Several complicating methodologic factors should be considered when a comparison method is used. The glucose concentration of capillary whole blood is lower than that of venous plasma (29). This difference is partly attributable to the hematocrit, or a fasting vs non-fasting state. One potential limitation of the performance of the Rightest GM310 is the hematocrit in a blood sample. Many studies have concluded that variation in the hematocrit significantly reduces the accuracy of SMBG measurements. A high hematocrit is associated with underestimation, whereas a low hematocrit causes overestimation of glucose concentrations (30–32). Therefore, hematocrits may constitute a significant clinical risk in evaluating the hypoglycemia symptoms that are encountered in the up to 20% of the neonatal population that commonly has high hematocrits (33, 34). We analyzed the effect of hematocrits in this clinical trial and obtained results similar to those of prior hematocrit studies. Fig. 2 in the online Data Supplement shows the effect of the hematocrit on glucose measurement.

In summary, the Bionime Rightest GM310 complies with ISO 15197:2003 criteria and produces acceptable glucose results for alternative test sites (finger-tip, palm, or arm) that are generally equivalent.

Author Contributions: *All authors confirmed they have contributed to the intellectual content of this paper and have met the following 3 requirements: (a) significant contributions to the conception and design, acquisition of data, or analysis and interpretation of data; (b) drafting*

or revising the article for intellectual content; and (c) final approval of the published article.

Authors' Disclosures of Potential Conflicts of Interest: *Upon submission, all authors completed the Disclosures of Potential Conflict of Interest form. Potential conflicts of interest:*

Employment or Leadership: Ming-Hsun Wu, Min-Sheng General Hospital, Taiwan; Mei-Yen Fang, Bionime Corporation; Lin-Ni Jen, Bionime Corporation; Hung-Chan Hsiao, Bionime Corporation; Andreas Muller, IMCARMED GmbH; Cheng-Teng Hsu, Bionime Corporation.

Consultant or Advisory Role: None declared.

Stock Ownership: None declared.

Honoraria: None declared.

Research Funding: This study was supported by an educational grant from the Bionime Corporation, Taiwan. The evaluation study received cooperation from the Min-Sheng General Hospital, Taiwan.

Expert Testimony: None declared.

Role of Sponsor: The funding organizations played no role in the design of study, choice of enrolled patients, review and interpretation of data, or preparation or approval of manuscript.

Acknowledgments: We would like to thank Ms. Tonia Hsiao for her helpful suggestions and the scientific skills provided by IMCARMED GmbH-Med.-Wiss. Abt., Germany. Additionally, we also appreciated Prof. Ted Knoy for his editorial assistance.

References

1. Self-monitoring of blood glucose. American Diabetes Association. *Diabetes Care* 1994;17:81–6.
2. Ricci F, Palleischi G. Sensor and biosensor preparation, optimisation and applications of Prussian Blue modified electrodes. *Biosens Bioelectron* 2005;21:389–407.
3. Bohme P, Floriot M, Sirveaux MA, Durain D, Ziegler O, Drouin P, Guerci B. Evolution of analytical performance in portable glucose meters in the last decade. *Diabetes Care* 2003;26:1170–5.
4. Wei H, Sun JJ, Xie Y, Lin CG, Wang YM, Yin WH, Chen GN. Enhanced electrochemical performance at screen-printed carbon electrodes by a new pretreating procedure. *Anal Chim Acta* 2007;588:297–303.
5. Kondepati VR, Heise HM. Recent progress in analytical instrumentation for glycemic control in diabetic and critically ill patients. *Anal Bioanal Chem* 2007;388:545–63.
6. Mehrvar M, Abdi M. Recent developments, characteristics, and potential applications of electrochemical biosensors. *Anal Sci* 2004;20:1113–26.
7. Weitgasser R, Gappmayer B, Pichler M. Newer portable glucose meters—analytical improvement compared with previous generation devices? *Clin Chem* 1999;45:1821–5.
8. D'Orazio P. Biosensors in clinical chemistry. *Clin Chim Acta* 2003;334:41–69.
9. Marquette CA, Lawrence MF, Blum LJ. DNA covalent immobilization onto screen-printed electrode networks for direct label-free hybridization detection of p53 sequences. *Anal Chem* 2006;78:959–64.
10. Wang J, Chen Q, Pedrero M, Pingarron JM. Screen-printed amperometric biosensors for glucose and alcohols based on ruthenium-dispersed carbon inks. *Anal Chim Acta* 1995;300:111–6.
11. Lee CH, Wang SC, Yuan CJ, Wen MF, Chang KS. Comparison of amperometric biosensors fabricated by palladium sputtering, palladium electrodeposition and Nafion/carbon nanotube casting on screen-printed carbon electrodes. *Biosens Bioelectron* 2007;22:877–84.
12. Cabaniss GE, Diamantis AA, Murphy WR Jr, Linton RW, Meyer TJ. Electrocatalysis of proton-coupled electron-transfer reactions at glassy carbon electrodes. *J Am Chem Soc* 1985;107:1845–53.
13. Zen JM, Song YS, Chung HH, Hsu CT, Kumar AS. Photoelectrochemical oxygen sensor using copper-plated screen-printed carbon electrodes. *Anal Chem* 2002;74:6126–30.
14. Zhang S, Wang N, Yu H, Niu Y, Sun C. Covalent attachment of glucose oxidase to an Au electrode modified with gold nanoparticles for use as glucose biosensor. *Bioelectrochemistry* 2005;67:15–22.
15. Li CX, Deng KQ, Shen GL, Yu RQ. Amperometric hydrogen peroxide biosensor based on horseradish peroxidase-labeled nano-Au colloids immobilized on poly(2,6-pyridinedicarboxylic acid) layer by cysteamine. *Anal Sci* 2004;20:1277–81.
16. Wu BY, Hou SH, Yin F, Li J, Zhao ZX, Huang JD, Chen Q. Amperometric glucose biosensor based on layer-by-layer assembly of multilayer films composed of chitosan, gold nanoparticles and glucose oxidase modified Pt electrode. *Biosens Bioelectron* 2007;22:838–44.
17. Huang CM, inventor. Structure and manufacturing method of disposable electrochemical sensor strip. US patent 7 063 776 B2. 2006 Jun 20.
18. Beregszaszi M, Tubiana-Rufi N, Benali K, Noel M, Bloch J, Czernichow P. Nocturnal hypoglycemia in children and adolescents with insulin-dependent diabetes mellitus: prevalence and risk factors. *J Pediatr* 1997;131:27–33.
19. Jungheim K, Koschinsky T. Glucose monitoring at the arm: risky delays of hypoglycemia and hyperglycemia detection. *Diabetes Care* 2002;25:956–60.

20. International Organization for Standardization. In-vitro diagnostic test systems-requirements for blood-glucose monitoring systems for self-testing in managing diabetes mellitus. ISO 15197. Geneva, Switzerland. ISO 15197:2003.
21. Chen HS, Kuo BI, Hwu CM, Shih KC, Kwok CF, Ho LT. Technical and clinical evaluation of an electrochemistry glucose meter: experience in a diabetes center. *Diabetes Res Clin Pract* 1998;42:9–15.
22. Dai KS, Tai DY, Ho P, Chen CC, Peng WC, Chen ST, et al. Accuracy of the EasyTouch blood glucose self-monitoring system: a study of 516 cases. *Clin Chim Acta* 2004;349:135–41.
23. Rivers SM, Kane MP, Bakst G, Busch RS, Hamilton RA. Precision and accuracy of two blood glucose meters: FreeStyle Flash versus One Touch Ultra. *Am J Health Syst Pharm* 2006;63:1411–6.
24. Crouch E, Cowell DC, Hoskins S, Pittson RW, Hart JP. A novel, disposable, screen-printed amperometric biosensor for glucose in serum fabricated using a water-based carbon ink. *Biosens Bioelectron* 2005;21:712–8.
25. American Diabetes Association. Consensus statement on self-monitoring of blood glucose. *Diabetes Care* 1996;19:S62–6.
26. Brunner GA, Ellmerer M, Sendhofer G, Wutte A, Trajanoski Z, Schaupp L, et al. Validation of home blood glucose meters with respect to clinical and analytical approaches. *Diabetes Care* 1998;21:585–90.
27. Rheney CC, Kirk JK. Performance of three blood glucose meters. *Ann Pharmacother* 2000;34:317–21.
28. Solnica B, Naskalski JW. Quality control of SMBG in clinical practice. *Scand J Clin Lab Invest Suppl* 2005;240:80–5.
29. Maley TC, D'Orazio P. Biosensors for blood glucose: a new question of what is measured and what should be reported. *Clin Lab* 1995;21:12–3.
30. Tang Z, Lee JH, Louie RF, Kost GJ. Effects of different hematocrit levels on glucose measurements with handheld meters for point-of-care testing. *Arch Pathol Lab Med* 2000;124:1135–40.
31. Rao LV, Jakubiak F, Sidwell JS, Winkelman JW, Snyder ML. Accuracy evaluation of a new glucometer with automated hematocrit measurement and correction. *Clin Chim Acta* 2005;356:178–83.
32. Karon BS, Griesmann L, Scott R, Bryant SC, Dubois JA, Shirey TL, et al. Evaluation of the impact of hematocrit and other interference on the accuracy of hospital-based glucose meters. *Diabetes Technol Ther* 2008;10:111–20.
33. Halamek LP, Benaron DA, Stevenson DK. Neonatal hypoglycemia, part I: background and definition. *Clin Pediatr (Phila)* 1997;36:675–80.
34. Deshpande S, Ward PM. The investigation and management of neonatal hypoglycaemia. *Semin Fetal Neonatal Med* 2005;10:351–61.