Problems in home monitoring of blood glucose

C. F. A. PANTIN
Ph.D., M.R.C.P.

D. BIHARI
M.B. B.S.

E. A. BROWN
B.M., M.R.C.P.

A. BLOOM
M.D., F.R.C.P.

Diabetic Unit, Whittington Hospital, London N19 5NF

Summary

Two hundred and forty blood glucose readings were made on 5 Glucochek machines by 2 different operators. The results on all machines correlated poorly with equivalent results from an automatic glucose analyser with major discrepancies at all glucose concentrations. There was a wide gap in performance between the 2 operators. Analysis of variance suggested that errors were not only due to inter-operator and inter-machine differences. Possible sources of error were shown to include time of reaction and the amount of blood on Dextrostix. Dextrostix colour changes measured by eye were as accurate as those by Glucochek without the rogue values found at higher glucose concentrations with Glucochek.

Introduction

Self monitoring of blood glucose concentrations is proving to be a method of achieving diabetic control that is more efficient than conventional urinalysis (Sönksen, Judd and Lowry, 1978; Walford *et al.*, 1978). These conclusions have been based on the use of Dextrostix (Ames) read by a reflectometer ('Eyetone' Ames) (Sönksen *et al.*, 1978) or Reflotest strips with a 'Reflomat' machine (Boehringer Mannheim) (Walford *et al.*, 1978). The disadvantages of these 2 techniques are the cost and the non-portability of these machines. Recently 'Glucochek' has become available on the market. This is a relatively inexpensive battery-operated portable machine, which is able to 'read' Dextrostix. The aims of this study were to assess the relative accuracy of blood glucose measurements made with Dextrostix and the Glucochek machine, and to identify possible sources of error.

Patients and methods

Venous blood specimens were randomly selected from those routinely taken at diabetic out-patient clinics and in diabetic wards. Some of each blood specimen was placed in a fluoride-containing tube for one parallel measurement of blood glucose to be

made on a Beckman automatic glucose analyser with standards at glucose levels of 5, 10, 20 mmol/l run initially and a 10 mmol/l standard run after every 10 unknown blood samples. The precision within a sample run on the glucose analyser was measured at different blood glucose concentrations ($n=4$, mean ($\pm$ s.e. mean)=3.8 (0), 5.02 (0.01), 8.0 (0.02), 12.67 (0.07), 22.63 (0.08); $P<0.0001$).

In all experiments, a drop of the fresh blood specimen was placed immediately on a Dextrostix (Ames Co., Division of Miles Laboratories Ltd, Stoke Poges, Slough 2LS 4LY, England). The manufacturer's instructions about timing, washing and quantities were followed, unless stated in an individual experiment. The Dextrostix colour changes were measured by eye, by Ames Eyetone meter or by Glucochek (Medistron Ltd, Alpine Works, Oak Road, Southgate, Crawley, Sussex R11 8AJ) again following the manufacturer's instructions for standardization and use.

Sixty-six blood specimens were analysed for glucose using Dextrostix and the Eyetone meter, and the results compared with control measurements.

In experiment 1, drops of blood from each of 48 blood specimens were placed on 5 separate Dextrostix. The Dextrostix colour change was measured on one of 5 Glucochek meters by 2 operators, working independently from a schedule randomized between machines and operators. The 2 operators were not regular users of either Dextrostix or Glucochek meters. The 240 readings were compared with the glucose analyser readings for inter-operator and inter-machine error using an analysis of variance and plotted against the control readings.

Experiments were performed to identify sources of error. The time during which blood reacted on the Dextrostix was deliberately changed to 45, 60 (the recommended time) and 75 sec. This experiment was performed firstly on 30 blood specimens using Dextrostix and Glucochek machines. Secondly, it was performed on 15 blood specimens using Dextrostix measured with Eyetone meter. Both experiments

used schedules with reaction times randomly selected from one of the times (45, 60, 75 sec), unknown to experimenters. Similarly, Oxford pipettes (Oxford Instruments Ltd, Osney Mead, Oxford OX2 0DX) spread either 5-, 10-, or 20- μ l drops of blood from 12 specimens on Dextrostix which were again measured by Eytone meter in randomly selected order. Each volume covered the Dextrostix.

Two experiments were performed to compare the accuracy of measuring the colour change of the Dextrostix by eye and by Glucochek machine. Seventeen blood specimens were analysed for glucose using 5 Dextrostix, each of whose colour changes was measured by eye and by one of 5 Glucocheks by independent observers. Fourteen blood specimens were analysed for glucose using one Dextrostix; for each the colour changes were measured by eye by 2 independent observers and in

random order rapidly on 5 different Glucochek machines.

Results

From experiment 1, Fig. 1 shows the means and ranges of the results found by the 5 Glucocheks for each blood specimen plotted versus the equivalent glucose analyser results. As shown in Fig. 1, the range of Glucochek results was wider at higher glucose levels with some startling discrepancies and a trend towards undervaluing the glucose level. An increase in range of results with increasing glucose values is expected. To reduce this natural dispersion, all further statistics were performed on the logarithm of the glucose values.

Linear regression analysis was performed (y = logarithm of Glucochek result, x = logarithm of glucose analyser result). The correlations of the results from each individual machine or operator

FIG. 1. Range (I—I) and mean (x) of the 5 Glucochek measurements plotted against the equivalent automatic glucose analyser measurement of blood glucose ($n=48$).

with the glucose analyser results were significantly different from zero, but still far from unity. The correlation coefficients (r) for the 5 machines were 0.56, 0.67, 0.77, 0.75, 0.79, $n=48$, $P<0.001$.

One operator's results correlated ($r=0.84$, $n=120$, $P<0.001$, slope=0.91) as well as those of the Eytone with the glucose analyser ($r=0.88$, $n=66$, $P<0.001$, slope=0.85). The second operator's results correlated less well ($r=0.60$, $n=120$, $P<0.001$, slope=0.83).

Carrying out an analysis of variance using the glucose analyser results, inter-operator and inter-machine differences, the variance between different machines ($P<0.02$) and between operators ($P<0.0001$) is significant. However, only three-quarters ($R^2=73$) of the variance in the Glucocheck results is explained by these sources.

Tables 1 and 2 show decreasing values obtained by the Glucocheck and Eytone machines with either decreased reaction times or decreased

amounts of blood on the Dextrostix. Using the paired t -test, at higher glucose concentrations, (>8 mmol/l), these effects are significant ($P<0.05$) if timing is decreased from 60 to 45 sec or if the quantity of blood on Dextrostix is reduced from 10 μ l to 5 μ l.

Table 3 shows that the results of measuring Dextrostix by eye and Glucocheck can be comparable. Visual comparison appears to avoid the false low readings occasionally seen on the Glucocheck.

Discussion

The aim of good diabetic control is to achieve blood glucose concentrations in the range of 5–10 mmol/l. Experience has shown that this is hard to achieve in most insulin-dependent patients using conventional urinalysis as a guide to insulin requirements. Good control has however been achieved by self monitoring of blood glucose (Sönksen *et al.*, 1978; Walford *et al.*, 1978). This has a high degree

TABLE 1. Glucocheck or Eytone results at differing reaction times as percentage of equivalent automatic glucose analyser results

Machine	Reaction time (secs)	Mean ($\pm$ s.e. mean)	
		Glucose concentration < 8 mmol/l	Glucose concentration > 8 mmol/l
Glucocheck	45	84.7 (1.4)	56 (0.9)
	60	107.4 (1.6)	80 (1.6)
	75	104.6 (2.1)	93.9 (1.41)
Eytone	45	97.7 (4.6)	93.4 (2.05)
	60	119.1 (2.6)	121.3 (2.3)
	75	138.6 (4.3)	140.2 (2.3)

TABLE 2. Eytone results with differing quantities of blood placed on Dextrostix as percentage of equivalent automatic glucose analyser results

Quantity of blood on Dextrostix (μ l)	Mean ($\pm$ s.e. mean)	
	Glucose concentration < 8 mmol/l	Glucose concentration > 8 mmol/l
5	107.5 (2.9)	73.1 (2.4)
10	109 (3.7)	89.6 (0.9)
20	124.9 (0.4)	110.1 (3.2)

TABLE 3. Glucocheck and eye readings compared with automatic glucose analyser results. Eye reading in brackets

Glucocheck (eye)							
	mmol/l	0–3	3–5	5–9.7	9.7–14	14–20	> 20 (by eye, > 14 only)
Automatic glucose analyser	0–3	4 (5)	1				
	3–5		11 (7)	9 (1)			
	5–9.7	2	5	51 (33)	1 (1)		
	9.7–14			3 (1)	14 (12)	2 (1)	
	14–20			1	8 (3)	9 (17)	2
	> 20			3	4 (2)	8 (30)	15

of patient acceptability and 92% of patients opined that they would like to buy a blood glucose monitoring machine 'if the price is right' (Sönksen *et al.*, 1978). The Glucochek machine was developed for patient use rather than hospital use. Since the patient at home does not have a laboratory service as a back-up, it is essential that the readings of the machine should be in the correct range. This study has shown that Dextrostix read by the Glucochek machine agreed reasonably with the laboratory measurements for blood glucose concentrations of less than 9 mmol/l.

With higher blood glucose concentrations, not only was the spread of Glucochek results large, but also it was not uncommon to get falsely low readings. Thus, the patient may get false reassurance when in fact his diabetes is out of control. This problem has also been reported by others (Borthwick and Ross, 1979). Known errors of blood glucose measurements by the Glucochek machine include: 1. Faulty application of blood to the Dextrostix. 2. Inaccurate timing of the reaction on the Dextrostix. 3. Excessive washing or drying of the Dextrostix removing colour as well as blood. 4. Faults in the machine itself.

This study confirms the need for the Dextrostix to be well covered with blood, although a thin film of blood has been suggested as being preferable to a thick film, especially at high blood glucose concentrations (Rennie, Keen and Southon, 1964).

Timing is also crucial, especially at higher blood concentrations. The difference in accuracy between the 2 operators confirms the need for comprehensive training of each patient in the techniques of glucose home monitoring. Faults in the Glucochek machine itself are hard to assess. The manufacturers claim that the machines read with a precision of $\pm 15\%$.

Unfortunately there is no method of calibrating individual machines as there is, for example, on the Ames Eyetone meter.

The final part of the study was to compare the results obtained from Dextrostix read by eye and then read by Glucochek. Previous studies (Marks and Dawson, 1964) have shown that Dextrostix readings by eye are reasonably accurate, especially at lower blood glucose levels. In the present study, with blood glucose levels between 5–10 mmol/l, the range of good diabetic control, only one out of 33 Dextrostix was misread by eye whereas 8 out of 59 were misread by Glucochek, 7 being too low. With blood glucose concentrations greater than 14 mmol/l, reading Dextrostix by eye again proved to be as unreliable as using the Glucochek machine, which not uncommonly gave a falsely low value. The authors agree that self monitoring of blood glucose is a means of achieving better diabetic control; at present, they are teaching their patients to read Dextrostix by eye, but they keenly await a portable, inexpensive, foolproof, machine which can accurately read blood glucose levels in the higher ranges. Unreliable patients yield unreliable results which may cause worry and panic.

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