ORIGINAL ARTICLE

Evaluation of the Average Daily Risk Range as a Measure of Glycemic Variability in Youths with Type 1 Diabetes

Susana R. Patton, PhD, CDE¹, Stephen A. DeLurgio, PhD,² and Mark A. Clements, MD, PhD³

Abstract

Objective: The Average Daily Risk Range (ADRR) is a measure of glycemic variability (GV) developed for adults with diabetes. Although the ADRR is increasingly being reported in pediatric diabetes research and may also be used in clinical management, it has never been examined for its sensitivity to predicting hyper- and hypoglycemia in youths or compared for its predictive ability with other measures of GV in youths. Thus, we present predictive validity data for the ADRR in youths with type 1 diabetes.

Materials and Methods: Glucometer data for 436 youths (mean age, 11.8 ± 3.8 years) were collected from a clinical database. Using these data, we computed the ADRR, SD of blood glucose, coefficient of variation of blood glucose, Low Blood Glucose Index, High Blood Glucose Index, the percentage of glucose values ≥ 70 and ≤ 180 mg/dL, the percentage of high glucose values >180 mg/dL and >400 mg/dL, and the percentage of low glucose values <70 mg/dL and <40 mg/dL in Month 1. We then compared these with episodes of hypo- and hyperglycemia in Month 2.

Results: The ADRR showed good concurrent validity with other measures of GV in youths experiencing hyperglycemic events but limited predictive validity in general and specifically with future hypoglycemic events. The percentages of current hyper- and hypoglycemic episodes appeared to be stronger predictors of future hyper- and hypoglycemic episodes, respectively.

Conclusions: In a large pediatric sample, the ADRR was not the strongest predictor of future glycemic excursion. The percentages of current hyper- and hypoglycemic episodes appear to be stronger predictors.

Introduction

PATIENTS WITH TYPE 1 DIABETES mellitus (T1DM) can experience wide variations in their glycemic levels because they require exogenous insulin to support normal glucose metabolism.¹ These wide variations can place patients with T1DM at increased risk for episodes of hypo- and hyperglycemia. Hypoglycemia exposes patients to uncomfortable counterregulatory symptoms (e.g., headaches, dizziness, confusion, irritability, weakness, sweating, racing pulse, poor coordination) in addition to risk of injury due to neuroglycopenia.^{2,3} In contrast, hyperglycemia is a cause of microvascular complications and a contributor to cardiovascular disease and macrovascular complications.⁴⁻⁶ Although glycated hemoglobin (HbA1c) is the benchmark measure by which we predict a patient's risk for diabetes-related complications,¹ HbA1c does not by itself reflect a patient's glycemic variability (GV), which also may associate with complication risks.⁴⁻⁶ Thus, there is evidence that in

addition to tracking a patient's HbA1c level, it may be helpful to measure GV and to include GV in the standardized clinical assessment.

Multiple measures of GV exist for research and clinical care.⁷ The Average Daily Risk Range (ADRR) is an example of one of these measures. The ADRR was developed to quantify a patient's risk for future hyper- and hypoglycemic episodes based on the occurrence of extremely high and low blood glucose levels.⁸ The ADRR is calculated using at least 14 days of self-monitoring blood glucose (SMBG) (three or more checks per day) and is designed to be equally weighted to both hyper- and hypoglycemic episodes in order to optimize prediction of future episodes of either hyper- or hypoglycemia.

The ADRR was originally developed and validated in a sample of adults with diabetes based on its ability to predict glycemic excursion up to 4 months out and its correlations with patients' HbA1c levels, SD of mean glycemic levels, and mean amplitude of glycemic excursions. In addition, the

¹Division of Behavioral Pediatrics, Department of Pediatrics, University of Kansas Medical Center, Kansas City, Kansas.

³Division of Endocrinology, ²Children's Mercy Hospital, Kansas City, Missouri.

researchers categorized and validated ADRR risk scores, with <20 as low risk, 21–40 as moderate risk, and >40 as high risk, to help with interpreting ADRR scores.⁸ Since then, the ADRR has been used in pediatric diabetes samples to measure GV.^{9–11}

However, the ADRR score has never been examined in a pediatric sample to determine if, as a continuous score, the ADRR is equally sensitive to predicting hyper- and hypoglycemia in youths, if the original risk categories of Kovatchev et al.⁸ are valid to predict future episodes of glycemic excursions in youths, or how the ADRR compares with other measures of GV in predicting hyper- and hypoglycemia in youths. There is also limited research comparing the ADRR to other measures of GV in pediatric patients.⁹ Thus, the current study explores these questions and yields useful normative and validity data for the ADRR in youths with T1DM.

Materials and Methods

This study used de-identified SMBG data extracted from a clinical database of patient records from 3,453 individuals. The inclusion rules were as follows: (1) patients were between 0 and 18 years old; (2) the patient cohort was the same for both Months 1 and 2; (3) patients had one HbA1c measure within the study time period; and (4) patients had a minimum of 14 days of SMBG in each month with three or more SMBG values per day. These rules yielded a sample of 436 youths. All youths had confirmed diagnoses of T1DM for at least 3 months prior to the date of data extraction. Institutional approval for this study was obtained before any data were retrieved. The Institutional Review Board granted a waiver of consent for the present study in accordance with 45 CFR 164.512(i)(1)(i).

Procedure

The data of this study included at least 14 days of SMBG levels in each of Months 1 and 2, an HbA1c level measured at the time of the SMBG data collection, and patients' age, gender, race/ethnicity, and duration of diabetes. Youths' SMBG values were imported into a spreadsheet to calculate GV scores (viz., ADRR, SD of SMBG, coefficient of variation [CoV] of SMBG, percentage of values <70 mg/dL [%low1], percentage of values ≥70 and ≤180 mg/dL [%mod1], percentage of values >180 mg/dL [%high1], Low Blood Glucose Index [LBGI], and High Blood Glucose Index [HBGI]) for Month 1. The spreadsheet was also used to compute the percentage of moderate hyper- (>180 mg/dL) and hypoglycemic (<70 mg/dL) episodes, the percentage in range (≥70 mg/dL and ≤180 mg/dL), and the percentage of extreme blood glucose readings (<40 mg/dL or >400 mg/dL) during Month 2 for each youth. Youths' ADRR scores were calculated using the original formula⁸ and analyzed as continuous and categorical variables based on published adult risk categories: low risk, ADRR <20; moderate risk, ADRR 20–40; and high risk, ADRR >40. The LBGI and HBGI were also developed by Kovatchev et al.^{8,12} and use normalized transformations of SMBG values, similar to the ADRR. However, LBGI and HBGI were designed to generate scores that have a near-zero correlation with each other, making them more highly predictive of episodes of hypo- and hyperglycemia, respectively.

Analyses

We calculated means, SDs, and frequencies to describe the sample. Correlations estimated the associations between youths' GV scores for Month 1 with their glycemic excursions in Month 2. Post hoc, a Bonferroni correction was applied to these results to establish an appropriate level of significance ($\alpha \leq 0.007$). Analysis of variance (ANOVA) tests compared youths' glycemic excursion in Month 2 by ADRR risk categories during Month 1. For the ANOVA, Tukey's test was used to control for error related to multiple comparisons.

To estimate the predictive accuracy of the 10 GV measures, each was used to fit and then predict the percentage of extreme and moderate hypoglycemia and extreme and moderate hyperglycemia in Month 2 using generalized linear models.

To validate actual out-of-sample clinical predictions, the database of 436 patients was divided into four different paired datasets of 218 patients (the first of the pair to estimate the coefficients and the second of the pair to apply those coefficients to a different set of data). This was performed four times by ranking observations from lowest to highest percentages of hypoglycemic, extreme hypoglycemic, hyperglycemic, and extreme hyperglycemic events and then alternating assignments to the developmental and validation datasets. For example, consider prediction of the percentage of extreme hypoglycemia in Month 2, for which the first of the paired datasets was used to estimate the regression coefficients that best model percentage of extreme hypoglycemia in Month 2 using a GV measure of Month 1 (e.g., ADRR). Then, these same regression coefficients were used to predict the percentage of extreme hypoglycemia in Month 2 in the validation dataset of 218 patients using the same GV measure (i.e., ADRR) of Month 1. We used this procedure to provide a way to measure the fit and prediction accuracies of each of the 10 GV measures.

Results of these estimations are summarized using the correlations and mean square errors (MSEs) of both fits and predictions of the actual percentages of events. Significance was set at $\alpha \leq 0.00625$ to control for family-wise error.

Results

The sample of 436 patients had a mean age of 11.8 ± 3.8 years (range, 0.07–17.9) and a mean duration of diabetes of 5.4 ± 3.2 years (range, 0.25–14.6 years). Fifty-three percent of the sample was male, 83% described themselves as non-Hispanic white, and 75% reported current insulin pump use. Youths had a mean HbA1c level of $9.2 \pm 2.0\%$ (76 ± 21.9 mmol/mol). With respect to youth age, gender, and HbA1c, the sample was representative of the clinic population from which it was drawn. Our diabetes clinic has a high rate of insulin pump use (approximately 83%), which is comparable to the rate reported in our present sample.

Youths' mean ADRR score for Month 1 was 43.0 ± 15.8 . Table 1 shows simple correlations between youths' measures of GV computed during Month 1 and measures of glycemic excursion during Month 2. Youths' mean blood glucose level in Month 1 demonstrated strong ($r \geq 0.50$) and significant correlations with youths' percentage of euglycemia, moderate hyperglycemia, and extreme hyperglycemia in Month 2, but not with the percentage of hypoglycemia or extreme

TABLE 1. CORRELATIONS OF GLYCEMIC MEASURES IN MONTH 1 AND PERCENTAGE OF EVENTS IN MONTH 2

Variable	ADRR1	ADRR2	%low2	%mod2	%high2	%ExLow2	%ExHigh2
ADRR1		0.879 ^a	-0.183 ^a	-0.763 ^a	0.727 ^a	0.073	0.742 ^a
HbA1c	0.461 ^a	0.237 ^a	-0.140 ^a	-0.206 ^a	0.226 ^a	-0.007	0.349 ^a
HBGI	0.936 ^a	0.850 ^a	-0.337 ^a	-0.775 ^a	0.789 ^a	-0.036	0.774 ^a
LBGI	0.239	-0.042	0.605 ^a	0.174 ^a	-0.355 ^a	0.392 ^a	-0.245 ^a
MBG	0.726 ^a	0.745 ^a	-0.426 ^a	-0.766 ^a	0.811 ^a	-0.071	0.770 ^a
SD	0.868 ^a	0.823 ^a	-0.147 ^a	-0.760 ^a	0.712 ^a	0.073	0.724 ^a
CoV	0.561 ^a	0.347 ^a	0.411 ^a	-0.252 ^a	0.082 ^a	0.252 ^a	0.100
%low1	0.035	-0.098	0.690 ^a	0.161 ^a	-0.372 ^a	0.346 ^a	-0.247 ^a
%mod1	-0.807 ^a	-0.757 ^a	0.188 ^a	0.849 ^a	-0.804 ^a	-0.071	-0.608 ^a
%high1	0.728 ^a	0.694 ^a	-0.401 ^a	-0.796 ^a	0.829 ^a	-0.057	0.615 ^a

n = 436.

^a*P* < 0.007.

%ExHigh2, percentage of extreme hypoglycemic events of Month 2; %ExLow2, percentage of extreme hypoglycemic events of Month 2; %high1, percentage of moderate hyperglycemic events of Month 1; %high2, percentage of moderate hyperglycemic events of Month 2; %low1, percentage of moderate hypoglycemic events of Month 1; %low2, percentage of moderate hypoglycemic events of Month 2; %mod1, percentage of euglycemic range events of Month 1; %mod2, percentage of euglycemic range events of Month 2; ADRR1, Average Daily Risk Range in Month 1; ADRR2, Average Daily Risk Range in Month 2; CoV, coefficient of variation of blood glucose of Month 1; HbA1c, glycated hemoglobin immediately before Month 1; HBGI, High Blood Glucose Index; LBGI, Low Blood Glucose Index; MBG, mean blood glucose of Month 1; SD, SD of blood glucose of Month 1.

hypoglycemia. All of the measures of GV correlated strongly and significantly with the percentage of euglycemia, moderate hyperglycemia, and extreme hyperglycemia in Month 2 with the exception of the LBGI, CoV, and %low1. However, only LBGI and %low1 correlated strongly and significantly with the percentage of moderate hypoglycemia in Month 2, and no measure of GV was strongly correlated with the percentage of extreme hypoglycemia in Month 2. Youths' ADRR scores in Month 1 showed strong and significant correlations with the percentage of euglycemia, moderate hyperglycemia, and extreme hyperglycemia in Month 2 and a weak correlation with the percentage of hypoglycemia in Month 2. Youths' ADRR scores in Month 1 did not correlate with the percentage of extreme hypoglycemia in Month 2. Youths' ADRR scores in Month 1 correlated strongly and significantly with all of the GV measures except for youths' LBGI and %low1, which were not significant.

As shown in Table 2, 7% of youths were categorized as low risk, 37% as moderate risk, and 56% as high risk when using the existing adult risk categories, showing a tendency for youths to have a moderately high risk of GV. The ANOVA tests demonstrate an increase in the percentage of moderate

hyperglycemia among youths when moving from the low-risk ($14 \pm 11\%$) to moderate-risk ($41 \pm 13\%$) to high-risk ($59 \pm 15\%$) categories ($F_{2,433} = 182.2$, $P < 0.001$). Similarly, an association was found when the percentage of total euglycemia was examined, with the percentage decreasing from $79 \pm 11\%$ in the low-risk category to $49 \pm 11\%$ in the moderate-risk category to $34 \pm 11\%$ in the high-risk category ($F_{2,433} = 251.4$, $P < 0.001$).

However, distribution of percentage of moderate hypoglycemia in Month 2 (%low2) did not follow the predicted pattern. Although the overall model was significant ($F_{2,433} = 9.7$, $P < 0.001$), there was no difference in the percentage of moderate hypoglycemia for youths in the low-risk category ($8 \pm 7\%$) versus the high-risk category ($7.5 \pm 6\%$). Youths in the moderate-risk category had a higher percentage of moderate hypoglycemia ($10 \pm 7\%$) than youths in either the low- or high-risk categories.

When estimating episodes of extreme hyperglycemia (>400 mg/dL), the overall ANOVA was significant ($F_{2,433} = 73.6$, $P \leq 0.001$), and the percentage of episodes of extreme hyperglycemia increased as youths' risk category increased ($0.08 \pm 0.4\%$, low risk; $0.3 \pm 0.3\%$, moderate risk; and $11 \pm$

TABLE 2. ANALYSIS OF VARIANCE OF AVERAGE DAILY RISK RANGE RISK CATEGORIES AT MONTH 1 AND PERCENTAGE OF EVENTS AT MONTH 2

Variable	Mean $\pm$ SD ADRR			Total	F	P
	Low risk	Moderate risk	High risk			
Percentage of sample	6.9%	36.7%	56.4%	100.0%		
%low2	$8.0 \pm 6.7\%$	$10.3 \pm 6.8\%$	$7.5 \pm 5.8\%$	0.085	9.70	0.00008
%ExLow2	$0.01 \pm 0.04\%$	$0.03 \pm 0.05\%$	$0.03 \pm 0.08\%$	0.003	1.48	0.23000
%mod2	$78.6 \pm 11.4\%$	$49.1 \pm 11.4\%$	$33.9 \pm 11.2\%$	0.426	251.40	0.00000
%high2	$13.5 \pm 10.7\%$	$40.6 \pm 13.5\%$	$58.6 \pm 14.7\%$	0.489	182.20	0.00000
%ExHigh2	$0.01 \pm 0.04\%$	$2.6 \pm 3.4\%$	$11.0 \pm 9.7\%$	0.072	73.58	0.00000

%ExHigh2, percentage of extreme hyperglycemic events of Month 2; %ExLow2, percentage of extreme hypoglycemic events of Month 2; %high2, percentage of moderate hyperglycemic events of Month 2; %low2, percentage of moderate hypoglycemic events of Month 2; %mod2, percentage of euglycemic events of Month 2; ADRR, Average Daily Risk Range.

10%, high risk). Yet, the ANOVA for episodes of extreme hypoglycemia (<40 mg/dL) was not significant ($F_{2,433} = 1.48$, $P < 0.23$), and there was virtually no variability based on youths' risk categories ($0.1 \pm 0.3\%$, low risk; $0.3 \pm 0.5\%$, moderate risk; and $0.3 \pm 0.8\%$, high risk).

The top half of Table 3 illustrates the correlations of fit and predictions of each bivariate regression model with the actual percentages of events, as well as the maximum correlations of predicted values of each bivariate relationship with the percentage events. In all cases, the highest correlations with percentage of events in Month 2 are the same percentage measures of Month 1. Or, in predicting episodes of moderate or extreme hypoglycemia in Month 2, the most predictive Month 1 measures were youths' percentage of moderate (%low1) and extreme (%ExLow1) hypoglycemia, respectively. Likewise, in predicting episodes of moderate or extreme hyperglycemia in Month 2, the most predictive Month 1 measures were youths' percentage of moderate (%high1) and extreme (%ExHigh1) hyperglycemia, respectively.

The MSEs of fits and predictions are found in the lower half of Table 3. The MSE is a widely accepted measure of predictive accuracy because it simultaneously captures the bias and dispersion of errors. Thus, for MSE, the lowest values are desirable because these indicate lower error dispersions and greater predictive ability. Table 3 shows that the

lowest MSE for the percentage of moderate and extreme hypoglycemia in Month 2 are youths' percentage of moderate hypoglycemia in Month 1 (%low1). Likewise, the lowest MSE for the percentage of moderate and extreme hyperglycemia in Month 2 are youths' percentage of moderate and extreme hyperglycemia in Month 1 (%high1 and %ExHigh1), respectively. These values also had the lowest mean and median fitted and predicted errors and the lowest median MSEs. Therefore, the results match the correlations and suggest that the most accurate predictor of frequency of future glycemic excursions is the immediate past frequency of glycemic excursions.

Discussion

The ADRR has been used previously as a measure of GV in pediatric samples,^{9–11} but here we present the first data exploring the validity of the ADRR in a large clinical sample of 1–18-year-old youths with T1DM. The ADRR showed good concurrent validity with youths' mean blood glucose, SD, CoV, percentage of moderate hyperglycemia in Month 1, and HBGI. However, the ADRR did not correlate with youths' LBG1 or percentage of moderate or extreme hypoglycemia in Month 1. With respect to our predictive models, the ADRR showed good predictive validity when correlated

TABLE 3. CORRELATIONS AND MEAN SQUARE ERRORS OF FITTED AND PREDICTED PERCENTAGES OF GLYCEMIC EVENTS

Month 1	%low2		%ExLow2		%high2		%ExHigh2	
	Fit	Predicted	Fit	Predicted	Fit	Predicted	Fit	Predicted
Correlations								
ADRR1	0.191 ^a	0.177 ^a	0.049	0.102	0.684 ^a	0.768 ^a	0.753 ^a	0.731 ^a
LBGI1	0.476 ^a	0.472 ^a	0.209 ^a	0.204 ^a	0.317 ^a	0.366 ^a	0.213 ^a	0.260 ^a
HBGI1	0.354 ^a	0.323 ^a	0.052	0.018	0.757 ^a	0.821 ^a	0.776 ^a	0.773 ^a
%low1	0.705^a	0.675^a	0.317 ^a	0.391 ^a	0.350 ^a	0.393 ^a	0.237 ^a	0.258 ^a
%ExLow1	0.294 ^a	0.307 ^a	0.467^a	0.448^a	0.062	0.004	0.002	–0.021
%high1	0.416 ^a	0.389 ^a	0.084	0.025	0.806^a	0.852^a	0.592 ^a	0.640 ^a
%ExHigh1	0.325 ^a	0.314 ^a	0.025	0.030	0.614 ^a	0.684 ^a	0.867^a	0.854^a
SD	0.144	0.152	0.063	0.086	0.669 ^a	0.754 ^a	0.721 ^a	0.727 ^a
CoV	0.436 ^a	0.386 ^a	0.272 ^a	0.243 ^a	0.063	0.101	0.100	0.100
MBG	0.441 ^a	0.413 ^a	0.089	0.050	0.785 ^a	0.837 ^a	0.762 ^a	0.781 ^a
MSE								
ADRR1	40.4	38.0	0.54	0.34	191.1	147.4	34.7	34.7
LBGI1	32.4	30.5	0.52	0.33	322.6	312.1	76.5	69.1
HBGI1	36.7	35.3	0.54	0.34	153.0	118.0	31.9	30.0
%low1	21.1	21.3	0.49	0.29	314.6	304.1	75.6	69.1
%ExLow1	38.3	35.5	0.42	0.31	357.3	360.2	80.2	74.0
%high1	34.7	33.5	0.54	0.34	125.5	99.3	52.1	43.8
%ExHigh1	37.5	35.4	0.54	0.34	223.3	193.7	19.9	20.2
SD	41.0	38.2	0.54	0.34	198.2	155.9	38.5	35.0
CoV	33.9	33.5	0.50	0.33	357.2	356.2	79.4	73.3
MBG	33.8	32.7	0.54	0.34	137.8	108.2	33.7	29.0

Predicted values are those using values not part of the fitting of model coefficients. Although not shown, the predictors with the lowest mean square error (MSE) also had the lowest mean and median errors and MSEs. For each column and category (correlations and MSE), the bold italic correlations are the highest (lowest) for that outcome.

^a $P < 0.006$.

%ExHigh1, percentage of extreme hyperglycemic events in Month 1; %ExHigh2, percentage of extreme hyperglycemic events in Month 2; %ExLow1, percentage of extreme hypoglycemic events in Month 1; %ExLow2, percentage of extreme hypoglycemic in Month 2; %high1, percentage of moderate hyperglycemic events in Month 1; %high2, percentage of moderate hyperglycemic events in Month 2; %low1, percentage of moderate hypoglycemic events in Month 1; %low2, percentage of moderate hypoglycemic events in Month 2; ADRR1, Average Daily risk Range for Month 1; CoV, coefficient of variation of blood glucose in Month 1; HBGI1, High Blood Glucose Index for Month 1; LBGI1, Low Blood Glucose Index for Month 1; MBG, mean blood glucose level in Month 1; SD, SD of blood glucose in Month 1.

with the percentage of hyperglycemia and euglycemia, but much weaker predictive validity when correlated with the percentage of hypoglycemia. Likewise, in ANOVA tests, the ADRR risk categories predicted future percentage hyperglycemia and euglycemia, but these categories did not predict future hypoglycemia in youths. Finally, exploratory bivariate models revealed that among youths, the percentage of immediate past frequency of glycemic excursions was the most accurate predictor of frequency of future excursions and not the ADRR.

Youths in the current sample had a mean ADRR score of 43.1 ± 15.8 in Month 1 and 43.4 ± 15.9 in Month 2, which were comparable to the mean ADRR scores reported in two previous studies recruiting very young children with T1DM^{9,10} and higher than the mean score reported in a study that recruited school-age youths.¹¹ It is possible that our ADRR score was higher because our sample included a wider age range of youths, including very young children and adolescents with T1DM, both subgroups of patients who may experience problems with insulin sensitivity related to their growth and development and thus may be more susceptible to GV.^{1,13} In the current study, 56% of youths had ADRR scores in the high-risk category. This percentage was lower than the percentage of very young children with T1DM with ADRR scores in the high-risk category as reported by Monaghan et al.⁹ (73.1%) and Patton et al.¹⁰ (69%), but much higher than the percentage of adults with T1DM with ADRR scores in the high-risk category as reported by Kovatchev et al.⁸ (28%). Unlike the previous adult study,⁸ when tested against a variety of other measures of GV, the ADRR scores in this sample of youths was not equally accurate in predicting the percentage of episodes of hyper- or hypoglycemia. Rather, the ADRR only accurately predicted future episodes of hyperglycemia and euglycemia. This outcome is similar to the results of a previous cross-sectional study of ADRR scores in very young children with T1DM, which also found that scores did not correlate with the percentage of concurrent moderate hypoglycemic episodes.⁹

Although our findings demonstrate that the ADRR does not predict future episodes of hypoglycemia, we did identify more accurate measures of future risk for hypoglycemia in youths, which were LBGI, the percentage of moderate hypoglycemic events in Month 1, and CoV. Likewise, we determined that the adult risk categories, when used in youths, appear limited to only predicting a youth's likelihood of future hyper- or euglycemia and not episodes of hypoglycemia.⁸ Within the clinical setting, the ADRR is easily deployable because it can be calculated using SMBG, and at least one software program (OneTouch, Zoom Pro Diabetes Management Software; LifeScan, Milpitas, CA) automatically computes an ADRR score.^{8,14} However, based on our data, we would propose that in youths, the best predictor of future hyper- or hypoglycemic episodes is the percentage of current episodes of hyper- or hypoglycemia, respectively. And, we would offer that these measures are also easily deployable in the clinic because they require only basic arithmetic (e.g., addition and division) and are likely to be easy for parents and youths to understand.

This study does present some limitations. Although the study used clinical data collected from a relatively large sample of youths with T1DM, overwhelmingly, youths self-identified as non-Hispanic white. In pediatric patients, the

incidence of T1DM is more common in persons of a non-Hispanic white background than other racial or ethnic group.¹⁵ Thus, we believe our sample is generally representative of the population of pediatric patients with T1DM in the United States. However, because our random sample yielded a relatively low number of youths of other races or ethnicities, our results may not generalize to more diverse patient samples. Our sample included 329 youths on an insulin pump (75% of the sample). Based on data from the T1 Diabetes Exchange, the overall percentage of patients using an insulin pump in the United States is estimated to be about 55%, suggesting our sample may over-represent U.S. pump users.¹⁶ However, within our clinic, approximately 83% of youths use an insulin pump for diabetes management, suggesting our sample may be representative of our patients. Finally, all of the data for this study were entirely observational and captured from patients' appointments in our pediatric diabetes center. It is common for youths to have multiple glucometers, but not to bring all of these meters to their routine diabetes appointments. Therefore, there is a possibility that our data do not capture all of youths' home glucometer data. But, although we may not have captured all available SMBG data for youths, we did capture sufficient data to calculate youths' ADRR scores, which at a minimum requires three SMBG checks per day for at least 14 out of 30 days.⁸

Conclusions

The ADRR has good concurrent validity with other measures of GV and mean blood glucose values in youths with T1DM experiencing hyperglycemic events, but limited predictive validity in general and specifically with hypoglycemic events, potentially limiting its utility in youths. Our analyses suggest that youths' percentage of current hyperglycemic episodes and percentage of current hypoglycemic episodes appear to be better predictors of future episodes of hyper- or hypoglycemia, respectively. These measures are not difficult to compute in a busy clinical setting and are easier to calculate than the other GV measures (i.e., ADRR, CoV, SD, LBGI, HBGI), while providing more accurate predictions of glycemic events as much as 1 month ahead. Our results suggest that the adult risk categories, when applied to youths, are a better indicator of the likelihood of future euglycemia than risk for glycemic excursion and should be interpreted with caution.

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Author Disclosure Statement

No competing financial interests exist.

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Address correspondence to:
Susana R. Patton, PhD, CDE
Division of Behavioral Pediatrics
Department of Pediatrics
University of Kansas Medical Center
3901 Rainbow Boulevard, MS 4004
Kansas City, KS 66160
E-mail: spatton2@kumc.edu