Impact of SMBG on Control of Diabetes as Measured by HbA_1

3-yr Survey of a Juvenile IDDM Clinic

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Three hundred twelve diabetic children and adolescents were seen in our diabetic clinic and instructed to test their capillary blood glucose (CBG) twice daily and to use an algorithm to adjust their short-acting insulin. Of this group, 219 youngsters had a full 3-yr period of observation. At each clinic visit, blood was obtained for fasting blood glucose and HbA_1 and, once a year, cholesterol and triglycerides were also measured. Patient and parent accuracy in measuring CBG was found to be adequate. The changes over time in HbA_1 were nondifferential across age and sex, and there was no difference in the level of HbA_1 between age and sex groups, the number of tests reported to have been done by the patients, the number of injections of insulin per day, or the serum cholesterol. There was a significant relationship between the HbA_1 and the fasting blood glucose ($P < .001$) measured by the laboratory as well as with the serum triglyceride ($P < .01$). The failure to improve diabetic control, despite measures that would have been expected to do so, was believed to relate more to a lack of compliance than to a flaw in the therapeutic approach. It was interesting to note that the adolescent patients in the study were in no worse control than the younger children in the group. Although better technical skills are available today to manage diabetes, the psychosocial approach to patient motivation requires improvement. *Diabetes Care* 11:484–88, 1988

Self-monitoring of blood glucose (SMBG) has become one of the most important tools of diabetic therapy. Many groups have demonstrated the efficacy of this technique in improving glycemic control of selected insulin-dependent diabetic (IDDM) patients treated with conventional therapy and intensified insulin administration (1–4). SMBG can be done with reagent strips alone or with reagent strips and a reflectance photometer. The efficacy of each technique, the reliability and precision of the different instruments available for that purpose, and individual patients' performance and short-term glycemic control have been reported many times over the last decade. However, information on the long-term effects of SMBG on the glycemic control of diabetic patients is not available. The purpose of our study was to assess the effects of SMBG on the long-term glycemic control of a large cohort of unselected young IDDM patients followed prospectively for a 3-yr period.

METHODS

Subjects. Three hundred twelve patients aged 1 to 22 yr followed at our diabetes clinic were initially enrolled in the study. Ninety-three were lost to follow-up as a consequence of their moving out of our area (24 subjects) or being transferred to adult care (69 subjects). Thus, 219 patients are the subject of this report, and they were followed for a total of 3 consecutive yr. At the end of the study, the number of fingertip punctures was measured in a subset of 86 randomly chosen patients who had recorded two to three blood glucose tests per day in their diaries.

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Treatment. After a 4-mo initiation period, patients were instructed to perform SMBG two to three times per day as well as to test for urinary acetone on the first morning urine and for urinary glucose on a second voided specimen at bedtime. SMBG was to be performed at least before breakfast and before supper and, in addition, when the bedtime urine test was negative for glucose. The evening snack was to be increased if the blood glucose proved to be <120 mg/dl at bedtime. Patients were treated with a mixture of intermediate-acting (NPH or, less frequently, Lente) and short-acting (CZI) insulin usually from Connaught Lab, Canada. The decision to treat with a single or twice-daily mixture of intermediate plus short-acting insulin was based on whether the fasting blood or urine glucose could or could not be controlled by a single injection. Algorithms, as illustrated in the prescription shown in the APPENDIX, were provided for the adjustment of the short-acting insulin according to the fasting and presupper blood or urine glucose tests. Instructions were given not to alter the algorithms or the dosage of the intermediate-acting insulin without first discussing the matter with the physician or nurse. All patients had had an initial admission at the time of diagnosis and received 7–10 days of intensive teaching. Additional teaching was given as needed, during subsequent hospitalizations or outpatient visits to the hospital. Patients were seen every 3–4 mo or more frequently when control was deemed to be unsatisfactory.

Beginning in the 2nd yr of the study, parents were asked to calculate the means for the fasting and presupper blood glucose tests at the end of each page of the diary (14 days) and to report by telephone values outside the range of 100–150 mg/dl, which we arbitrarily established as a safe goal. The clinic staff would then alter the insulin prescription as needed and/or shorten the interval between clinic visits if indicated. Failure to reduce the HbA_1 to <12% over a period of several months resulted in readmission to the hospital for control, wherever possible. After discharge, telephone follow-up was ensured in order to further adjust the basic insulin dosage to fit the level of home activity.

At each clinic visit a fasting sample of blood was obtained for laboratory estimation of glucose and HbA_1 and the patients were asked to do a visual Chemstrip bG on the same sample to verify their accuracy. Blood for cholesterol and triglyceride measurement was drawn yearly. The clinic secretary compiled the means of all blood glucose values recorded in the patients' diaries since the previous clinic visit, thus obtaining mean SMBG readings for the fasting and presupper tests for periods varying between 3 and 4 mo. The diaries were also expected to contain information about daily insulin dosages, hypoglycemia, and other events relating to control. Patients' or parents' accuracy in measuring capillary blood glucose (CBG) was assessed during clinic visits as mentioned earlier. There was a significant correlation between the CBG measured by them and the laboratory value obtained from the same blood sample (yr 1: r^2 .76, $P < .01$; yr 2: r^2 .78, $P < .001$; yr 3: r^2 .80, $P < .01$).

Analytic methods. SMBG was performed for the most part with Chemstrip bG read visually. The urine was tested with Chemstrip UG 5000K for glycosuria and ketonuria. Plasma glucose was determined by a glucose oxidase technique (Beckman glucose analyzer, Beckman, Fullerton, CA). Total glycosylated hemoglobin (HbA_1) was measured by agar gel electrophoresis without previous hemolysis of the blood, via the Corning method as previously described (5). The mean (± SD) HbA_1 in nondiabetic children in our institution at the time was 6.8 ± 1.02% (range 5–10.5%). Only three of our patients were known to have "abnormal" hemoglobin; their HbA_1 values were corrected for this factor.

Statistical analysis. Standard summary statistics, such as means and standard deviations, were used to describe the distributions of the patient characteristics. Repeated measures analysis of covariance was used to evaluate the effect of the covariance under study (age, sex, monitoring score, number of injections per day, and laboratory fasting blood glucose, cholesterol, and triglyceride) on the degree of control, as measured by HbA_1 over time. The monitoring score refers to the frequency and the type (urine or blood) of self-monitoring as recorded in the patient's diary. A score of 1 refers to the absence of any recorded tests, a score of 2 refers to patients recording both urine and blood tests but showing <14 blood glucose tests requested per week, and a score of 3 was given to patients recording ≥14 blood glucose tests per week with or without additional urine tests. All analyses were conducted with BMDP statistical software (6).

RESULTS

Table 1 describes the demographic and clinical characteristics at entry into the study. Table 2 shows the mean ± SD HbA_1 values throughout the 3-yr period. There was a highly significant increase in HbA_1 from yr

TABLE 1
Demographic and clinical characteristics at entry into study

n	219
Sex (% female)	47.5
Age	
<12 yr (%)	39.7
12–16 yr (%)	38.4
>16 yr (%)	21.9
Mean ± SD	12.6 ± 5.2
Mean duration of IDDM (yr)	5.0 ± 3.9
Mean monitoring score	2.3 ± 0.5
Mean injections per day (*n*)	1.3 ± 0.5
Mean HbA_1 at entry (%)	11.4 ± 2.1

Means are presented ±SD.

TABLE 2
Mean HbA_1 values over time by age, sex, and year of study

	n	Year 1	Year 2	Year 3
Females				
<12 yr	44	11.4 ± 1.5	12.0 ± 1.5	11.8 ± 1.5
12–16 yr	41	11.8 ± 2.3	12.6 ± 2.2	12.1 ± 1.7
>16 yr	19	11.5 ± 2.8	12.1 ± 2.3	11.6 ± 2.3
Total	104	11.6 ± 2.1	12.2 ± 1.1	11.9 ± 1.8
Males				
<12 yr	43	11.1 ± 1.4	12.2 ± 1.6	12.1 ± 1.6
12–16 yr	43	11.3 ± 1.7	12.1 ± 1.7	11.6 ± 1.6
>16 yr	29	11.2 ± 1.4	11.6 ± 1.5	11.8 ± 1.8
Total	115	11.2 ± 1.5	12.0 ± 1.6	11.8 ± 1.7
Mean ± SD	219	11.4 ± 1.8	12.1 ± 1.8	11.8 ± 1.7

Values are means ± SD.

1 to yr 2 (11.4 ± 1.8 vs. 12.1 ± 1.7%; $P < .001$) but a significant decrease in HbA_1 from yr 2 to yr 3 (12.1 ± 1.8 vs. 11.8 ± 1.7%, $P < .006$). These changes over time in HbA_1 were nondifferential across age and sex as indicated by nonsignificant interactions. In addition there was no difference in the level of HbA_1 between age and sex groups, monitoring score, number of injections per day, or level of serum cholesterol. In contrast, fasting blood glucose measured by the laboratory on clinic visits were significantly related ($P < .001$) to HbA_1 as was the serum triglyceride concentration ($P < .01$).

During the 3 yr of this survey the patients continued their normal life-styles, participating in age-related activities in their communities. Hospitalization statistics for the entire 3-yr period were as follows: 100 hospitalizations for improvement of control and psychosocial factors, 15 admissions for severe hypoglycemia (6 in yr 1, 4 in yr 2, and 5 in yr 3); 12 admissions for ketoacidosis, and 74 admissions for reasons unrelated to diabetes.

Of the 86 patients in whom there was a systematic examination of the hands for evidence of fingertip punctures, 23% had no evidence whatsoever of stab marks and their mean HbA_1 was 13.8 ± 1.7%; 23% had <10 marks (HbA_1 12.4 ± 2.7%) and the remaining 54% had ≥10 punctures (HbA_1 10.7 ± 1.5%). The difference between the groups was statistically significant (<.05). Eighty-eight percent of the children <12 yr of age had >10 finger punctures, whereas among the children >12 yr of age, only 46% had >10 finger punctures.

Of the 99 patients who dropped out of the study, we were able to contact 56. They were asked to provide as many HbA_1 results as they could give us. The group as a whole registered a mean HbA_1 value of 11.7 ± 2.3% on values ranging from 1 to 3 per patient during the time our study was in progress. The patients also reported the following major diabetes-related health events: pregnancy with loss of the fetus (1); diabetic ketoacidosis (4); admission for control (1); pyelonephritis (1); severe hypoglycemia resulting in a fall and subsequent paraplegia (1); background retinopathy (4); nephropathy and proliferative retinopathy (1).

DISCUSSION

SMBG has gained widespread acceptance and has proven feasible (7) in the childhood population with IDDM. It provides much more useful information than urine testing and would be expected to help insulin adjustment and thereby improve metabolic control. Experience with selected groups of patients on intensified insulin schedules based on regular blood glucose monitoring has shown impressive improvement in metabolic control as measured by HbA_1 (1–4).

Reports on the effects of SMBG done in conjunction with conventional insulin regimens (1 or 2 injections/day) have shown variable results (7–10). Our 3-yr study shows a slight overall worsening of control in the 1st yr, a slight improvement in the second, but no statistically significant change over the entire period.

Interestingly there was no difference in glycemic control between the sexes and different age groups. In particular, contrary to other reports (11), we found our adolescents to be in no worse control than other age groups. We believe that this reflects our practice to give as much insulin as is required to achieve reasonable control (the dosage being well above 1 U/kg during the growth spurt) and to avoid underinsulinization, a factor described to be responsible for poor control in adolescents (12,13).

The only significant correlations with HbA_1 were the fasting blood glucose levels measured by our laboratory at the time of clinic visits and the serum triglyceride concentration. The monitoring score and number of insulin injections per day would have been expected to correlate with HbA_1, but did not; the reasons are unclear. Our patients' technical skill in performing SMBG was adequate and others have had similar experience in this age group (14). However, we frequently noticed diaries that appeared to have been produced at the last moment before the clinic visit and whose results, as expressed by the mean CBG for the morning and supper tests, did not reflect the HbA_1 concentrations found at the clinic visit. Interestingly there was a correlation between mean HbA_1 and finger-prick marks.

We feel that the lack of improvement in glycemic control observed in our study relates more to the failure to perform SMBG in a consistent fashion or at all than to any inherent deficiency of SMBG. Other studies in similar clinic populations, albeit shorter in duration and smaller in sample size, have shown a lack of significant statistical or clinical difference in glycemic control between patients performing SMBG versus patients performing urine tests (8,15), or between patients perform-

ing SMBG coupled with intensive education versus patients receiving intensive education alone (9). Wing et al. (16) assessed compliance with SMBG using an 11-item questionnaire and reported that, in the month previous to the study, 26% of the patients indicated that they had been testing ≥3 times/day, 37% had been testing 1–2 times/day, and the rest had tested infrequently or never. Their findings are in agreement with our objective evidence that overall compliance with SMBG is adequate in ~50% of the young diabetic population studied. We agree with their conclusion that teaching patients how and when to monitor their blood glucose level is not sufficient to improve glycemic control. In a study done in adult patients using reflectance meters with memory chips, Mazze et al. (10) showed that noncompliance with SMBG was relatively high and that the pattern of noncompliance consisted of adding fabricated test scores to the logbook and omitting or lowering actual test values. When patients were made aware of the memory capability of the reflectance meters, overreporting and underreporting decreased and reliability and precision increased but without any significant changes in the mean blood glucose concentration. The authors concluded that steps to improve glycemic control need to link the positive behavior fostered by the modified reflectance meters with appropriate behavior regarding insulin administration and dietary regulation.

There are several possible reasons for the failure of SMBG to improve HbA_1 in our study. We have objective evidence (as assessed by finger punctures) that only 50% of this subset of patients was strictly adhering to frequent SMBG. In fact we were able to demonstrate, at least in a small number of patients, that glycemic control was significantly better in the group of children who had objective evidence of SMBG (>10 finger punctures). We also observed from the diaries that despite advice to contact us when persistent hyperglycemia was noted, many patients failed to do so. Thus, long delays ensued and hyperglycemia was maintained until the next clinic visit, several weeks or months later. It may also be that twice- to thrice-daily SMBG is insufficient, and that our treatment objectives (means of 100–150 mg/dl) were not sufficiently stringent. Changes in the other components of diabetic therapy, such as mode of insulin administration and diet regulation might not have been implemented as often as test results dictated. Finally, the efficacy of insulin administration used in conventional therapy (1–2 injections/day) may not be sufficient to substantially improve glycemic control in a large number of patients even if all components of the treatment in addition to SMBG are carefully adhered to.

We agree with Davidson (17) that it would be unfortunate if this and other studies led to the conclusion that SMBG was of no benefit. During the course of this study numerous other advantages emerged from the use of SMBG that should encourage its regular use. SMBG gives the patients and their families a sense of security during intercurrent illnesses when glycemic control is more difficult to achieve; it also establishes or disproves the presence of hypoglycemia when patients are symptomatic or in danger of hypoglycemia after exercise or during sleep. In addition, although the study group showed no change over the years, our overall clinic admission statistics showed that, toward the end of the study, there was a decrease in the number of admissions for diabetic ketoacidosis, severe hypoglycemia, and intercurrent illnesses.

Before making the statement that SMBG is of no benefit, we must address the issue of adherence to the prescribed regimen. We believe noncompliance to be the most important hurdle in the way of achieving good glycemic control. The problem in any study of the factors that interfere with or improve adherence is the difficulty of assessing adherence behavior itself (18). Verbal self-reports (19), clinician ratings (20), and home observations (21) have shown limited value in the measurement of adherence for reasons of patient denial and physician bias. In addition to adherence, other variables such as emotional factors and stress may affect glucose control. For children with IDDM, adherence usually requires once- or twice-daily insulin injections, multiple urine or blood glucose testing, consistent day-to-day caloric intake with particular attention to fixed carbohydrate:fat:protein ratios, strictly spaced meals, the implementation of insulin and dietary changes for exercise, intercurrent illnesses, and response to hypoglycemic episodes. It stands to reason that the complexity of the treatment regimen is one of the main factors associated with poor compliance (19) and that adherence to one aspect of the treatment is generally not strongly related to adherence to other aspects (22).

We have ever better technical means to aid patients in managing their insulin adjustment, but we have not achieved the same ability to motivate them to perform what is necessary to improve glycemic control. A clear communication of the objectives expected by the physician and careful attention to education that takes into account individual health beliefs, capabilities, and limitations are essential first steps. Psychological factors that may interfere with adherence also must be taken into consideration, and in individual cases, psychological counseling may result in improved behavior.

In conclusion, this study suggests that although SMBG is an important adjunct to the treatment of diabetes mellitus, simple teaching and a physician's recommendation to use it are not sufficient to improve glycemic control. Appropriate interpretation of the SMBG results with consistent implementation of insulin dose and dietary changes are essential. Further studies are needed to evaluate the relative importance of each of the aspects involved in the implementation of SMBG in order to establish its efficacy in the long-term glycemic control of diabetic patients treated with conventional insulin therapy. Until a cure for diabetes becomes available through fundamentally new medical and/or technolog-

ical advances, SMBG properly done and properly acted on remains in our opinion a valuable tool in the management of IDDM.

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APPENDIX

Example of a prescription for a single dose of NPH and an algorithm for CZI:

Breakfast

30 U of *intermediate-acting* insulin (NPH) every day. (*Do not change dosage without discussion with nurse or doctor.*)

And a sliding scale of *short-acting* insulin (CZI) according to test:

- 4 U for blood glucose ≤80 mg/dl (or negative urine)
- 6 U for blood glucose between 80 and 120 mg/dl (urine trace)
- 8 U for blood glucose between 120 and 180 mg/dl (urine 1%)
- 8 U for blood glucose between 180 and 240 mg/dl (urine 2%)
- 10 U for blood glucose ≥240 mg/dl (urine 3–5%)

Supper

0 U of *intermediate-acting* insulin (NPH) every day. (*Do not change dosage without discussing with nurse or doctor.*)

And a sliding scale of *short-acting* insulin (CZI) according to test:

- 0 U for blood glucose ≤80 mg/dl (or neg. urine)
- 0 U for blood glucose between 80 and 120 mg/dl (urine trace)
- 2 U for blood glucose between 120 and 180 mg/dl (urine 1%)
- 3 U for blood glucose between 180 and 120 mg/dl (urine 2%)
- 4 U for blood glucose ≥240 mg/dl (urine 3–5%)

REFERENCES

1. Skyler J (Ed.): Symposium on blood glucose self-monitoring. *Diabetes Care* 4:392–426, 1981
2. Schiffrin A, Belmonte MM: Multiple daily self-glucose monitoring: its essential role in long-term glucose control in insulin-dependent diabetic patients treated with pump and multiple subcutaneous injections. *Diabetes Care* 5:479–84, 1982
3. Schiffrin A, Belmonte MM: Comparison between continuous subcutaneous insulin infusion and multiple injections of insulin: a one-year prospective study. *Diabetes* 31:255–64, 1982
4. Schiffrin A, Desrosiers M, Moffatt M, Belmonte MM: Feasibility of strict diabetes control in insulin-dependent diabetic adolescents. *J Pediatr* 103:522–27, 1983
5. Aleyassine H, Gardiner RJ, Blankstein LA, Dempsey ME: Agar gel electrophoresis determination of glycosylated hemoglobin: effect of variant hemoglobins, hyperlipidemia and temperature. *Clin Chem* 27:472–75, 1981
6. Dixon WJ, Brown MB, Engelman L, Frame J, Hill M, Jennrich R, Toporek J: *BMDP Statistical Software 1985 Manual*, Berkeley, CA, Univ. of California Press, 1985, p. 359–87
7. Geffner ME, Kaplan SA, Lippe BM, Scott HL: Self monitoring of blood glucose levels and intensified insulin therapy: acceptability and efficacy in childhood diabetes. *JAMA* 249:2913–16, 1983
8. Daneman D, Siminerio L, Transue D, Betschart J, Drash A, Becker D: The role of self-monitoring of blood glucose in the routine management of children with insulin-dependent diabetes mellitus. *Diabetes Care* 8:1–4, 1985
9. Mann NP, Noronha JL, Johnston DI: A prospective study to evaluate the benefits of long-term self-monitoring of blood glucose in diabetic children. *Diabetes Care* 7:322–26, 1984
10. Mazze RS, Pasmantier R, Murphy JA, Shamoon H: Self-monitoring of capillary blood glucose: changing the performance of individuals with diabetes. *Diabetes Care* 8:207–13, 1985
11. Mann NP, Johnston DI: Total glycosylated hemoglobin (HbA_1) levels in diabetic children. *Arch Dis Child* 57:434–37, 1982
12. Mann NP, Johnston DI: Improvement in metabolic control in diabetic adolescents by the use of increased insulin dose. *Diabetes Care* 7:460–64, 1984
13. Rosenbloom, AL: Diabetes control and adolescents. *Diabetes Care* 8:304, 1985
14. Clarson C, Daneman D, Frank M, Link J, Perlman K, Ehrlich RM: Self-monitoring of blood glucose: how accurate are children with diabetes at reading Chemstrip bG? *Diabetes Care* 8:354–58, 1985
15. Carney RM, Schecter K, Homa M, Levandoski L, White N, Santiago J: The effects of blood glucose testing versus urine sugar testing on the metabolic control of insulin-dependent diabetic children. *Diabetes Care* 6:378–80, 1983
16. Wing RR, Lamparski DM, Zaslow, S, Betschart J, Siminerio L, Becker D: Frequency and accuracy of self-monitoring of blood glucose in children: relationship to glycemic control. *Diabetes Care* 8:214–18, 1985
17. Davidson MB: Futility of self-monitoring of blood glucose without algorithms for adjusting insulin doses. *Diabetes Care* 9:209–10, 1986
18. Glasgow RE, Wilson W, McCaul KD: Regimen adherence: a problematic construct in diabetes research (Editorial). *Diabetes Care* 8:300–301, 1985
19. Haynes R, Taylor D, Sackett D (Eds.): *Compliance in Health Care*. Baltimore, MD, Johns Hopkins Univ. Press, 1979, p. 1–7
20. Blackwell B: Drug therapy: patient compliance. *N Engl J Med* 289:246–52, 1973
21. Watkins J, Williams T, Martin D, Hogan M, Anderson E: A study of diabetic patients at home. *Am J Public Health* 57:452–59, 1967
22. Ary DV, Toobert D, Wilson W, Glasgow RE: Patient perspective on factors contributing to nonadherence to diabetes regimen. *Diabetes Care* 9:168–72, 1986