# Rapid Changes in Postprandial Blood Glucose Produce Concentration Differences at Finger, Forearm, and Thigh Sampling Sites

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**OBJECTIVE** — To compare pre- and postmeal capillary blood glucose concentrations measured at the finger, forearm, and thigh in adults with diabetes.

**RESEARCH DESIGN AND METHODS** — For phase 1, capillary blood glucose concentrations were measured at six time points (premeal and at ~60, 90, 120, 150, and 180 min postmeal) using a blood glucose monitoring system and technician-obtained samples collected from finger, forearm, and thigh sites of 42 adults with diabetes. The finger samples were also tested with a laboratory instrument. For phase 2, ~14 weeks later, the testing procedures were repeated with 38 subjects from the original study population.

**RESULTS** — Meter finger results were accurate at all time points. Alternate sites tended to produce lower glucose readings compared to finger readings at times when glucose was increasing rapidly (60 and 90 min postmeal). Forearm-to-finger differences correlated with rates of glucose change ($r = 0.56$, $P < 0.001$), as did the thigh-to-finger differences ($r = 0.52$, $P < 0.001$). Other factors, such as subject age, BMI, diabetes type, and insulin dependence did not have a significant impact on site differences. When the testing procedures were repeated with the same subjects, the pattern of site differences was consistent, although individual results were variable.

**CONCLUSIONS** — Changes in blood glucose immediately after a meal may be identified at finger sites before detection at forearm or thigh sites. Alternate site testing appears to be a useful option for routine self-monitoring before meals; however, patients and clinicians should recognize that results may be different from fingertip results when glucose levels are changing rapidly.

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Self-monitoring of blood glucose (SMBG) currently requires the user to perform a skin puncture and then transfer blood from the puncture site to a test strip. Newer test strips are designed for use with very small blood samples, in some cases <1 μl (1). The smaller sample volume allows users to perform a shallower finger puncture or perform a skin puncture at an alternate blood sampling site, such as the forearm or thigh, thus reducing the pain associated with testing and allowing the fingertips time to heal. The option to test at alternative sample sites may lead to better patient compliance with blood glucose testing regimens. However, because patients may switch back and forth between finger sites and alternate sites in their monitoring practice, the equivalence of blood glucose measurements made at various times with samples from different sites is an important consideration. The purpose of this investigation was to compare blood glucose concentrations of adults with diabetes when measured at different sites (finger, forearm, and thigh) before and after a meal and to determine whether subjects showed repeatable patterns when tested on different occasions.

## RESEARCH DESIGN AND METHODS

— Institutional review board approval and informed consent were obtained before each phase of the study. Subjects recruited for the studies were individuals at least age 18 years with a prior diagnosis of type 1 or type 2 diabetes. Table 1 gives the characteristics of the subject population. In all, 42 subjects completed the first phase of the study in December 2000. Testing was repeated ~14 weeks later, with 38 of the 42 subjects returning, to determine whether the observed glucose relationships were reproducible. The role of the subjects was limited to *1*) providing relevant demographic, medical, and dietary information; *2*) maintaining normal diet and medication practices during the study; and *3*) acting as a source of blood samples for technician-performed tests.

All testing was conducted at LifeScan Laboratories in Milpitas, California. Each phase of the study consisted of six testing sessions (premeal and ~60, 90, 120, 150, and 180 min postmeal) in which subjects were tested with a glucose monitoring system using finger, forearm, and thigh blood samples. All testing sessions were scheduled to minimize impact on the subjects' daily diabetes management regimens. Subjects reported for testing at least 1 h before breakfast or lunch (or 1 h before a premeal insulin administration, if applicable). After the premeal testing, each

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**Abbreviations:** PD, percentage difference; SMBG, self-monitoring of blood glucose.
A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

**Table 1—*Subject characteristics***

| | Phase 1 | Phase 2 |
|---|---|---|
| *n* | 42 | 38 |
| Sex (M/F) | 16/26 | 15/23 |
| Age (years) | 47.9 ± 12.2 | 48.1 ± 12.3 |
| Diabetes | | |
| Type (1/2) | 15/27 | 13/25 |
| Using insulin | 17 | 15 |
| BMI (kg/m$^2$) | 31.8 ± 7.2 | 30.7 ± 6.8 |
| Hematocrit (%) | 42.7 ± 4.9 | 42.0 ± 3.9 |
| Test time (A.M./P.M.) | 31/11 | 29/9 |

Data are *n* or means ± SD.

subject was offered a meal from one of two menus (breakfast or lunch, depending on the time of testing), and the meal items consumed by each subject were documented. The total carbohydrate content was ~115 g for breakfast and ~143 g for lunch. After the meal, subjects returned to the testing area to complete the remaining five testing sessions.

All skin punctures and glucose tests were performed by trained technicians. The order of sites tested (i.e., finger, forearm, and thigh) was varied between subjects, with minimal elapsed time between sites. For each testing session, the forearm and finger samples were collected from the same arm (right or left), but the choice of arm varied between testing sessions. Forearm samples were collected from the anterior or medial side of either forearm, in a soft fleshy area free of visible veins or excess hair. Thigh samples were collected from the anterior or medial surface of either thigh, ~6 in above the knee. Finger samples were collected using either side of the tip of any finger on either hand.

Forearm and thigh sampling sites were prepared by vigorously rubbing the sample site with the hand for several seconds. If rubbing alone did not promote adequate blood flow, a warming pad was used. Penlet Plus Blood Samplers with clear caps (LifeScan, Milpitas, CA) were used for all forearm and thigh skin punctures. To obtain enough blood for meter and laboratory tests, a Tenderlett finger incision device (International Technidyne, Edison, NJ) was used to perform all fingertip skin punctures.

Capillary blood glucose concentrations were measured using the One Touch Ultra Blood Glucose Monitoring System (LifeScan), which combines glucose oxidase chemistry with an electrochemical detection method. The system is designed for rapid (5 s) quantitative measurement of blood glucose using small volumes (1 μl) of capillary whole blood. A set of five glucose meters and a single lot of test strips were used for each phase of the study. Laboratory evaluation before the study demonstrated strip-to-strip coefficients of variation of <4% at blood glucose concentrations of ~40, 80, 250, and 400 mg/dl.

During each testing session, comparative blood glucose tests were performed with finger samples using a YSI 2700 Select Biochemistry Analyzer (Yellow Springs Instruments, Yellow Springs, OH). The YSI 2700 uses a glucose oxidase method with electrochemical detection to measure glucose concentrations in a 25-μl sample (plasma or whole blood) diluted with 600 μl of buffer. Within-day and between-day coefficients of variation of ≤ 3.5% have been reported using protein-based quality control solutions (2). Samples collected in heparinized collection tubes were tested immediately to obtain whole-blood glucose results and were then centrifuged and tested again to obtain plasma glucose concentrations. Hematocrits were measured using a STAT-CRIT instrument (Wampole Laboratories, Cranbury, NJ).

In each phase, meter system accuracy was verified by comparing meter finger results with the corresponding YSI plasma glucose values. Least-squares linear regression was used to evaluate the relation between methods, and error grid analysis was used to determine the clinical significance of the meter versus YSI differences (3). Between-subject mean glucose concentrations at the three sampling sites were compared using repeated measures ANOVA. Testing sessions were identified as nominal time points (e.g., premeal, 60-min); however, actual times between testing sessions varied slightly from subject to subject. All statistical testing was performed at the 5% level of significance. Glucose concentration differences between alternate sites (forearm or thigh) and finger meter measurements were calculated as percentage differences (PDs) for each subject, according to the following equation: PD = 100 × (alternate site glucose – YSI finger glucose)/YSI finger glucose.

**RESULTS** — In both phases, meter finger results at all time points were closely matched with the corresponding YSI plasma results. For phases 1 and 2, regression slopes = 0.95 and 0.94, intercepts = 0.6 and −1.8 mg/dl, $S_{xy}$ = 18.3 and 18.1, $r$ = 0.98 and 0.97, and $n$ = 246 and 227, respectively. Error grid analysis of data from both phases showed that ≥95% of the meter finger measurements fell within zone A and 100% of the measurements fell within zones A + B. Thus, meter finger results showed high degrees of statistical and clinical accuracy.

All sampling sites showed a large increase in blood glucose after the meal, followed by a leveling and a gradual decline thereafter (Fig. 1*A* and *C*). Finger glucose concentrations (meter and YSI) peaked during the 90-min session, whereas forearm and thigh concentrations peaked somewhat later (~120 min) and at a lower glucose concentration. This same pattern was observed in both phases of the study. In each phase, between-subject glucose variations (± SD) were substantial yet consistent in magnitude across the three sampling sites at each time point. The observed variations in YSI and meter finger results were nearly identical at each time point, suggesting that the variation was not dependent on the method. Repeated-measures ANOVA for mean glucose showed statistically significant differences ($P < 0.05$) among sampling sites at 60 min in phase 1. Differences for all other sampling sites and time points were not statistically significant. Analysis for the covariates age, BMI, test time (A.M./P.M.), diabetes type, and insulin dependence suggested that site differences might be more pronounced in older subjects (age >40 years), subjects tested in the morning, and subjects not taking insulin; however, the differences were not statistically significant. Diabetes type and

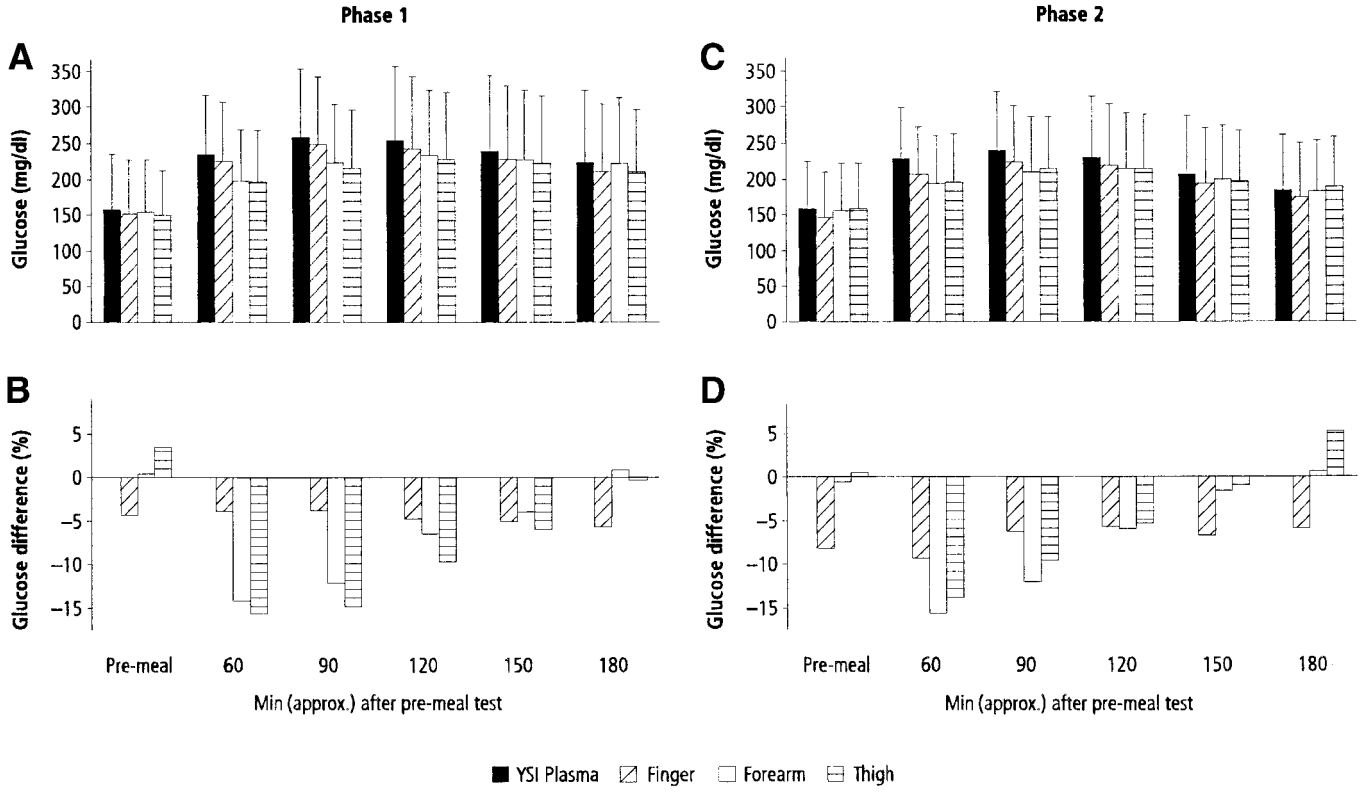


**Figure 1**—*Shown are phase 1 mean subject glucose* (A) *and mean percentage differences* (B) *and phase 2 mean subject glucose* (C) *and mean percentage differences* (D).

BMI did not have a consistent effect on site differences.

The observed time lags between alternate site and finger glucose concentrations were reflected in the mean PDs for each phase. Whereas finger PDs were consistent at each time point, forearm and thigh PDs were slightly positive during premeal testing, became substantially negative for at least 90 min, and then returned close to the premeal values by 180 min (Fig. 1*B* and *D*). This observation suggested to us that the sign and magnitude of the forearm and thigh PDs might be related to the direction and rate of blood glucose changes. To investigate this possibility, the correlation between the estimated rate of glucose change after eating and the subject forearm and thigh PDs was assessed using linear regression analysis. At each time point, the rate of glucose change ($mg \cdot dl^{-1} \cdot min^{-1}$) was estimated as the difference in YSI readings between the current and previous time points divided by the elapsed time between measurements.

The relation between PDs and the estimated rates of glucose change for both phases combined is shown in Fig. 2. The data indicate that at higher rates of blood glucose change (positive or negative), the differences between finger and alternate site blood glucose concentrations became greater. Linear regression analysis supports the observed relationship for both forearm ($r = 0.56$, $P < 0.001$) and thigh PDs ($r = 0.52$, $P < 0.001$).

**CONCLUSIONS** — When blood glucose is changing rapidly, different blood collection sites can provide different measured glucose concentrations. This has been demonstrated in studies showing capillary glucose to be significantly higher than venous glucose after a liquid glucose load (4–6). Until recently, the fingertip has been the only practical sampling site for SMBG. As systems for collecting and measuring blood glucose at alternate anatomical sites gain acceptance, the equivalence of glucose concentrations at these sites becomes an important factor in glycemic self-management.

Recently, Koschinsky and Jungheim (7) compared forearm and finger capillary blood samples from patients with type 1 diabetes. They reported clinically relevant differences between sites as finger glucose fell into the hypoglycemic range. The data in our study demonstrated a similar phenomenon over a wide range of glucose concentrations and further illustrated that rapid glucose changes, either increasing or decreasing, were associated with large site differences in some subjects. It has been suggested that arm-to-finger differences may be minimized by rubbing the test site before blood collection (8). In our studies, both forearm and thigh sites were rubbed before testing, and in some cases a warming pad was used, yet site-to-site differences were not entirely mitigated. A recent report on the use of an automated vacuum device for alternative site SMBG has indicated that arm results agree well with finger values using this device (9). The report, however, did not discuss the impact of rapid blood glucose changes on site-to-site differences.

In summary, glucose values measured at forearm and thigh sampling sites might lag behind values obtained from the finger when glucose levels are changing rapidly. This lag may produce significant differences in blood glucose concentrations measured at these sites. Our data indicated that site differences

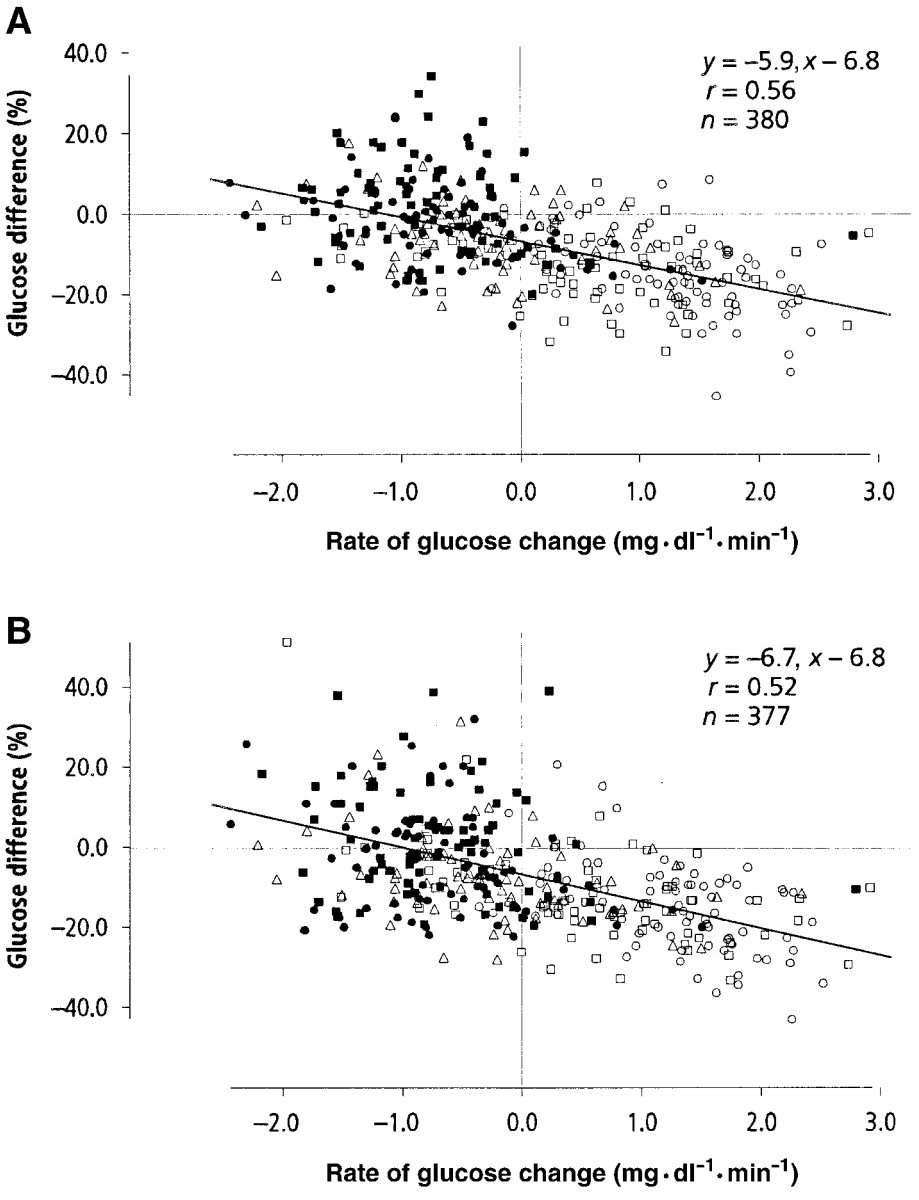


**Figure 2**—*Percentage differences versus rate of glucose change (both phases) for forearm* (A) *and thigh results* (B). *Approximate time after pre-meal test:* ○*, 60 min;* □*, 90 min;* △*, 120 min;* ●*, 150 min; and* ■*, 180 min.*

observed at specific times were not attributable to performance limitations of the glucose monitoring system. Although the lag appeared to be repeatable, the magnitude of site differences for individual subjects appeared to be inconsistent, presumably depending on the rate of glucose change at the time of the comparison. Alternate site sampling has the potential to increase patient compliance with SMBG; however, patients should rely on the finger site for testing within 2 h after meals, or at other times when blood glucose is likely to change rapidly (e.g., following an insulin dose). Although this study did not directly evaluate the detection of hypoglycemia, our findings were consistent with the recommendation that finger testing be used when there is a question of hypoglycemia, as they confirmed that hypoglycemia is likely to be detected sooner at the finger than at the arm or thigh. These recommendations should be clearly communicated to health care providers and patients through educational materials and training.

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