Frequency of Self-Monitoring of Blood Glucose during the School Day Is Associated with the Optimal Glycemic Control among Korean Adolescents with Type 1 Diabetes

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Background: This study aimed to evaluate the relationship between the frequency of self-monitoring of blood glucose (SMBG) and glycosylated hemoglobin (HbA1c) levels among Korean adolescents with type 1 diabetes mellitus (T1DM). Factors affecting the SMBG frequency were analyzed in order to improve their glycemic control.

Methods: Sixty-one adolescents aged 13 to 18 years with T1DM were included from one tertiary center. Clinical and biochemical variables were recorded. Factors associated with SMBG frequency were assessed using structured self-reported questionnaires.

Results: Average total daily SMBG frequency was 3.8±2.1 and frequency during the school day was 1.3±1.2. The mean HbA1c level was 8.6%±1.4%. As the daily SMBG frequency increased, HbA1c levels declined (P=0.001). The adjusted odds of achieving the target HbA1c in participants who performed daily SMBG ≥5 significantly increased 9.87 folds (95% confidence interval [CI], 1.58 to 61.70) compared with those performed SMBG four times a day. In the subjects whose SMBG frequency <1/day during the school day, an 80% reduction in the adjusted odds ratio 0.2 (95% CI, 0.05 to 0.86) showed compared to the group with performing two SMBG measurements in the school setting. The number of SMBG testing performed at school was significantly high for individuals assisted by their friends (P=0.031) and for those who did SMBG in the classrooms (P=0.039).

Conclusion: Higher SMBG frequency was significantly associated with lower HbA1c in Korean adolescents with T1DM. It would be necessary to establish the school environments that can facilitate adequate glycemic control, including frequent SMBG.

Keywords: Adolescent; Blood glucose self-monitoring; Diabetes mellitus, type 1; Schools

INTRODUCTION

Self-monitoring of blood glucose (SMBG) is a fundamental tool of diabetes management in especially multiple daily insulin injection-treated type 1 diabetes mellitus (T1DM) individuals. Intensive diabetes management in order to maintain optimal glycemic control was identified as reducing the development and progression of chronic complication in T1DM patients [1-3]. SMBG plays the numerous beneficial roles in predicting insulin demand, notifying hypoglycemia, providing stable glucose variability, etc.

Several studies have documented that higher frequency of daily SMBG are associated with lower glycosylated hemoglobin (HbA1c) levels in pediatric T1DM [4-10]. On the other hand, association studies were rare in particular ethnicities and geographic area like Asia with a low background incidence of...
T1DM. To date, no study has reported the association with SMBG measurement and HbA1c values among Korean adolescents with T1DM. Furthermore, it has been published that the mean HbA1c level in Korean pediatric T1DM is higher compared with those in Western Pacific and Asian countries [11]. During adolescence, diabetes care and glucose control become more difficult than the other-age group. Adolescents with T1DM have a tendency to lack of adherence to diabetes management and poor glycemic control [12,13].

The aim of this study was to investigate the relationship of SMBG to glycemic control among Korean adolescents with T1DM. The factors affecting SMBG frequency were evaluated with a structured questionnaire in order to achieve their adequate glycemic control.

METHODS

Subjects
This study was conducted between March 2015 and February 2016 on adolescents with T1DM aged 13 to 18 years who visited a tertiary hospital in Korea (n=73). The exclusion criteria were individuals with underlying disorders such as malignancy (n=1), chronic kidney disease (n=1), mental retardation (n=3), using real-time continuous glucose monitoring or flash glucose monitoring (n=1), and recent history of new-onset of T1DM (n=6) within the previous 1 year. The study was approved by the Institutional Review Board of Inha University Hospital (IUH-IRB 15-1454). Written informed consents were obtained from all participants and their legal guardians. All procedures were performed in accordance with the Declaration of Helsinki.

Methods
Total 61 subjects were enrolled for the study. This study was performed using a structured one-time questionnaire survey and a retrospective review of medical records. The questionnaires comprised of three categories about related factors to SMBG frequency were completed by individuals or their parents. Evaluated factors were included behaviors of diabetes self-care (e.g., the frequency and pattern of daily SMBG, whether the patient kept a blood glucose diary, and the individual’s understanding about diabetes), family-related factors (e.g., family structure, parents’ marital status, the main caregiver, a family history of diabetes, and family supports), and school-related factors (e.g., obstacles to measure of SMBG, the frequency and places of SMBG per day in the school setting during 6 months before enrollment). In addition, the questionnaire for school-related factors contained the following inquiry: Who has helped you to manage your illness? Who is aware of your illness? Who has informed others about your illness? Where have you been conducted SMBG at school?

The following data were obtained from the medical records: age, gender, height, weight, body mass index (BMI), duration of illness, HbA1c, C-peptide level, insulin regimen, total daily insulin dosage (TDD, dose/kg), presence of diabetes-related complications, and frequency of admission for poor metabolic control of T1DM. HbA1c levels were based on the results of the test at the time of survey.

Statistical methods
Descriptive statistics were indicated as the mean±standard deviation, or ratio. Comparisons of relevant factors between groups divided by the SMBG frequency were assessed by using the Student t-test or the chi-square test. The correlation between the SMBG frequency and HbA1c was analyzed using simple linear regression analysis. Multiple logistic regression analysis using the frequency of SMBG as a dummy variable was performed to assess achievement of the target HbA1c level (7.5%) according to daily frequency of SMBG and frequency in the school setting. The results were reported as the odds ratios (ORs) and 95% confidence intervals (CIs) with adjustment for variables. Multiple linear regression analysis was conducted to assess the association between school-related factors and SMBG testing performance in the school setting. The results were shown with regression coefficients, 95% CIs, and P values after adjusting for variables (diabetes mellitus [DM] family history, daily insulin dosage). IBM SPSS version 19 (IBM Co., Armonk, NY, USA) was used for statistical analysis.

RESULTS

Patient characteristics
Of the 61 participants, 36% were male (n=22) and the mean age was 15.5±1.9 years. All subjects have received multiple daily insulin-injection regimens without insulin pump. There was no one using real-time continuous glucose monitoring or flash glucose monitoring. The mean diabetes duration was 6.0±3.8 years while the mean BMI-standard deviation score was 0.39±0.95. The mean TDD was 0.93±0.36 IU/kg and the mean C-peptide level was 0.26±0.31 ng/mL. The mean HbA1c
The mean numbers of SMBG performance during the school day was 1.3±1.2 times per day. While total 10 participants (16.4%) reported less than one SMBG checks per day, 18 subjects (29.5%) checked blood glucose less than one time per day in schools. About half of participants (n=31) was provided with school supports from teachers or friends for glycemic control including SMBG measurements. Only 9.8% (n=6) of all subjects received assistance from friends, and 32.8% performed their SMBG in classrooms during the school day (Table 1). On average, the subjects performed 1.4±1.0 insulin injection per day at school.

Comparison of related factors in T1DM adolescents according to daily frequency of SMBG and frequency during the school day

According to the guidelines of International Society of Pediatric and Adolescent Diabetes (ISPAD), SMBG frequency is recommended more than or equal to four times per day [14,15]. Since middle and high school students in Korea spend an average of 10 hours (8 to 14 hours) a day at school, half out of required daily SMBG numbers in students with T1DM is supposed to be carried out at the school setting. Subjects were divided into two groups, each of whom performed SMBG more than or equal to four times and less than four times, depending on the number of daily SMBG testing. Subjects in a group that performed SMBG ≥4 times/day showed significantly higher
TDD, higher SMBG frequency at school and lower DM family history compared to subjects in other group with less than four times of daily SMBG (Table 2). On the other hand, there was no significant factors between two groups, which more than or equal to two times a day of SMBG or less than two times a day of SMBG during the school day (Table 2).

The association between optimal glycemic control and frequency of SMBG
As the frequency of SMBG increased, HbA1c levels declined; the average fall in HbA1c was 0.42%, depending on increase in the number of SMBG per day (Fig. 1). Upon the stepwise multiple logistic regression analysis, the odds of achieving the target HbA1c in participants who performed SMBG ≥5 times per day significantly increased 9.87 folds (95% CI, 1.58 to 61.70; P=0.014) after adjustment for family history of DM and TDD compared with those performed SMBG four times a day (Table 3). In the subjects whose SMBG frequency was less than once a day during the school day, the adjusted odds to reach target HbA1c (<7.5%) significantly decreased to 0.2 folds (95% CI, 0.05 to 0.86; P=0.031). This result showed an 80% reduction in the OR compared to the reference group, which performing two blood glucose measurements in the school setting. All subjects in group of daily SMBG at school ≥3 were in

Table 2. Comparison of related factors in type 1 diabetes mellitus adolescents according to daily total frequency of SMBG and frequency during the school day

| Factor                        | Daily total SMBG frequency | P value | Daily SMBG frequency at school | P value |
|-------------------------------|----------------------------|---------|-------------------------------|---------|
|                               | ≥4 times/day | <4 times/day | P value | ≥2 times/day | <2 times/day | P value |
| Number                        | 33           | 28         | 0.175 | 21           | 40         | 0.115 |
| Age, yr                       | 15.0±1.8     | 15.6±1.4   |        | 14.8±1.7     | 15.5±1.6   | 0.129 |
| Female sex                    | 22 (71.0)    | 15 (60.0)  | 0.411 | 16 (72.7)    | 23 (58.9)  | 0.178 |
| DM duration, yr               | 6.1±4.0      | 5.5±3.5    | 0.321 | 5.1±3.2      | 6.1±4.0    | 0.178 |
| Insulin dosage, IU/kg/day     | 1.09±0.36    | 0.76±0.34  | 0.029 | 0.92±0.35    | 0.94±0.38  | 0.872 |
| DM family history             | 5 (15.2)     | 12 (42.8)  | 0.015 | 5 (22.8)     | 12 (30.7)  | 0.485 |
| Marital status of parents     | 26 (78.8)    | 23 (82.1)  | 0.842 | 18 (81.9)    | 31 (79.5)  | 0.892 |
| Family supports               | 23 (69.9)    | 20 (71.4)  | 0.781 | 15 (68.2)    | 28 (71.8)  | 0.682 |
| Blood glucose diary           | 12 (36.3)    | 9 (32.1)   | 0.524 | 8 (38.1)     | 15 (37.5)  | 0.561 |
| SMBG at school                | 30 (90.9)    | 13 (46.4)  | 0.006 | NA           | NA         | NA    |
| Insulin injection in school, time/day | NA       | NA         | NA    | 1.7±0.80     | 1.2±1.1    | 0.081 |

Values are presented as mean±standard deviation or number (%). SMBG, self-monitoring of blood glucose; DM, diabetes mellitus; NA, not applicable.

Table 3. OR of achieving the target glycosylated hemoglobin level (<7.5%) according to daily frequency of SMBG and frequency in the school setting

| No. of frequency | No. of subject | OR (95% CI) | P value | AOR (95% CI) | P value |
|------------------|----------------|-------------|---------|--------------|---------|
| Daily total SMBG | ≥5             | 16          | 7.33 (1.47–36.66) | 0.015 | 9.87 (1.58–61.70) | 0.014 |
|                  | 4              | 17          | Reference | Reference     |         |
|                  | ≤3             | 28          | 0.76 (0.15–3.78) | 0.741 | 0.77 (0.11–5.58) | 0.793 |
| Daily SMBG at school | ≥3          | 6           | NA b     | NA b         | NA b    |
|                  | 2              | 15          | Reference | Reference     |         |
|                  | ≤1             | 40          | 0.2 (0.08–0.99) | 0.048 | 0.2 (0.05–0.86) | 0.031 |

OR, odds ratio; SMBG, self-monitoring of blood glucose; CI, confidence interval; AOR, adjusted odds ratio; NA, not applicable.

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HbA1c <7.5% (Table 3).

The association between school-related factors and SMBG frequency in the usual school setting

In order to investigate the association of school-related factors on the frequency of SMBG testing at school [16], a multiple linear regression analysis was performed. Subjects who received assistance from friends (β, 0.294; 95% CI, 0.104 to 2.085; P=0.031) and those who performed SMBG in classrooms (β, –0.291; 95% CI, –1.483 to –0.040; P=0.039) showed higher number of SMBG during the school day, as compared with those who did not. However, assistance from teachers was not associated with SMBG frequency in the usual school setting (Table 4).

DISCUSSION

With the introduction of glucometers 40 years ago, SMBG has emerged as the most important tool in glycemic control. The frequency of SMBG could be seen as a surrogate tool for self-care of diabetes. Checking the accurate blood glucose value is the starting point for adjusting insulin dose, physical exercise, and lifestyle [4].

In general, youth with T1DM frequently shows a poor compliance to self-care of diabetes including performance of SMBG [14,15]. In light of potential occurrences and progress of chronic diabetic complications during puberty, building healthy lifestyle to achieve proper diabetes management is linked to the healthy adulthood in the future. Pubertal changes make them more likely to form unhealthy lifestyle, while daily insulin requirements increase as a result of physiologic pubertal insulin resistance [17]. Also, parents-T1DM adolescent’s relationships are often challenged which can create diabetes care-related family conflict and adversely affect adequate glycemic control. Despite of proven unfavorable aspects during adolescent period, SMBG is necessary for individuals to achieve optimal glycemic control. This study showed that frequent blood glucose monitoring in Korean adolescents with T1DM reflects commitment to diabetes control, which is consistent with the results of several studies on youths in other countries [4,5,7,9] and Korea [18]. The mean HbA1c reduction was 0.42% for one additional SMBG per day under the SMBG frequency up to 5 per day, this is similar to the results reported by Ziegler et al. [4]. Also, Consensus Guidelines of ISPAD and American Diabetes Association recommended that four or more times per day are generally necessary for pediatric T1DM [14,16], which nearly corresponds to the results of this study.

This study showed that Korean T1DM adolescents whom performed SMBG more than or equal to five times daily tended to have significantly target blood glucose levels compared with those who did not. In this study, the mean total frequency of SMBG in Korean T1DM adolescents was 3.8 per day. As compared with the mean frequency of SMBG performed by European (DPV-WISS database) [4] and American adolescents [7], which were 4.4 per day and 5.2 per day respectively, Korean adolescents presented fewer testing frequency. Further, the proportion of adolescents performing SMBG less than once per day was 16.4% (10/61), which is about twice as much as that of Korean adults with T1DM (8.7%) [19]. It is indicated

| Variable | β | 95% CI | P value |
|----------|---|--------|---------|
| Who has helped you to manage your illness? | | | |
| Teachers vs. none | 0.209 | –0.157 to 1.215 | 0.128 |
| Friends vs. none | 0.294 | 0.104 to 2.085 | 0.031 |
| Who is aware of your illness? | | | |
| Teachers only vs. friends | 0.352 | –0.942 to 1.343 | 0.726 |
| Who has informed others about your illness? | | | |
| Myself vs. others | 0.169 | –0.277 to 1.173 | 0.220 |
| Where have you been conducted SMBG at school? | | | |
| Another place vs. classroom | –0.291 | –1.483 to –0.040 | 0.039 |

Multiple linear regression analysis was performed.
SMBG, self-monitoring of blood glucose; CI, confidence interval.
*Adjusted for variable including diabetes mellitus family history, daily insulin dosage, \( P < 0.05 \).
the seriousness of the aspect on blood glucose self-monitoring among T1DM adolescents in Korea.

The most significant factor affecting the daily SMBG frequency in T1DM Korean youth could be the SMBG frequency during the school day. School-life is one of the most important environmental factors among adolescents in Korea because they spend as long as 8 to 14 hours per day at school. In this study, high school students presented a lower overall daily SMBG counts (total daily 3.1 SMBG including 0.9 SMBG at school) than middle school students (total daily 4.6 SMBG including 1.3 SMBG at school), which may be because they spend more time during the school day than middle school students and life patterns are fixed.

Even about 29% of all subjects reported less than one blood glucose measurement per day at the school setting, and the average frequency of SMBG during the school day was only 1.3 ± 1.2 times per day. There might be several possible reasons to explain these results. First of all, adolescents have a tendency to avoid becoming the center concern of attention from their friends and teachers due to diabetes self-care [20-22]. The unwillingness of most adolescents to inform friends of their diabetes condition has also been reported, which found that one third of Korean youth with T1DM performed self-insulin injections in school toilet [23]. Secondly, about half (50.9%) of adolescents reported low compliance with SMBG due to lack of time during school life, which can be interpreted as environmental constraints such as short break and inappropriate spatial conditions in school [24]. Environmental factors could be the most important parts affecting SMBG adherence to teenagers. Thirdly, proper diabetes-care system at school has not yet been established in Korea. One-third of Korean health teachers had no any experiences for managing students with diabetes [25].

Several studies in other countries have revealed that students with diabetes should receive appropriate care, including aid provided by trained staffs in school to reduce the risk of short- and long-term complication [26,27]. In this study, teachers’ help did not influence the frequency of SMBG, which may be due to improper school-intervention system for diabetes care in Korea. The number of SMBG measurements in the school setting was significantly higher for individuals who were helped by their friends and those who measured SMBG in the classrooms. The findings suggest that a supportive school system including peer participation for diabetes-care should be developed [28,29]. Family supports of diabetes management did not affect the frequency of daily SMBG, which was consistent with previous studies [22,23].

This study has several limitations. Firstly, the number of enrolled participants was insufficient. Secondly, there may have been response biases due to using questionnaires. Thirdly, there was not enough survey into factors that may affect diabetes control, such as annual household income, and parental education level.

However, this is the first study to validate the correlation between the number of daily SMBG and HbA1c levels in Korean adolescents with T1DM, and to investigate the condition that SMBG testing can be properly at school. In conclusion, the daily SMBG frequency was significantly associated with HbA1c levels among T1DM adolescents in Korea. It would be necessary to establish the school environments that can facilitate adequate glycemic control as well as proper SMBG testing during the school day.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Parkin CG, Davidson JA. Value of self-monitoring blood glucose pattern analysis in improving diabetes outcomes. J Diabetes Sci Technol 2009;3:500-8.
2. Karter AJ. Role of self-monitoring of blood glucose in glycemic control. Endocr Pract 2006;12 Suppl 1:110-7.
3. Diabetes Control and Complications Trial Research Group, Nathan DM, Gennuth S, Lachin J, Cleary P, Crofford O, Davis M, Rand L, Siebert C. The effect of intensive treatment of diabetes on the development and progression of long-term complications in insulin-dependent diabetes mellitus. N Engl J Med 1993;329:977-86.
4. Ziegler R, Heidtmann B, Hilgard D, Hofer S, Rosenbauer J, Holl R; DPV-Wiss-Initiative. Frequency of SMBG correlates with HbA1c and acute complications in children and adolescents with type 1 diabetes. Pediatr Diabetes 2011;12:111-7.
5. Haller MJ, Stallvey MS, Silverstein JH. Predictors of control of diabetes: monitoring may be the key. J Pediatr 2004;144:660-1.
6. Levine BS, Anderson BJ, Butler DA, Antisdell JE, Brackett J, Lafe LM. Predictors of glycemic control and short-term adverse outcomes in youth with type 1 diabetes. J Pediatr 2001;139:197-203.
7. Miller KM, Beck RW, Bergenstal RM, Goland RS, Haller MJ, McGill JB, Rodriguez H, Simmons JH, Hirsch IB; T1D Exchange Clinic Network. Evidence of a strong association between frequency of self-monitoring of blood glucose and hemoglobin A1c levels in T1D exchange clinic registry participants. Diabetes Care 2013;36:2009-14.
8. Bui H, Perlman K, Daneman D. Self-monitoring of blood glucose in children and teens with diabetes. Pediatr Diabetes 2005;6:50-62.
9. Helgeson VS, Honcharuk E, Becker D, Escobar O, Siminerio L. A focus on blood glucose monitoring: relation to glycemic control and determinants of frequency. Pediatr Diabetes 2011;12:25-30.
10. Karter AJ, Ackerson LM, Darbinian JA, D’Agostino RB Jr, Ferrara A, Liu J, Selby JV. Self-monitoring of blood glucose levels and glycemic control: the Northern California Kaiser Permanente Diabetes registry. Am J Med 2001;111:1-9.
11. Craig ME, Jones TW, Silink M, Ping YJ. Diabetes care, glycemic control, and complications in children with type 1 diabetes from Asia and the Western Pacific Region. J Diabetes Complications 2007;21:280-7.
12. Morris AD, Boyle DI, McMahon AD, Greene SA, MacDonald TM, Newton RW. Adherence to insulin treatment, glycemic control, and ketoacidosis in insulin-dependent diabetes mellitus. The DARTS/MEMO Collaboration. Diabetes Audit and Research in Tayside Scotland. Medicines Monitoring Unit. Lancet 1997;350:1505-10.
13. Mortensen HB, Robertson KJ, Aanstoot HJ, Danne T, Holl RW, Hougaard P, Atchison JA, Chiarelli F, Daneman D, Dinesen B, Dorchy H, Garandeau P, Greene S, Hoey H, Kaprio EA, Kocova M, Martul P, Matsuura N, Schoenle EJ, Sovik O, Swift PG, Tsou RM, Vanelli M, Aman J. Insulin management and metabolic control of type 1 diabetes mellitus in childhood and adolescence in 18 countries. Hvidore Study Group on Childhood Diabetes. Diabet Med 1998;15:752-9.
14. Rewers MJ, Pillay K, de Beaufort C, Craig ME, Hanas R, Acerini CL, Maahs DM; International Society for Pediatric and Adolescent Diabetes. ISPAD Clinical Practice Consensus Guidelines 2014. Assessment and monitoring of glycemic control in children and adolescents with diabetes. Pediatr Diabetes 2014;15 Suppl 20:102-14.
15. Evans JM, Newton RW, Ruta DA, MacDonald TM, Stevenson RJ, Morris AD. Frequency of blood glucose monitoring in relation to glycaemic control: observational study with diabetes database. BMJ 1999;319:83-6.
16. Goldstein DE, Little RR, Lorenz RA, Malone JI, Nathan DM, Peterson CM; American Diabetes Association. Tests of glycaemia in diabetes. Diabetes Care 2004;27(Suppl 1):s91-3.
17. Smith CP, Williams AJ, Thomas JM, Archibald HR, Algar VD, Bottazzo GF, Gale EA, Savage MO. The pattern of basal and stimulated insulin responses to intravenous glucose in first degree relatives of type 1 (insulin-dependent) diabetic children and unrelated adults aged 5 to 50 years. Diabetologia 1988;31:430-4.
G. Peer and family support in children and adolescents with type 1 diabetes. J Pediatr Psychol 2002;27:429-38.
29. Bearman KJ, La Greca AM. Assessing friend support of adolescents’ diabetes care: the diabetes social support questionnaire-friends version. J Pediatr Psychol 2002;27:417-28.