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Original Article

A prospective study of blood glucose detection using arterial blood gas analysis and peripheral glucometry after cardiac surgery with cardiopulmonary bypass: accuracy and influences

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Abstract: The objectives of this study were to evaluate the accuracy of blood glucose measurements and to analyze the clinicopathological and experimental factors affecting the accuracy of blood glucose measurement devices. The study enrolled 172 patients who underwent cardiac surgery with cardiopulmonary bypass. Arterial, peripheral, and venous blood samples were collected simultaneously every hour to 10 hours after surgery. The arterial, peripheral, and venous blood glucose levels were detected by using an arterial blood gas analyzer, blood glucose monitoring system, and laboratory-based automatic biochemistry analyzer, respectively. We determined that blood glucose levels increased after surgery, peaked at postoperative 6 hours, and then decreased to levels similar to those measured at 2 hours after the surgery. Unacceptable error rates of the glucose meter were significantly greater than error rates of the blood gas analyzer at all time points. Clinical factors influencing the measurement of the arterial blood glucose level included the venous blood glucose level and hematocrit. In conclusion, our results indicate that exclusive use of peripheral glucometry for patients recovering from cardiac surgery with cardiopulmonary bypass may lead to inaccurate measurement of blood glucose. Furthermore, perioperative glycemic control should take a patient's unique clinical characteristics into account.

Keywords: Arterial blood glucose, blood gas analysis, cardiac surgery, cardiopulmonary bypass, glucose meter, peripheral blood glucose, point-of-care

Introduction

Cardiopulmonary bypass (CPB) is a form of extracorporeal circulation in which the venous blood is pumped out of the body and transfused back into the body after *in vitro* oxygenation. In this way, blood circulation can be maintained while bypassing the heart and lungs. Hyperglycemia occurs frequently after CPB surgery due to the influence of factors such as anesthesia, surgical trauma, hypotension, nonpulsatile perfusion, or blood dilution [1, 2]. These factors induce metabolic stress, a state that involves altered secretion of cytokines and hormones and results in insulin resistance [3]. In patients undergoing CPB, hyperglycemia is harmful to the heart due to factors such as altered coagulation, inflammation, and nitric oxide signaling [3]. Hyperglycemia also increases the risk of cardiac and non-cardiac complications such as arrhythmias, cerebral edema, disruption of the blood-brain barrier, and mediastinitis [4]. Accordingly, several studies have demonstrated that perioperative hyperglycemia is associated with increased mortality and surgical complications [5-7].

While hyperglycemia is a poor predictor of outcome, hypoglycemia can also be problematic, as it has been associated with an increased risk of complications, such as myocardial infarction and stroke, after cardiac surgery [5, 8]. For this reason, timely and precise control of blood glucose levels is crucial in the postsurgical period. Intensive insulin therapy (IIT) can maintain a patient's blood glucose level within a normal range (4.44-6.11 mmol/L) and significantly decrease the complication rates and mortality of critically ill patients in a surgical intensive care unit (SICU) [9, 10]. Insulin therapy requires accurate assessment of blood glucose levels; therefore, inaccurate measurement may cause medical staff to make incorrect adjustments to the real-time insulin dosage. Such mistakes can aggravate disease because of the development of hypo- or hyperglycemia.

Blood glucose monitoring methods commonly used after CPB surgery in the ICU include laboratory-based detection of glucose in venous blood, peripheral blood glucose detection with a glucose meter, and arterial blood glucose detection by a blood gas analyzer (BGA). These 3 methods have their own advantages and disadvantages: detection of venous blood glucose via biochemical analysis is a well established procedure that produces accurate and reliable results, and it can be used as a reference for evaluating the results of other methods. However, biochemical analysis is time-consuming, expensive, and must be performed by trained personnel. Therefore, it is not suitable for routine postoperative blood glucose monitoring in the ICU. Glucose meters and BGAs can be used at the bedside or in the ICU, respectively, and both have shorter turnaround times and lower costs than does laboratory-based measurement [11]. The advantages of these devices must be balanced against their accuracy, which can be affected not only by clinical features but also by aspects of sample collection [12-14]. Although glucose meters are thought to be less accurate than other methods, the published studies enrolled a general population of critically ill patients [15, 16]. Specific data are lacking on the comparative accuracy of these devices in patients undergoing cardiac surgery and CPB.

In this prospective, single center, single arm, comparative study, we collected blood samples from 3 different origins (venous, arterial, and peripheral) and measured the blood glucose levels up to 10 hours after CPB surgery by using laboratory assessment, a BGA, and a glucose meter, respectively. Our objectives were first, to compare the accuracy of blood glucose detection by arterial blood gas analysis and peripheral glucometry with that of laboratory-based measurements; and second, to analyze the factors affecting the accuracy of blood glucose monitoring in patients undergoing CPB. Our results will help health care professionals to improve perioperative glycemic control in this group of patients.

Materials and methods

Patients and procedures

This was a prospective study that was approved by the institutional review board of the Fujian Provincial Hospital. The study enrolled patients who underwent CPB surgery and were admitted to the ICU of the Fujian Provincial Hospital between January 2013 and November 2013. The inclusion criteria were as follows: (1) The patient must have undergone elective cardiac surgery and stayed in the SICU after surgery; (2) The patient must have had cardiac surgery with CPB; and (3) The patient was an adult aged 18 years or older. Informed consent was obtained from all of the patients. Exclusion criteria were as follows: (1) The patient underwent emergency surgery or surgery for reasons other than congenital or rheumatic heart disease; (2) Collecting the arterial and peripheral blood samples took more than 5 minutes; and (3) The patient received continuous renal replacement therapy during autologous blood transfusion, as this clinical factor could have affected the accuracy of arterial blood glucose detection. The following data were collected from the patients' medical records: demographic data including age, gender, and type of surgery; and clinical data including underlying diseases, degree of disease severity (Acute Physiology and Chronic Health Evaluation [APACHE] II score), presence of a peripheral skin condition such as piebaldism or cyanosis, vital signs (temperature, mean arterial pressure), activated clotting time (ACT), and use of related drugs (insulin, glucose, or vasoactive drugs).

For all patients, cardioplegia was accomplished by using a chilled crystalloid solution that did not contain steroids. Standard procedure for CPB was to maintain blood glucose at 6.2-8.3 mmol/L. Following surgery, patients were monitored in the Department of Intensive Care. When hyperglycemia was present, insulin was transfused via a micropump; oral glucose-lowering drugs were not used. When the blood glucose level was ≥10.0 mmol/L, 50 ml of normal saline was mixed with 50 U of insulin (regular insulin; RI) and transfused at a rate of 4 ml/h. The dose of RI was adjusted as follows: when the reduction in blood glucose was >4 mmol/L, the infusion rate was reduced by 2 U/h; when the reduction was 2.1-4 mmol/L, it was reduced by 1 U/h; when the reduction was 1-2 mmol/L, or the increase in blood glucose was <2 mmol/L, the rate was kept stable; when the reduction was <1 mmol/L, the rate was increased by 1 U/h; and when the increase was 2.1-4 mmol/L, the rate was increased by 2 U/h. In the perioperative period, blood glucose was controlled at ≤10 mmol/L. Glycated hemoglobin was not routinely monitored during this study.

Sample collection and measurement of blood glucose levels

The arterial, peripheral (by finger stick), and venous blood samples were collected simultaneously at 1, 2, 4, 6, 8, and 10 hours after cardiac surgery with CPB in the ICU. The blood glucose level was measured by using the BXY4-GEM3000 blood gas analyzer (IL Company, MA, USA) for arterial blood, the One Touch UltraVue blood glucose monitoring system (Johnson & Johnson, NJ, USA) for peripheral blood, and an automatic biochemistry analyzer (Thermo Fisher Scientific, MA, USA) for venous blood. The blood glucose levels and blood gas values were determined at the time points mentioned above. The venous blood glucose values measured with the biochemistry analyzer was used as the standard control. The accuracies of the arterial and peripheral measurements were evaluated and the factors influencing the accuracy of the BGA and the glucose meter were determined. The blood collection and glucose measurement procedures were conducted by appointed study personnel.

Standards for measurement error

The International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) recommends that the error rate be limited to <20% of the reference value for glucose levels >75 mg/dL; for glucose levels that are ≤75 mg/dl, error should be controlled within 15 mg/dL of the reference among 95% of readings [17].

Statistical analysis

Data analyses were carried out by using SPSS 20.0 (IBM PASW, IL, USA). All statistical tests were 2-tailed and a *P* value <0.05 was considered statistically significant. The significant value was adjusted to 0.008 when differences between venous blood glucose (VBG) and arterial blood glucose (ABG) (or peripheral blood glucose [PBG]) at various time points were examined. Mean and standard deviation (SD) were calculated for age, median and interquartile range were calculated for blood glucose (i.e. venous, peripheral and arterial) levels, and count and percentages were calculated for categorical variables including gender, medical history, type of operation, and measurement error. McNemar's test was used to test whether the error rates of measuring ABG and PBG was comparable. The Wilcoxon signed rank test was performed to test the difference between VBG and ABG (or PBG) at all time points. A linear mixed model based on log10-transformed data was implemented to analyze differences in blood glucose levels derived from each type of measurement over time. A generalized estimating equation (GEE) was also performed to examine the factors that effected measurement error in the level of ABG and PBG. Clinical and demographic factors that had a *P* value <0.05 in the univariate GEE were considered to be significant paramonitoring systems and were then included in the multivariate equation; age and gender were also included in the final model regardless of the significance of the result in the univariate analysis. We also compared the 'Quasi Likelihood under Independence Model Criterion' (QIC) of the final model and an intercept-only model. With this type of assessment, a smaller QIC indicates a better model.

Results

Patient demographics

At the start of this study, 200 patients were screened and initially enrolled. However, 4 patients died during the study, and 13 withdrew consent. In addition, a change in the enrollment criteria led us to withdraw one 3-year-old child, 2 patients who received surgery for patent ductus arteriosus, and 8 patients who underwent resection of a left atrial myxoma. Therefore, a total of 172 patients were included in the analysis. Demographic and clinical characteristics of the patients are summarized in **Table 1**. Half of the patients were women. The majority of patients (68.02%) required surgery because of rheumatic heart disease, and 34% of patients had a history of previous heart disease. At the

Table 1. Baseline characteristics of the patients enrolled in this study

Characteristic n = 172	Mean ± SD (range)/ count (%)
Age, years	50.19 ± 13.15 (18-79)
Gender	
Men	85 (49.42)
Women	87 (50.58)
Medical history	
Heart disease	58 (33.72)
Diabetes	8 (4.65)
Hypertension	7 (4.07)
Surgery[1,2]	
For congenital heart disease	28 (16.28)
For rheumatic heart disease	117 (68.02)
Bentall procedure	7 (4.07)
For coronary artery bypass graft	20 (11.63)

Abbreviations: SD, standard deviation. [1]Operations for congenital heart disease include atrial septal defect, ventricular septal defect, and Tetralogy of Fallot; operations for rheumatic heart disease include aortic valve replacement, double valve replacement, mitral valvuloplasty, and tricuspid valvuloplasty. [2]Some patients received at least 2 procedures at the same time.

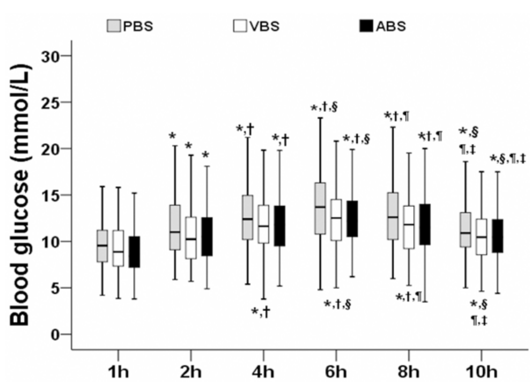

Figure 1. Temporal trends in blood glucose levels of postsurgical CPB patients. The blood glucose levels (y-axis) were measured hourly for 10 hours (x-axis) after surgery. The Box plots illustrate the median (solid line in the middle of each box), P_{25} (the bottom of the box), and P_{75} (the top of the box). Lines extending from the box indicate the minimum and maximum observed values. A linear mixed model based on log10-transformed data was implemented to test the effects of time on each type of blood glucose measurement and the effects of the type of blood glucose measurement (both $P<0.001$). *Indicates significantly different from 1 h, $P<0.05$. †indicates significantly different from 2 h, $P<0.05$. §Indicates significantly different from 4 h, $P<0.05$. ¶Indicates significantly different from 6 h, $P<0.05$. ‡Indicates significantly different from 8 h, $P<0.05$. Abbreviations: ABG = arterial blood glucose; CPB = cardiopulmonary bypass; h, hour; PBG = peripheral blood glucose; VBG = venous blood glucose.

time of enrollment, a small percentage of patients (8.72%) had diabetes or hypertension.

Assessment of blood glucose

The blood glucose levels measured by each device at the 6 time points of the study are illustrated in **Figure 1**. All 3 measurements showed a similar trend: the blood glucose level increased from 1 hour after surgery, peaked at 6 hours, then decreased by 10 hours to levels similar to those measured 2 hours after the operation. Despite similar temporal patterns, the level of venous blood glucose (VBG) differed slightly from ABG and substantially from PBG. The mean differences between VBG measurements and those of ABG and PBG are summarized in **Table 2**. At all time points examined, VBG values >75 mg/dL were lower than PBG values, but we did not observe a clear trend for differences between VBG and ABG. The small number of patients with VBG <75 mg/dL or VBG = 75 mg/dL did not allow a comparison of blood glucose measurements for these patients.

Accuracy of blood glucose measurement

To assess the comparative accuracy of ABG and PBG measurements, we determined the number and percentage of patients whose blood glucose level fell outside of the acceptable range established by measuring VBG, the standard control (see Methods). The error rates for both devices are reported in **Table 3**. The unacceptable error rate of ABG was substantially and significantly lower than that of PBG at all time points examined, and for all time points but 1 hour, the error rate of PBG was at least 2-fold more than that of ABG.

Factors associated with measurement error

To gain more information about the variability associated with determining blood glucose, we used statistical methods to determine which clinical or demographic factors could influence the measurement devices' error rates. Univariate analysis of ABG determined that the level of VBG and hematocrit (HCT) were related to the measurement error (**Table 4**). Moreover, the influence of these 2 factors remained statistically significant in a multivariate analysis

Table 2. Differences between blood glucose levels measured by a biochemistry analyzer, blood gas analyzer, or glucose meter

Difference	Time of sample	VBG ≤75 mg/dL			VBG >75 mg/dL			
		Patients, n	Value of VBG	Range	Patients, n	Mean ± SD	Range	*P*
ABG-VBG	1 h	1	33.1	33.1	171	-5.4 ± 32.3	-131.4~159.8	0.169
	2 h	0			172	2.2 ± 29.9	-106~140.8	0.205
	4 h	1	25.4	25.4	171	-1.1 ± 35	-198.5~89.6	0.206
	6 h	0			170	1.1 ± 33.3	-129.6~124.9	0.151
	8 h	1	1.8	1.8	171	-0.1 ± 33.3	-195.5~87.1	0.077
	10 h	0			171	-0.1 ± 30.7	-191~110.7	0.112
PBG-VBG	1 h	1	81.7	81.7	171	11.3 ± 36.1	-128.2~165.2	<0.001*
	2 h	0			172	16.3 ± 41.1	-158.4~154.4	<0.001*
	4 h	1	29	29	171	18.5 ± 44.5	-180~136.1	<0.001*
	6 h	0			170	20.1 ± 44.6	-194.4~150.3	<0.001*
	8 h	1	70.2	70.2	171	19.2 ± 39.8	-190.8~149	<0.001*
	10 h	0			171	9.9 ± 41.2	-178.4~91.8	<0.001*

Abbreviations: ABG, arterial blood glucose; h, hour; PBG, peripheral blood glucose; SD, standard deviation; VBG, venous blood glucose. *Indicates significant difference (P<0.008) between VBG and either ABG or PBG; *P* values derived from the Wilcoxon signed rank test.

Table 3. Error rates of arterial and peripheral blood glucose measurement at each time point

Time	Arterial blood glucose[1]		Peripheral blood glucose[1]		*P*
	Acceptable Error n (%)	Unacceptable Error n (%)	Acceptable Error n (%)	Unacceptable Error n (%)	
1 h	140 (81.4)	32 (18.6)	116 (67.4)	56 (32.6)	0.001*
2 h	148 (86)	24 (14.0)	108 (62.8)	64 (37.2)	<0.001*
4 h	144 (83.7)	28 (16.3)	112 (65.1)	60 (34.9)	<0.001*
6 h	146 (85.9)	24 (14.1)	112 (65.9)	58 (34.1)	<0.001*
8 h	151 (87.8)	21 (12.2)	123 (71.5)	49 (28.5)	<0.001*
10 h	152 (88.9)	19 (11.1)	116 (67.8)	55 (32.2)	<0.001*

Abbreviations: h, hour. [1]n = 172 for all time points but 6 h and 10 h; n = 170 for 6 h and n = 171 for 10 h. *Indicates significant difference (P<0.05) in error rate between ABG and PBG; *P* values derived from the McNemar's test.

that also included age and gender. A lower risk of measurement error was found for patients with hyperglycemia than for those with a normal level of blood glucose. HCT >40% was a risk factor for error relative to HCT <40%. Upon comparing the 'Quasi Likelihood under Independence Model Criterion' (QIC) of the final model to an intercept-only (null) model, we found a significant change in the QIC (difference = -20.319, P = 0.002). The smaller QIC indicates that the associations are robust. Univariate analysis of PBG revealed that hyperglycemia was the only factor that influenced error rate; therefore, no multivariate analysis was conducted for this outcome (**Table 5**). As with ABG, the risk of error for measurement of PBG was lower for patients with hyperglycemia. For both ABG and PBG, the time at which the samples were collected and the gender of the patients had no influence on the rates of measurement error.

Discussion

In this prospective study, we examined the comparative accuracy of peripheral glucometry and arterial BGA for measurement of postoperative glucose in patients who underwent CPB. To our knowledge, this study is one of only a few prospective comparisons of a blood gas analyzer and a glucose meter that enrolled patients undergoing CPB [15, 18-20]. Additionally, ours is the largest study to date. Our results indicate that both techniques perform similarly to the standard control in detecting the time at which glucose levels peaked after surgery. While levels of ABG measured by BGA were similar to those of the standard control, levels of PBG detected with a glucose meter were substantially higher at all time points. Moreover, the error rates of the glucose meter were significantly higher than

Table 4. Effectors of error in measurement of arterial blood glucose

n = 172	Crude OR (95% CI)	P^1	$OR_{adjusted}$ (95% CI)	P^1
Age, years				
<45	Reference		Reference	
45-57	1.15 (0.68, 1.94)	0.600	1.22 (0.72, 2.06)	0.466
>57	0.65 (0.39, 1.08)	0.098	0.68 (0.4, 1.17)	0.163
Female	0.69 (1.05, 0.45)	0.080	0.68 (0.44, 1.03)	0.071
Level of venous blood glucose[2]				
Hypoglycemia	8 (0.71, 89.89)	0.092	7.91 (0.68, 92.3)	0.099
Normal	Reference		Reference	
Hyperglycemia	0.58 (0.38, 0.89)	0.013*	0.58 (0.37, 0.90)	0.014*
Vasoactive drug use	1.22 (0.72, 2.05)	0.462		
Abnormal fingertip temperature[3]	0.95 (0.53, 1.73)	0.877		
APACHE II score >10	0.72 (0.41, 1.26)	0.252		
Lactic acid >2 mmol/L	1.11 (0.61, 2)	0.731		
Po_2, mmHg				
<80	1.49 (0.47, 4.69)	0.499		
80-100	Reference			
>100	1.98 (0.95, 4.12)	0.067		
Pco_2, mmHg				
<35	1.36 (0.91, 2.04)	0.135		
35-45	Reference			
>45	0.52 (0.25, 1.12)	0.094		
HCT >40%	2.99 (1.22, 7.31)	0.016*	2.49 (1.05, 5.88)	0.038*
Time of sample		0.436		
1 h	Reference			
2 h	1.41 (0.82, 2.43)	0.217		
4 h	1.18 (0.69, 2.01)	0.555		
6 h	1.37 (0.76, 2.48)	0.298		
8 h	1.64 (0.92, 2.94)	0.094		
10 h	1.83 (0.97, 3.45)	0.062		

Abbreviations: APACHE, Acute Physiology and Chronic Health Evaluation; CI, confidence interval; HCT, hematocrit; h, hour; OR, odds ratio; Po_2, partial pressure of oxygen; Pco_2, partial pressure of carbon dioxide; Reference, reference group. [1]*P*-values were estimated by using the generalized estimating equation. [2]Hypoglycemia was defined as a level of venous blood glucose ≤80 mg/dL and hyperglycemia refers to a venous blood glucose level >150 mg/dL. [3]Abnormal fingertip temperature was defined as pale skin or purple patches on the fingertips or as swollen fingers. *Indicates statistical significance, *P*<0.05.

those of the BGA. Clinical factors influencing the measurements obtained by the BGA included VBG and HCT. Our findings indicate that the exclusive use of peripheral glucometry for patients recovering from CPB surgery may lead to inaccurate measurement of blood glucose levels. Furthermore, this study highlights the need to consider a patient's unique clinical characteristics when implementing perioperative glycemic control.

The results of our study should be interpreted together with those of 3 other studies of glucose measurement in patients undergoing cardiac procedures. Karon and colleagues also analyzed patients who underwent CPB, but compared the performance of one type of glucose meter with arterial, venous, and peripheral whole blood samples [18]. These authors determined that glucose levels in the capillary samples were similar to those of the control, which was laboratory-based measurement of plasma glucose, while arterial and venous samples were significantly higher. Denfeld and colleagues determined the accuracy of arterial blood glucose levels measured by a glucose

Table 5. Effectors of error in measurement of peripheral blood glucose

n = 172	Crude OR (95% CI)	P^1
Age, years		
<45	Reference	
45-57	1.14 (0.75, 1.73)	0.531
>57	1.15 (0.75, 1.76)	0.519
Female gender	1.11 (0.79, 1.57)	0.535
Level of venous blood glucose[2]		
Normal or hypoglycemia	Reference	
Hyperglycemia	0.51 (0.36, 0.73)	<0.001*
Vasoactive drug use	1.41 (0.92, 2.15)	0.111
Abnormal fingertip temperature[3]	1.24 (0.76, 2.03)	0.381
APACHE II score >10	1.45 (0.95, 2.22)	0.087
Lactic acid >2 mmol/L	1.22 (0.75, 1.98)	0.417
Po_2, mmHg		
<80	1.5 (0.76, 2.97)	0.244
80-100	Reference	
>100	0.97 (0.58, 1.62)	0.911
Pco_2, mmHg		
<35	1.21 (0.88, 1.67)	0.238
35-45	Reference	
>45	1.2 (0.75, 1.91)	0.451
HCT >40%	0.92 (0.45, 1.88)	0.826
Time of sample		0.482
1 h	Reference	
2 h	0.81 (0.54, 1.22)	0.324
4 h	0.90 (0.6, 1.35)	0.611
6 h	0.92 (0.6, 1.41)	0.710
8 h	1.21 (0.78, 1.89)	0.399
10 h	1.02 (0.65, 1.59)	0.931

Abbreviations: APACHE, Acute Physiology and Chronic Health Evaluation; CI, confidence interval; HCT, hematocrit; OR, odds ratio; Po_2, partial pressure of oxygen; Pco_2, partial pressure of carbon dioxide; Reference, reference group. [1]*P*-values were estimated by using the generalized estimating equation. [2]Hypoglycemia was defined as a level of venous blood glucose ≤80 mg/dL and hyperglycemia refers to a venous blood glucose level >150 mg/dL. As there were only 3 patients with hypoglycemia and the estimated ORs were unavailable (no event of acceptable error at some time points), these data were combined with that of the normal group. [3]Abnormal fingertip temperature was defined as pale skin or purple patches on the fingertips or as swollen fingers. *Indicates statistical significance, P<0.05.

meter in patients undergoing cardiothoracic surgery [19]. Their results indicate that glucose levels were significantly higher than control levels, obtained by using a laboratory-based procedure to measure plasma glucose of the same arterial sample. An analysis of HCT levels revealed that higher HCT (>29%) was associated with a smaller discrepancy between test and control values. Moller and colleagues studied blood glucose levels in patients who had undergone one of several types of cardiac surgery [20]. While their main objective was to assess the performance of intravascular microdialysis, they also compared arterial and venous blood glucose levels measured by BGA to plasma glucose levels measured with a laboratory-based procedure. Levels of glucose in both samples were not significantly different from those of controls.

The data from the studies of Karon and Denfeld, which suggest that use of a glucose meter with arterial or venous blood may not be as accurate as is the use of capillary blood, support our approach of using a BGA to analyze arterial blood and a glucose meter to analyze a peripheral sample. While we cannot state with certainty why our findings differ from those of Karon and colleagues regarding the accuracy of glucose meters for measuring PBG, several possibilities exist. The difference could be due to the device, which differed between the 2 studies [21, 22]. Another possibility is the use of insulin. Inoue and colleagues have reported that insulin therapy is associated with increased error rates of glucose meters [15].

In this study, we characterized the factors that affect the accuracy of blood glucose measurement. It has been known for some time that hematocrit levels influence the output of glucose meters [23, 24], and a recent study by Daves and colleagues determined that the effects are device-dependent [25]. While the mechanisms by which HCT alter the function of glucose meters have been characterized [26], less is known of its effects on BGAs. Because both glucose meters and BGAs can use amperometric detection of glucose oxides activity, the mechanisms of hematocrit interference may be similar.

This study had several limitations. First, the observed differences in blood glucose levels in peripheral blood versus venous and arterial blood may be limited to the machines that we tested, and may not apply to machines of other brands, or different models. Second, we did not analyze the accuracy of measurements for venous, arterial, and peripheral blood glucose with each of the 3 devices being assessed in this study. Although our conclusions may not apply for other combinations of sample type and method used to measure blood glucose, our findings can serve as a reference for additional analyses in patients undergoing CPB. Third, we did not collect data on the length of time a patient was on CPB, the total time of the cross-clamp, or the total length of time of the surgery. These details should be evaluated in future studies. Finally, the small number of patients with diabetes and those who received insulin infusion did not allow us to assess or compare error rates among these subpopulations of patients.

In conclusion, this study analyzed the accuracy of blood glucose measurement by arterial blood gas analysis and peripheral glucometry in perioperative CPB patients. Although both types of measurements can correctly detect the trends in glucose levels after CPB surgery, peripheral glucometry may overestimate the actual blood glucose level of the patient. Peripheral glucometry is also accompanied by significantly higher error rates than is arterial blood gas analysis. When using a BGA, the accuracy of glucose measurement after CPB can be affected by multiple clinical factors including HCT and the glucose level itself: patients in a hyperglycemic state had a lower risk of error for measurement of ABG than did patients with normal glucose levels. Proper glycemic control in patients undergoing CPB requires consideration of all of these factors, some of which should be examined in more detail in future studies.

Disclosure of conflict of interest

None.

Abbreviations

ABG, arterial blood glucose; APACHE, Acute Physiology and Chronic Health Evaluation; BGA, blood gas analyzer; CABG, coronary artery bypass graft; CI, confidence interval; CPB, cardiopulmonary bypass; h, hour; ICU, intensive care unit; HCT, hematocrit; IIT, intensive insulin therapy; OR, odds ratio; PBG, peripheral blood glucose; Pco_2, partial pressure of carbon dioxide; Po_2, partial pressure of oxygen; Reference, reference group; SD, standard deviation; SICU, surgical intensive care unit; VBG, venous blood glucose.

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