Influence of ambient temperature on the correlation between self-monitoring of blood glucose and plasma glucose values in diabetes management

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ABSTRACT

INTRODUCTION: Self-monitoring of blood glucose (SMBG) helps patients with diabetes mellitus maintain glycemic control. However, few reports exist on whether ambient temperature can influence SMBG values.

AIM: To investigate the effect of ambient temperature on the association between SMBG and plasma glucose (PG) values.

METHODS: The study was conducted between 2003 and 2010 in diabetic patients (n=2777, male/female = 1216/1561, mean age = 60.5 ±13.6 years) for whom the measurements of SMBG and PG were performed simultaneously (66 197 samples were measured). SMBG and PG were both measured by enzyme methods. Correlation coefficients were determined between SMBG and PG values, and the differences between their values were compared based on the temperature.

RESULTS: SMBG and PG were closely correlated at each temperature. The PG–SMBG difference was smallest at an ambient temperature of 20°C, around which SMBG differed from PG with temperature; namely, the SMBG value decreased as the ambient temperature increased, while the SMBG value increased as the ambient temperature decreased.

DISCUSSION: The present data indicate that the ambient temperature can minimally but significantly influence SMBG values. Further studies about the relevance of these findings on patient self-care are warranted.

KEYWORDS: Blood glucose self-monitoring; diabetes mellitus; patient education; self care; skin temperature; temperature

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Introduction

Self-monitoring of blood glucose (SMBG) enables patients to instantly and conveniently measure their own blood glucose levels, and is used in diabetes self-care.[1] SMBG is effective for glycaemic control in patients with diabetes mellitus (particularly in Type 1 diabetes).[2] Thus, the SMBG value measurement is a useful tool for at-home patient care, as well as in the outpatient and inpatient care settings.

In our clinic, plasma glucose (PG) values from venous blood samples and SMBG values are measured simultaneously at outpatient visits. Checking the correlation between SMBG and PG values helps patients gain insight into using SMBG. In principle, SMBG values are measured with blood glucose meters that use an enzyme reaction.[3] The International Federation of Clinical Chemistry and Laboratory Medicine (IFCC) working group has recommended that glucose meters be calibrated to the PG concentration, irrespective of the sample type or technology.[4] A temperature sensor is built into the main device as a control mechanism for adjusting the enzyme reaction rate to match the ambient temperature, allowing accurate values to be obtained.[5] Differences in SMBG values due to temperature, within the range of usual ambient temperatures, are reported to be negligible to the extent that clinical decisions are not affected.[6] Conversely, one study comparing SMBG values for ground temperatures between 25°C and 8°C reported that the meters can either underestimate or overestimate PG values.[7] In addition, when patient skin temperature is cool (15.5°C), lower SMBG values have been reported compared with warm skin temperature (35°C).[8] We have noted that, particularly during the winter, the SMBG values are higher than the PG values. Other medical centres have likely had the same experience.[9]

Of note, there are very few investigations concerning the influence of ambient temperature on the difference between SMBG and PG values, although studies have examined measurement techniques as a factor influencing SMBG values.[3,10] Given that SMBG values are obtained by meters using an enzyme reaction, and considering the reports and experience to date,[3,5–10] the possibility that ambient temperature may affect the readings of the SMBG devices—in other words, influence SMBG values—remains a subject to be investigated. Therefore, in this study, we examined the influence of ambient temperature on discrepancies between SMBG values and PG values in diabetic patients.

WHAT GAP THIS FILLS

What we already know: Self-monitoring of blood glucose (SMBG) assists patients with diabetes to maintain glycaemic control. Ambient temperature may influence SMBG values.

What this study adds: Although SMBG and plasma glucose levels are closely correlated, the ambient temperature can minimally but significantly influence SMBG values. The clinical relevance of this influence on patient care should be further confirmed.

Methods

This study was conducted between January 2003 and October 2010 in diabetic outpatients in whom patient-measured SMBG values and measurement of PG values were performed simultaneously. For the ambient temperature on the day of measurement, we used the mean temperature in the region where our hospital is located, obtained from meteorological statistical information from the public homepage of the Japan Meteorological Agency.[11] The study protocol was approved by the Institutional Ethics Committee.

The blood was sampled at a daytime clinic visit for each patient. The PG values and SMBG values were obtained from medical records. The PG value was measured by an enzyme method using venous blood collected in sample tubes containing a glycolysis inhibitor (sodium fluoride) and an anticoagulant (EDTA-2Na). The auto-analyser was supplied from Arkray, Inc. (Type GA-1150, Kyoto, Japan). The intra- and inter-assay coefficients of variations are always <1.0%, and are confirmed once every two hours. Our laboratory participates in the nationally certified programme of quality assurance for Clinical Laboratory Quality Control Survey of the Japanese Association of Medical Technologists. The SMBG value was measured with a device based on an enzyme method (glucose oxidase or glucose dehydrogenase), using whole blood from the fingertip collected by the patients themselves. The meters used in this study conformed to the recommendations by the IFCC working group.[4]

We expressed the PG values and SMBG values as mean ± standard deviation. The SMBG values were compared with the PG levels at each temperature by an unpaired t-test. The PG values were considered as a reference for comparison with the SMBG values, so the PG–SMBG difference between them was calculated by subtracting the SMBG value from the PG value. For the correlation between PG and SMBG values, the correlation coefficient was determined. Comparison of differences was analysed by analysis of variance (ANOVA) and the Tukey's multiple comparison test. The level of statistical significance was set at 5%.

Results

This study included 2777 diabetic patients (male/female = 1216/1561, mean age = 60.5 ±13.6 years) with a total of 66 197 individual measurements taken of the SMBG and PG values. There were 124 patients with Type 1 diabetes (male/female = 42/82, mean age = 48.1 ±14.3 years) with a total of 6540 separate measurements taken, and 2653 patients with Type 2 diabetes (male/female = 1174/1479, mean age = 61.8 ±12.9 years) with a total of 59 657 separate measurements. The PG and SMBG levels were 10.92 ±4.17 mmol/L and 11.42 ±4.21 mmol/L at an ambient temperature of 5°C (p<0.001), 10.68 ±4.06 mmol/L and 11.06 ±4.17 mmol/L at 10°C (p<0.001), 10.59 ±4.09 mmol/L and 10.78 ±4.12 mmol/L at 15°C (p<0.001), 10.61 ±4.13 mmol/L and 10.61 ±4.17 mmol/L at 20°C (p=0.947), 10.36 ±3.91 mmol/L and 10.22 ±3.99 mmol/L at 25°C (p<0.001), and 10.45 ±3.97 mmol/L and 10.12 ±3.94 mmol/L at 30°C (p<0.001). Thus, the values of SMBG and PG were significantly different from each other at each temperature, except for at 20°C.

Table 1. Difference between plasma glucose (PG) and self-monitoring of blood glucose (SMBG) values at ambient temperatures of 5–30°C

Ambient temperature (°C)	Sample number (n)	PG-SMBG difference (mmol/L)	P value (vs 20°C)
5	448	-0.50±1.29	<0.001
6	1405	-0.55±1.30	<0.001
7	1571	-0.37±1.34	<0.001
8	2455	-0.43±1.28	<0.001
9	2170	-0.40±1.30	<0.001
10	2400	-0.39±1.27	<0.001
11	2211	-0.38±1.18	<0.001
12	2597	-0.33±1.18	<0.001
13	2510	-0.28±1.22	<0.001
14	2520	-0.26±1.14	<0.001
15	1942	-0.19±1.11	<0.001
16	2993	-0.14±1.14	0.001
17	1990	-0.17±1.11	<0.001
18	2741	-0.03±1.16	1.000
19	2013	-0.04±1.18	1.000
20	2920	0.00±1.08	Referent
21	2510	0.07±1.05	0.014
22	3526	0.11±1.05	0.001
23	2991	0.10±1.06	0.005
24	2810	0.14±1.08	<0.001
25	2347	0.13±1.03	< 0.001
26	2093	0.14±1.06	<0.001
27	2497	0.17±1.01	<0.001
28	4218	0.24±1.02	<0.001
29	3764	0.31±0.99	<0.001
30	4555	0.33±1.02	<0.001

The PG–SMBG difference was calculated by subtracting the SMBG value from the PG value.

The PG–SMBG value difference was smallest at an ambient temperature of 20°C. As shown in Table 1, around this central temperature (20°C), compared to the PG values, the SMBG values increased as the temperature decreased; conversely, the SMBG values decreased as the temperature increased. In addition, these data trends were the same between the patients with Type 1 diabetes and the patients with Type 2 diabetes (data not shown).

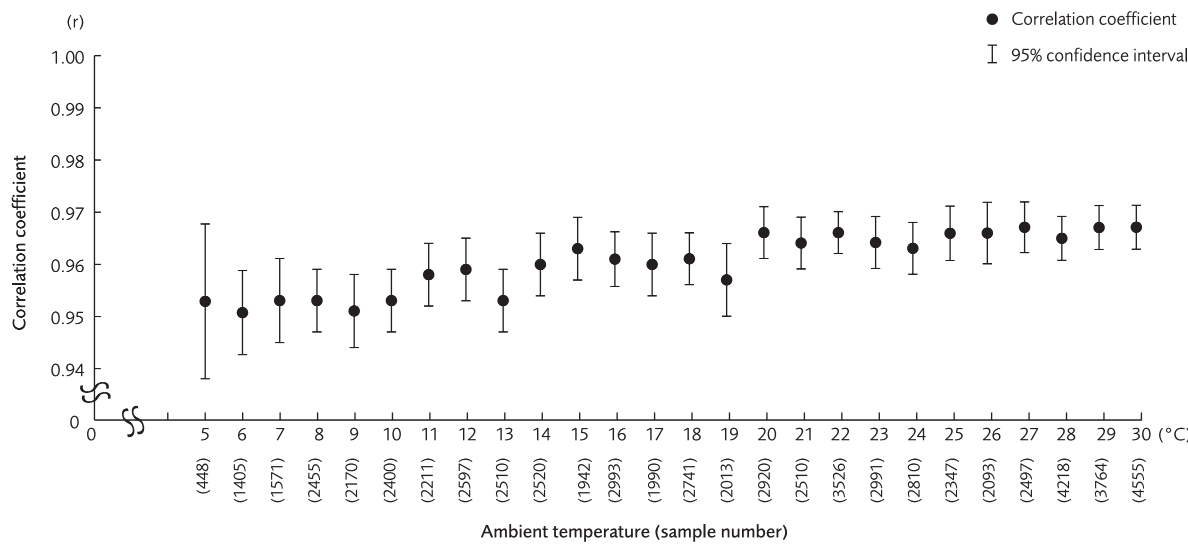
During the study period, the mean temperature was 19.0°C (minimum 1.5°C, maximum 36.6°C). At each temperature, the correlation coefficients overall were close (r=0.951–0.967; Figure 1). The highest coefficients were at temperatures ≥27°C; the coefficients progressively weakened, and the lowest coefficients were at temperatures ≤13°C.

Discussion

Our present study produced the following two interesting findings: (1) Although an overall close correlation between SMBG values and PG values was observed, the correlation between SMBG and PG tended to be weaker at a lower ambient temperature range than at a higher temperature range. (2) The PG–SMBG value difference was smallest at an ambient temperature of 20°C. Using this as a reference temperature, with regard to the PG–SMBG value difference, as the ambient temperature increased, the SMBG value decreased; conversely, as the ambient temperature decreased, the SMBG value increased.

In general, indoor temperature is dependent on the ambient temperature, and SMBG value measurements are almost always performed indoors. For example, when air conditioning is used, the indoor temperature does not necessarily correspond to the ambient temperature, while both temperatures are, to some extent, correlated with

Figure 1. Correlation coefficients of plasma glucose (PG) and self-monitoring of blood glucose (SMBG) values at ambient temperatures of 5–30°C



each other. The present study used ambient temperature, not indoor temperature, so we should caution that the results may be underestimated. Considering the possibility of underestimation to real practice, our findings are worthy of attention. The SMBG was, however, performed within a few minutes, or at least 10 minutes, after each patient's clinic visit, and the meters used in each patient were exposed to the temperature level near the ambient, but not the indoor, temperature. Thus, we felt that using ambient temperature was applicable to our study.

Enzyme activity is greatly influenced by temperature, with a 1.5- to 3-fold increase for every increase of 10°C between 20°C and 40°C.[12] To control this, a temperature sensor is usually built into the main unit of the SMBG device, and by adjustment of the reaction rate to match the ambient temperature, measured values are obtained.[4] This control mechanism explains why our SMBG values correlated well with PG values, with only small differences.

The reason for a somewhat weaker correlation at lower ambient temperatures is probably as follows. At lower ambient temperatures, the skin surface temperature is lower, and the temperature of the blood applied to the sensor of the SMBG device is also decreased. Compared to when the skin surface temperature is higher, even if the control mechanism to match the ambient temperature is functioning, the enzyme reaction in the SMBG device may become unstable. In addition, under such possible unstable conditions, we found an interesting phenomenon regarding the difference between PG values and SMBG values at higher and lower ambient temperatures. Specifically, the higher the ambient temperature, the lower the SMBG value; the lower the ambient temperature, the higher the SMBG value; and the direction of difference compared with the PG value was different. From our results, the enzyme reaction in the SMBG device seems to be accelerated at low temperatures. This may be due to a limit of the control mechanism in adjusting to the device temperature. In other words, as opposed to the assumed reaction rate with temperature adjustment of the SMBG device, the actual reaction rate is higher at temperatures <20°C, and lower at temperatures >20°C.

The influence of ambient temperatures should also be considered when educating patients about SMBG. Measurement at an ambient temperature of 20°C, at which the difference between the SMBG and PG values is minimal, is recommended. Problems in patient self-care to which the degree of PG–SMBG value discrepancies seen in our study might lead should be investigated in future work. In particular, climatic variations are a worldwide issue;[13] therefore, our results may also require careful consideration from a risk-management and climatic–medical perspective.

We acknowledge that the data in our study were obtained in a 'real-world' clinical setting, rather than an experimental setting. Other factors influencing the SMBG values are blood volume and blood viscosity in relation to ambient temperature.[14] In addition, certain foods and prescribed drugs might affect the results. These data were not included in this study. Altitude can be an influencing factor;[14] our study was conducted in a single clinic with the same altitude. Furthermore, information on the meters used by each patient was not included in this study. As the technology and algorithm for adjusting the enzyme reaction to match ambient temperature can vary between meters for SMBG (although this information is not available to the public), whether or not all meters show similar results must be addressed as a future challenge. We believe this may give patients more valuable information in using the meters for SMBG.

In conclusion, our study found, particularly at very high and low ambient temperatures, that SMBG values are slightly, yet significantly, influenced by ambient temperature, exhibiting a discrepancy from PG values. The clinical significance of this finding requires further investigation.

COMPETING INTERESTS
None declared.

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