Differences in the Management of Type 1 Diabetes Among Adults Under Excellent Control Compared With Those Under Poor Control in the T1D Exchange Clinic Registry

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OBJECTIVE—Optimizing glycemic control in type 1 diabetes is important to minimize the risk of complications. We used the large T1D Exchange clinic registry database to identify characteristics and diabetes management techniques in adults with type 1 diabetes, differentiating those under excellent glycemic control from those with poorer control.

RESEARCH DESIGN AND METHODS—The cross-sectional analysis included 627 participants with HbA_{1c} <6.5% (excellent control) and 1,267 with HbA_{1c} ≥8.5% (fair/poor control) at enrollment who were ≥26 years of age (mean ± SD 45.9 ± 13.2 years), were not using continuous glucose monitoring, and had type 1 diabetes for ≥2 years (22.8 ± 13.0 years).

RESULTS—Compared with the fair/poor control group, participants in the excellent control group had higher socioeconomic status, were more likely to be older and married, were less likely to be overweight, were more likely to exercise frequently, and had lower total daily insulin dose per kilogram ($P < 0.0001$ for each). Excellent control was associated with more frequent self-monitoring of blood glucose (SMBG), giving mealtime boluses before a meal rather than at the time of or after a meal, performing SMBG before giving a bolus, and missing an insulin dose less frequently ($P < 0.0001$ for each). Frequency of severe hypoglycemia was similar between groups, whereas diabetic ketoacidosis was more common in the fair/poor control group.

CONCLUSIONS—Diabetes self-management related to insulin delivery, glucose monitoring, and lifestyle tends to differ among adults with type 1 diabetes under excellent control compared with those under poorer control. Future studies should focus on modifying diabetes management skills in adult type 1 diabetes patients with suboptimal glycemic control.

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The Diabetes Control and Complications Trial (DCCT) demonstrated that lowering average blood glucose levels leads to decreased microvascular and macrovascular complications (1,2). In the intervening years, much advancement has been made in an attempt to improve diabetes management through the development of insulin analogs, improvement of insulin infusion pumps, and development of continuous glucose monitoring (CGM) systems. Certified diabetes education programs provide evidence-based information to patients on ways to achieve optimal diabetes control, and in the current digital era, information about the carbohydrate content of food is at the fingertips of many patients. However, although some patients have excellent glycemic control on the basis of HbA_{1c} values, it is not always apparent how their diabetes management differs from patients who have poor diabetes control. The large T1D Exchange clinic registry database provides an opportunity to cross-sectionally analyze differences in patient characteristics as well as aspects of diabetes management in adult patients with HbA_{1c} values in the excellent range compared with those with values in the fair/poor range.

RESEARCH DESIGN AND METHODS

The T1D Exchange Clinic Network includes 67 U.S. pediatric and adult endocrinology practices. A registry of individuals with type 1 diabetes commenced enrollment in September 2010 (3). Each clinic received approval from an institutional review board, and informed consent was obtained from adult participants and parents or guardians of minors; assent from minors was obtained as required. Data were collected for the registry's central database from participant medical records and by having the participant or parent complete a comprehensive questionnaire, as previously described (3).

To have a substantial separation between groups with regard to HbA_{1c} values, excellent glycemic control was arbitrarily defined as an average HbA_{1c} <6.5% in the past 12 months and fair/poor control as an average HbA_{1c} ≥8.5% in the past 12 months. The present report includes data on participants enrolled through 1 August 2012 who were

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≥26 years of age, had type 1 diabetes for ≥2 years, and had an average HbA_{1c} level in the 12 months before enrollment of either <6.5 or ≥8.5%. The lower limit of 26 years was used because the registry data indicate that participants 18–25 years of age more closely resembled 13–17 year olds than older adults. Participants for whom data were not available to characterize as either a pump or injection user were excluded. In addition, users of real-time CGM were excluded because key aspects of diabetes management might differ between CGM users and nonusers, and the percentage of CGM users was small. Of the 5,475 T1D Exchange clinic registry participants meeting the non-HbA_{1c} inclusion criteria, 11% (n = 627) were classified as having excellent control (HbA_{1c} <6.5%), and 23% (n = 1,267) were classified as having fair/poor control (HbA_{1c} ≥8.5%); the other 65% (n = 3,581) with HbA_{1c} between 6.5 and 8.4% were not included in the analyses.

Data used in the analyses were obtained from a questionnaire completed by the participant, the elements of which included questions about diabetes management, lifestyle (marital and employment status, exercise), family history, and socioeconomic factors. BMI was determined from height and weight measurements at the most recent office visit. HbA_{1c} levels, mainly measured with point-of-care devices (60% DCA 2000 [Bayer] and DCA Vantage [Siemens], 6% other point-of-care devices, 38% laboratory, 2% unknown), were obtained from the clinic chart. The mean ± SD number of HbA_{1c} values per participant was 2.9 ± 1.3 in the excellent control group and 2.6 ± 1.3 in the fair/poor control group. Severe hypoglycemia (SH) was defined as the occurrence of hypoglycemia-induced seizure or loss of consciousness. Diabetic ketoacidosis (DKA) was defined as the occurrence of ketoacidosis that resulted in overnight hospitalization.

Characteristics between the excellent control versus fair/poor control groups were compared by t test for continuous variables and χ^2 test for categorical variables (Mantel-Haenszel statistics for ordered categories). Separate analyses were conducted for insulin pump and injection users. Analyses initially were conducted in four age-groups (26–<31, 31–<50, 50–<65, and ≥65 years) but then pooled across age-groups because results among the age-groups appeared similar. In view of the large sample size and number of variables evaluated, only $P < 0.01$ was considered to be meaningful. SAS version 9.3 (SAS Institute, Cary, NC) was used for the analyses.

RESULTS—The characteristics of the 627 participants with excellent control and 1,267 with fair/poor control are shown in Table 1. Compared with the fair/poor control group, the excellent

Table 1—*Participant characteristics in the excellent and fair/poor HbA_{1c} control groups*

	Excellent HbA_{1c} <6.5% (n = 627)	Fair/poor HbA_{1c} ≥8.5% (n = 1,267)	P value
Age (years)	47.6 ± 14.2	45.0 ± 12.6	0.0001
Age-group			
26–<31 years	81 (13)	198 (16)	
31–<50 years	286 (46)	632 (50)	
50–<65 years	172 (27)	354 (28)	
≥65 years	88 (14)	83 (7)	
Female sex	316 (50)	712 (56)	0.02
Race/ethnicity			<0.0001
White non-Hispanic	582 (93)	1,071 (85)	
Black non-Hispanic	7 (1)	101 (8)	
Hispanic or Latino	19 (3)	49 (4)	
Other race/ethnicity	17 (3)	41 (3)	
Duration of type 1 diabetes (years)	22.9 ± 14.7	22.7 ± 12.1	0.7
BMI[a] (kg/m^2)	26.0 ± 4.8	28.2 ± 5.9	<0.0001
BMI category			
Normal/underweight (14.5–<25 kg/m^2)	231 (48)	293 (32)	
Overweight (25–<30 kg/m^2)	172 (36)	336 (37)	
Obese (≥30 kg/m^2)	78 (16)	285 (31)	
Household income[b]			<0.0001*
<$25,000	33 (7)	184 (20)	
$25,000–<$50,000	77 (16)	243 (26)	
$50,000–<$75,000	87 (18)	196 (21)	
≥$75,000	281 (59)	311 (33)	
Education[c]			<0.0001*
Less than a high school diploma	10 (2)	61 (5)	
High school diploma/GED	130 (22)	514 (45)	
Associate's degree	41 (7)	146 (13)	
Bachelor's degree	218 (37)	291 (25)	
Master's degree, doctorate, or professional degree	184 (32)	135 (12)	
Insurance status[d]			<0.0001
Private	428 (85)	735 (69)	
Other	70 (14)	274 (26)	
No insurance	8 (2)	54 (5)	
Marital status			<0.0001
Living alone[e]	133 (22)	471 (40)	
Married/living together	464 (78)	718 (60)	
Employment status			0.3
Student	14 (2)	32 (3)	
Working full/part time	372 (63)	703 (60)	
Not working	208 (35)	445 (38)	

Data are mean ± SD or n (%). GED, general educational development. *Mantel-Haenszel χ^2 statistics. [a]One hundred forty-six participants missing BMI in the excellent control group and 353 in the fair/poor control group because of unavailable height or weight data. [b]One hundred forty-nine participants missing household income data in the excellent control group and 333 in the fair/poor control group. [c]Forty-four participants missing education data in the excellent control group and 120 in the fair/poor control group. [d]Analysis is limited to those <65 years of age because of availability of Medicare insurance to all ≥65 years of age. Thirty-three participants missing insurance data in the excellent control group and 121 in the fair/poor control group. [e]Includes single, separated, divorced, and widowed.

control group on average was 2.6 years older; less likely to have a BMI in the overweight or obese range; more likely to be white non-Hispanic; more likely to have a higher income, higher education level, and private insurance; and more likely to be married ($P < 0.0001$ for each). Duration of diabetes was similar in the two groups. In the excellent control group, 336 (54%) were using an insulin pump compared with 580 (46%) in the fair/poor control group ($P = 0.001$).

A number of factors related to diabetes management differed significantly ($P < 0.0001$) between the excellent control and fair/poor control groups (Table 2), with similar findings among both pump and injection users (Supplementary Tables 1–3). Those in the excellent control group more frequently performed self-monitoring of blood glucose (SMBG) (72 vs. 36% reporting SMBG frequency ≥5 times/day), including more frequent SMBG measurements before giving a bolus (56 vs. 32% reporting always doing this); less frequently missed insulin doses (94 vs. 55% reporting missing a dose <1/week); more often gave a mealtime insulin bolus before a meal rather than at the time of or after a meal (69 vs. 54%); and more frequently exercised ≥3 days/week (72 vs. 59%). In both pump and injection users, the average total daily insulin dose was lower in the excellent control group than in the fair/poor control group ($P < 0.0001$), and the ratio of bolus to basal insulin was higher ($P = 0.001$). A comparison of the excellent and fair/poor control groups on diabetes management factors is shown in Table 2. At least three of the four key aspects of diabetes management (SMBG ≥5 times/day, always performing SMBG before giving a bolus, giving a meal bolus before the meal, and missing an insulin dose <1 time/week) were reported by 62% of the excellent group and 26% of the fair/poor group ($P < 0.0001$).

Among pump users (Supplementary Table 2), the excellent control group tended to have a greater number of basal insulin rate changes per day (3.9 ± 2.1 vs. 3.4 ± 2.0, $P = 0.001$); average duration of pump insertion was similar in the excellent and fair/poor control groups (3.3 ± 0.7 vs. 3.3 ± 0.8 days, $P = 0.2$). Among injection users (Supplementary Table 3), most participants in both the excellent and the fair/poor control groups were using a regimen that included short- and long-acting insulins.

Hypoglycemia-induced seizure or loss of consciousness within the prior

Table 2—*Comparison of diabetes management characteristics in the excellent and fair/poor HbA_{1c} control groups*

	Excellent HbA_{1c} <6.5% (n = 627)[a]	Fair/poor HbA_{1c} ≥8.5% (n = 1,267)[a]	P value
Self-reported SMBG frequency/day	6.45 ± 2.94	4.24 ± 2.30	<0.0001
Times/day			
0–2	32 (5)	221 (19)	
3–4	137 (23)	538 (45)	
5–9	337 (56)	383 (32)	
≥10	94 (16)	43 (4)	
Frequency of SMBG before giving bolus at time of meal[b]			<0.0001*
Never/rarely	17 (4)	102 (11)	
Sometimes/most of the time	170 (40)	553 (57)	
Always	235 (56)	311 (32)	
Total daily insulin dose (units/kg/day)	0.54 ± 0.26	0.67 ± 0.33	<0.0001
Tertiles			
1st (<0.48 units/kg/day)	258 (44)	330 (29)	
2nd (0.48–<0.68 units/kg/day)	195 (33)	371 (32)	
3rd (≥0.68 units/kg/day)	134 (23)	455 (39)	
Number of boluses on a typical day			0.006
≤2	50 (9)	111 (10)	
3–4	316 (54)	725 (63)	
≥5	217 (37)	308 (27)	
Ratio of bolus to basal insulin	1.43 ± 2.02	1.10 ± 1.70	0.001
Ratio categories			
<0.9	191 (34)	542 (51)	
0.9–<1.5	193 (35)	333 (31)	
≥1.5	172 (31)	185 (17)	
Bolus given for daytime snacks			0.0003*
Never/ rarely	165 (29)	415 (35)	
Sometimes/most of the time	287 (51)	619 (52)	
Always	108 (19)	148 (13)	
Timing of mealtime insulin bolus			<0.0001
Not given regularly	10 (2)	68 (6)	
Before meal	420 (69)	648 (54)	
During or after meal	87 (14)	328 (27)	
Depends on glucose level prior to meal	89 (15)	167 (14)	
Insulin:carbohydrate ratio used to determine amount of insulin bolus			<0.0001
No/do not know	130 (23)	310 (28)	
Yes, all three meals the same	285 (51)	621 (56)	
Yes, three meals not all the same	141 (25)	176 (16)	
Frequency of missing insulin dose			<0.0001*
Never	426 (70)	390 (32)	
<1 time/week	141 (23)	274 (23)	
1–2 times/week	31 (5)	286 (24)	
≥3 times/week	7 (1)	261 (22)	
Frequency of exercise[c]			<0.0001
0 days/week	42 (10)	157 (18)	
1–2 days/week	73 (18)	192 (23)	
3–5 days/week	201 (50)	360 (42)	
6–7 days/week	90 (22)	142 (17)	
Composite of four factors[d]	2.73 ± 0.92	1.69 ± 1.17	<0.0001
Factors			
0	3 (1)	215 (18)	
1	59 (10)	346 (29)	
2	166 (27)	334 (28)	
3	250 (41)	229 (19)	
4	128 (21)	87 (7)	

Data are mean ± SD or n (%). *Mantel-Haenszel χ^2 statistics. [a]Number of participants ranges from 556 to 606 in the excellent control group and from 1,107 to 1,211 in the fair/poor control group, depending on availability of data for each factor (except for frequency of SMBG and frequency of exercise). [b]Two hundred five participants missing frequency of SMBG data in the excellent control group and 301 in the fair/poor control group. [c]Two hundred twenty-one participants missing frequency of exercise data in the excellent control group and 416 in the fair/poor control group. [d]The composite variable (range 0–4) comprises four dichotomous items (0/1): bolus before meal, always SMBG before giving a bolus at time of meal, miss doses <1 time/week, and SMBG frequency ≥5 times/day.

12 months was reported by 13% of the excellent control and 12% of the fair/poor control groups ($P = 0.7$). DKA was reported by 1 and 12%, respectively ($P < 0.0001$). Sixty-two percent of the excellent control group described their general health as very good or excellent compared with 21% of the fair/poor control group ($P < 0.0001$). Fifty percent of the excellent control group reported that they never or rarely felt stress about their diabetes compared with 27% of the fair/poor control group ($P < 0.0001$).

CONCLUSIONS—Analysis of the large T1D Exchange clinic registry database provided the opportunity to gain a better understanding of why some adults with type 1 diabetes achieve better glycemic control than others. Some of the differentiating features indirectly contributed, such as income, education level, health insurance, and marital status, mostly indicators of higher socioeconomic status that are likely not modifiable. This association with socioeconomic status has been demonstrated in pediatric patients but has not been well studied in adult populations (4,5). Because potentially modifiable factors associated with glycemic control are of the most interest, we intentionally did not adjust for socioeconomic status in evaluating differentiating aspects of diabetes management. We only considered $P < 0.01$ to be significant in view of the multiple factors evaluated, and almost all significant associations had a $P < 0.0001$, reflecting the large sample size. Although it seems unlikely that differential reporting between groups would account for the significant differences found, it is possible that some of the differences could be underestimates if participants in the fair/poor control group misreported some of the information more often than those in the excellent control group, such as frequency of missed insulin doses.

Although for all diabetes management factors there was overlap between the excellent and fair/poor control groups, several factors stood out as tending to differentiate the two groups, particularly frequency of SMBG measurements, frequency of missing an insulin dose, and timing of the meal bolus. An association between SMBG frequency and HbA_{1c} has been shown in other studies (6–9). The finding related to timing of the meal bolus is consistent with findings in patients with type 1 diabetes describing lower glycemic excursions when insulin is given 20 min before a meal compared with immediately before or 20 min after a meal (10); however, a randomized crossover study in type 2 diabetes did not find a beneficial effect of giving an early bolus before a meal on HbA_{1c} (11). The observational nature of the present study precludes a definitive statement regarding causality. Nevertheless, it is important for insurers to consider that reducing restrictions on the number of test strips provided per month may lead to improved glycemic control for some patients with type 1 diabetes, resulting in a potential cost-savings from both short- and long-term complications.

Of note, participants with excellent HbA_{1c} values had lower BMIs, exercised more frequently, and had lower total daily insulin dose per kilogram. Although it is not possible to establish a causal relationship, exercise improves insulin sensitivity (12), as does lowering BMI (13). The fact that total daily insulin doses also were lower suggests that there may be a degree of insulin resistance in those with the higher HbA_{1c} levels that could be affected by an increase in exercise and weight loss. Additionally, participants with excellent control were more likely to report an improved sense of overall health as well as lack of stress about diabetes. Whether these findings are because of a sense of self-efficacy resulting in improved diabetes management or whether the improved perception of health is related to better diabetes control is difficult to determine. If improved perception of health leads to improved health, then perhaps counseling and educational programs can be important components of diabetes management.

The lack of an increase in SH in patients with excellent control compared with those with fair/poor control is reassuring in knowing that a low HbA_{1c} level can be achieved with a risk for SH that is no higher than the risk in those with fair/poor control. This finding differs from DCCT findings in which there was a strong association between lower HbA_{1c} levels as a result of intensive management and an increase in SH (1). However, but the finding is consistent with a more recent study (14) that did not demonstrate an association between lower HbA_{1c} and frequency of SH episodes. This may be due to an improvement in insulin management through the use of short-acting insulin analogs or diabetes education, resulting in appropriate adjustment of insulin doses with mild hypoglycemia. In contrast, the frequency of DKA, not surprisingly, was higher in the fair/poor control group.

In conclusion, diabetes self-management related to insulin delivery, glucose monitoring, and lifestyle tends to differ when comparing adults with type 1 diabetes under excellent control with those under poorer control. A better understanding of the aspects of diabetes self-management associated with better glycemic control on the part of patients may lead to improved control and better long-term outcomes with lower risk of microvascular and macrovascular complications. Future studies should focus on modification of diabetes management skills in adult patients with type 1 diabetes who have suboptimal glycemic control.

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