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Featured Article

Featured Article: Trajectories of Glycemic Control Over Adolescence and Emerging Adulthood: An 11-Year Longitudinal Study of Youth With Type 1 Diabetes

Vicki S. Helgeson,[1] PhD, Abigail Kunz Vaughn,[1] BS, Howard Seltman,[1] PhD, Trevor Orchard,[2] MD, Ingrid Libman,[3] MD, and Dorothy Becker,[3] MBBCh

[1]Carnegie Mellon University, [2]University of Pittsburgh and, [3]Children's Hospital of UPMC and University of Pittsburgh

All correspondence concerning this article should be addressed to Vicki Helgeson, PhD, Department of Psychology, Carnegie Mellon University, Pittsburgh, PA 15213, USA. E-mail: vh2e@andrew.cmu.edu

Abstract

Objective To identify trajectories of glycemic control over adolescence and emerging adulthood and to test whether demographic and psychosocial variables distinguished these trajectories. **Methods** We enrolled 132 youth with type 1 diabetes when they were average age 12 and followed them for 11 years. We used group-based trajectory modeling to identify distinct patterns of glycemic control, and examined whether age 12 demographic and psychosocial variables distinguished the subsequent trajectories. **Results** We identified 5 trajectories of glycemic control: stable on target, stable above target, volatile late peak, stable high, and inverted U. Parent social status and household structure distinguished the more problematic trajectories from the stable on target group. Friend conflict, psychological distress, unmitigated communion, and self-care behavior at age 12 distinguished problematic glycemic control trajectories from the stable on target group. **Conclusions** These results can be used to identify youth who are at risk for deteriorating glycemic control over adolescence.

Key words: adolescence; emerging adulthood; glycemic control; trajectory analysis; type 1 diabetes.

Adolescence is marked by fluctuations and deterioration in glycemic control among youth with type 1 diabetes (Helgeson, Siminerio, Escobar, & Becker, 2009). Reasons for these changes include the difficulty in keeping up with increasing insulin requirements caused by hormonal changes associated with puberty (Goran & Gower, 2001; Moran et al., 1999), as well as psychosocial factors that include psychological distress, personality variables, and changing relationships with parents and friends (Helgeson et al., 2009). Studies that show a deterioration in glycemic control across adolescence are largely cross-sectional; the ones that are longitudinal typically examine a small timeframe and/or have only a few measurements of glycemic control over time. In recent years, several studies have identified distinct patterns of change in glycemic control over adolescence and emerging adulthood and used demographic, disease, and psychosocial variables to predict membership in these groups (Helgeson et al., 2010; Hilliard, Wu, Rausch, Dolan, & Hood, 2013; King et al., 2012; Luyckx & Seiffge-Krenke, 2009; Schwandt et al., 2017). The majority of these studies have identified two or three patterns of change over adolescence, typically finding one group with acceptable glycemic control that is stable over time and one or two other groups with higher levels of HbA1c that show different degrees of deterioration (Helgeson et al., 2010; Hilliard et al., 2013; King et al., 2012; Luyckx & Seiffge-Krenke, 2009). But even these studies typically capture only a small portion of adolescence.

The primary goal of the present study was to identify distinct patterns of change in glycemic control over the span of adolescence and emerging adulthood, beginning when youth were average age 12 and ending when they were average age 23. We had the opportunity to follow youth with type 1 diabetes for a longer period than any of the previous studies, with one recent exception (Schwandt et al., 2017)—11 years that spanned adolescence and emerging adulthood. Although it is widely accepted that HbA1c declines over adolescence, it is not clear how glycemic control changes over emerging adulthood—especially in comparison with adolescence. Only two studies to our knowledge sampled both adolescents and emerging adults. One methodologically strong study followed 72 youth from Germany over adolescence (ages 14–17) into emerging adulthood (ages 21–25) and identified three distinct trajectories (Luyckx & Seiffge-Krenke, 2009). The proposed study follows a larger cohort ($n = 132$) of youth from the United States continuously throughout adolescence and emerging adulthood without a 4-year interruption. A recent publication of T1D Exchange clinics evaluated HbA1c over 10 years, including an 8- to 18-year-old cohort and a 16- to 26-year-old cohort (Clements et al., 2016). They found that HbA1c increased during adolescence up until ages 16–17, at which time it plateaued for several years, and then gradually declined. However, they did not examine whether there were distinct trajectories of HbA1c over these periods. We wanted to determine if we could distinguish youth who retained stable glycemic control over adolescence and emerging adulthood from those who showed a deterioration over adolescence that then improved during emerging adulthood. Thus, we not only examined linear rates of change over the 11 years but allowed for quadratic and cubic trends.

We note that a recent study examined 11 years of glycemic control, following German and Austrian youth from age 8 to age 19 (Schwandt et al., 2017). This study is noteworthy for its large sample size ($n = 6{,}433$) and its identification of five distinct trajectories of glycemic control. However, this study ended at the cusp of emerging adulthood. In addition, this study did not address the second goal of our article in the depth that we did, as we describe below.

The second goal of this study was to distinguish the distinct patterns of change in glycemic control with demographic, disease, and psychosocial variables. We adopted the risk and resistance framework (Wallander, Varni, Babani, Banis, & Wilcox, 1989) to pursue this goal. This framework is an expansion of the stress and coping model and has been used to understand how children adapt to chronic physical disorders (Wallander & Varni, 1998). These disorders, such as diabetes, are conceptualized as an ongoing strain. Risk factors impede adjustment, whereas resistance factors facilitate adjustment. Although the framework is typically applied to understanding disease adjustment, here we apply the model to understand influences on diabetes outcomes—specifically, glycemic control.

Demographic variables that have been identified as risk factors in previous trajectory analyses include lower social status (Helgeson et al., 2010), minority race (Hilliard et al., 2013), lack of two-parent household (Helgeson et al., 2010), and higher body mass index (Helgeson et al., 2010). Effects of diabetes duration have been mixed (Hilliard et al., 2013), as has female sex (Hilliard et al., 2013; Schwandt et al., 2017). One study found that those who were on insulin pumps were less likely to be in a deteriorating glycemic control group (Schwandt et al., 2017). Compared with an on target glycemic control group that remained stable over time, previous research has shown that some family support is a resistance factor (King et al., 2012; Luyckx & Seiffge-Krenke, 2009). Friend relationship variables have been rarely investigated, but one study identified friend conflict as a risk factor for membership in a high HbA1c and deteriorating glycemic control group (Helgeson et al., 2010). Psychological distress has also been identified as a risk factor for membership in trajectories of deteriorating glycemic control (King et al., 2012; Hilliard et al., 2013). Adherence during early adolescence appears to be a resilience factor (Helgeson et al., 2010; Schwandt et al., 2017).

In the present study, we examined some of the same demographic factors that have been examined as risk and resistance factors by previous investigators: social status, household structure, minority race, sex, diabetes duration, and use of insulin pump. We hypothesized that trajectories with higher glycemic control and deteriorations in control will be characterized by lower parent social status, not residing in two-parent household, minority race, and not being on an insulin pump. Given the mixed findings in prior research, we had no predictions regarding sex or diabetes duration. We also examined psychological distress, predicting that trajectories characterized by high glycemic control and deteriorating control would contain more distressed youth. We hypothesized that parent relationship quality and self-care behavior would be resistance factors, characterizing trajectories with on target stable glycemic control over the 11 years. We examined friend relationship variables as potential resistance (i.e., support) and risk (e.g., friend conflict) factors, as they were predictive in a previous study (Helgeson et al., 2010) but have not been investigated by other researchers.

Finally, we examined a personality trait that reflects a vulnerability to influence by others as a risk

factor: unmitigated communion (Helgeson & Fritz, 1998). Unmitigated communion reflects a focus on others to the exclusion of the self. It is associated with a set of interpersonal difficulties that reflect overinvolvement with others, such as being intrusive, overly nurturant, and establishing relationships by putting others' needs before one's own (Helgeson & Fritz, 1998). Unmitigated communion also is associated with a constellation of interpersonal problems that reflect self-neglect, such as difficulties asserting one's needs, being exploitable, inhibiting self-expression to avoid conflict with others, and self-effacement (Helgeson & Fritz, 1998). Because those with diabetes need to attend closely to themselves to care for their illness, those with a focus outward may suffer. Indeed, unmitigated communion has been linked to poor diabetes outcomes in previous research (Helgeson, Escobar, Siminerio, & Becker, 2007), in part owing to an overinvolvement in others' problems. Other research on adolescents with type 1 diabetes has identified links of conceptually similar constructs to glycemic control. Extreme peer orientation (i.e., sacrificing what is best for the self to gain peer acceptance) was linked to deteriorating glycemic control (King et al., 2012) in one study, and the extent to which youth with type 1 diabetes assumed friends would react negatively to self-care behavior was linked to poor glycemic control in another (Hains et al., 2007). Unmitigated communion is linked to the perception that others evaluate the self negatively (Helgeson & Fritz, 1998). Thus, we predict that unmitigated communion will characterize trajectories with higher glycemic control and deteriorations in glycemic control over adolescence.

In expanding on previous research, we followed a cohort of 132 adolescents with type 1 diabetes for 11 continuous years that spans adolescence and the early stages of emerging adulthood to identify distinct trajectories of glycemic control. We examined a wider array of demographic and psychosocial variables than has been evaluated by previous research as potential risk and resistance factors for trajectory membership.

Method

Participants

Participants were 132 youth with type 1 diabetes recruited from Children's Hospital in 2002–2004. Letters of invitation were sent to all adolescents with diabetes who were approximately 11–13 years of age, had been diagnosed with type 1 diabetes for at least one year, and were attending Children's Hospital ($n = 307$). Families could return a postcard indicating that they did not want to be contacted by phone about the study. Twenty families returned these postcards, refusing contact about the study without us being able to determine eligibility. We reached 261 of the remaining 287 families by phone and determined that 90 were not eligible. Of the 171 eligible families, 39 refused and 132 agreed. Thus, our effective response rate was 77%.

Participants were followed through three separate studies: Teen Health Study (THS), which focused on the transition through adolescence (ages 12–16); Transition Times Study (TTS), which focused on the transition out of high school into emerging adulthood (ages 17–19); and Research on Emerging Adults' Changing Health (REACH), which focused on the early stage of emerging adulthood (ages 21–23). These data are from all three studies. Informed consent was obtained from parents, and assent was obtained from children in the THS and the TTS. However, when youth turned 18, consent was obtained. Informed consent was obtained from the youth with diabetes in REACH. All three studies were approved by the appropriate institutional review boards. Monetary compensation was provided for participation in each study.

Instruments

Demographic information included participant sex, race, year of diagnosis, family structure (two-parent vs. non-two-parent household), and parents' social status, which takes into consideration education and occupational status (Hollingshead, 1975). Demographics of the original sample at enrollment and at the end of the study are shown in Table I.

The instruments described below were administered in Year 1 of THS when children were average age 12. Descriptive information for each of the instruments, including the range and reliabilities, are shown in Supplementary Table SI. All instruments were completed by the teen with diabetes, unless otherwise specified.

Psychosocial variables included Kerr and Stattin's (2000) eight-item mother and father relationship quality measures. Because mother and father relationship quality were correlated ($r = .45$, $p < .001$), we averaged the two to form an overall parent relationship quality index. We measured friend support and friend conflict with the Berndt and Keefe (1995) friendship questionnaire. The unmitigated communion scale (Helgeson & Fritz, 1998) was administered to assess the personality trait of being overly involved in others to the exclusion of the self.

Psychological distress was assessed with depressive symptoms from the 10-item Children's Depression Inventory Short Form (Kovacs, 1985, 2001), anxiety from the Revised Children's Anxiety Scale (Stark & Laurent, 2001), and anger from the Differential Emotions Scale (Izard, Libero, Putman, & Haynes, 1993). These instruments have well-established validity and reliability. Because the three scales were correlated (r's range from .22 to .43, all p's $< .001$), we

Table I. *Demographic Variables of the Sample*

Study Variable	At start of study (n=132)	At REACH year 1 (n =99)
Sex	47% male	44% male
Race	93% white	92% white
Ethnicity	96% non-Hispanic	96% non-Hispanic
Live with biological mother and father	74%	
Age	12.11 ± .75 years	22.87 ± .55 years
Social status	[a]41.97 ± 11.05	38% college graduates
HbA1c	8.18 ± 1.27	8.83 ± 1.68
Diabetes duration	4.92 ± 2.97 years	15.67 ± 3.12 years
Insulin pump (vs. MDI)	26%	60%
Parent relationship quality	4.05 (.55)	
Mother relationship quality	4.06 (.57)	
Father relationship quality	4.04 (.75)	
Friend support	3.69 (.67)	
Friend conflict	1.81 (.63)	
Unmitigated communion scale	2.81 (.66)	
Psychological distress	.01 (.75)	
Children's Depression Inventory	1.15 (.22)	
Revised Children's Anxiety Scale	1.65 (.38)	
Differential Emotions Scale: Anger	1.77 (.60)	
BASC Externalizing[b]	52.30 (12.17)	
BASC Internalizing[a]	54.19 (10.97)	
Self-Care Inventory	4.01 (.45)	

[a]Measured with Hollingshead (1975) social status.
[b]Measured by parent report.

standardized them and took the average to form a psychological distress index.

Parents completed the Behavioral Assessment System for Children (Reynolds & Kamphaus, 1992) with respect to their teen, which assesses an array of emotional and behavioral problems and has excellent reliability and validity. We focused on the internalizing and externalizing composite indices.

We administered the 14-item Self-Care Inventory (La Greca, Swales, Klemp, & Madigan, 1988; Lewin et al., 2009) to youth with diabetes, which was updated by adding eight more contemporary items (Helgeson, Reynolds, Siminerio, Escobar, & Becker, 2008). This scale asks respondents to indicate how well they followed their physicians' recommendations for glucose testing, insulin administration, diet, exercise, and other diabetes behaviors and reflects domains of self-care that have been regarded as important by the American Diabetes Association. The scale has been associated with glycemic control among adolescents (Delamater, Applegate, Edison, & Nemery, 1998; La Greca et al., 1988).

Glycemic Control

Glycemic control was measured with glycosylated hemoglobin A1c or HbA1c. During the THS, HbA1c was abstracted from all clinic appointments documented in medical records from Children's Hospital (measure by HPLC [Tosoh Instruments, San Francisco] with normal range 4.6–6.1%). The number of HbA1cs during the THS ranged from 3 to 24, with a M of 13.46 (SD = 4.21). During the TT, youth were interviewed once a year for three consecutive years and physicians were contacted for the most recent measure of glycemic control. The majority of these physicians were endocrinologists and are likely to have used the DCA Vantage Analyzer. Those followed by a primary care physician are likely to have sent their patients to Labcorp or Quest laboratories. Available information shows good correlation across the HbA1c spectrum for these assays, although results may show a small bias. The number of HbA1cs collected in the TT ranged from 0 to 3, with a mean of 2.22 (SD = 1.06). Some participants interviewed in the TT study did not have an HbA1c measured every year (either because the physician did not order an HbA1c or the participant did not have the prescription filled). Finally, in REACH, youth were interviewed in-person, and HbA1c was measured using the DCA Vantage Analyzer (Siemens, USA). Although 107 participants (81% of original sample) were interviewed for Wave 1 of REACH, 99 had an HbA1c recorded; missing HbA1c data were largely because of participants having moved out of the area.

Overview of the Analysis

We used SAS procedure trajectory, a group-based trajectory modeling procedure that Jones, Nagin, and Roeder (2001) created, to identify developmental trajectories of behavior. Briefly, outcomes are treated as censored normal data following a polynomial time course, given a discrete latent class assignment.

Procedure trajectory isolates distinct trajectories (one for each latent class) and fits a mixture model to calculate the probability of membership in each latent class for each participant. The majority of people clearly fall in a single class. Procedure trajectory uses all nonmissing data for each participant to estimate that participant's trajectory, then pools estimates across participants to estimate the group trajectories, resulting in greater weight given to participants with more data.

We used the procedures established by Nagin (2005) to identify the number of groups representing relatively homogenous clusters of trajectories of HbA1c over the 11 years. First, we examined the raw data graphically for all participants. We plotted each individual's HbA1c trajectory and examined the individual plots for distinct patterns of change. Based on our visual inspection of the data, we tested models that ranged from two to six groups. In addition to identifying the number of trajectory groups, we also were identifying the pattern of each trajectory (i.e., quadratic, linear). We began by allowing for cubic trends for each trajectory and simplified to quadratic or linear patterns as described below. We centered age in these analyses.

Our final model selection was based on three criteria: (1) the Bayesian Information Criterion (BIC), (2) the meaningfulness of the distinctions among trajectories, and (3) number of participants in each trajectory group. We discarded one participant because the person had only one data point throughout the studies. A decrease in BIC signifies an improvement in model fit, with a 10-point drop indicating strong evidence for the alternative model (Jones et al., 2001). The BIC is used for model selection (Jones et al., 2001; Nagin, 2005).

Once distinct groups were identified, we used procedure trajectory to predict group membership with risk factors. Here "risk factor" is a statistical term reflecting the independent variable used to predict group membership. An advantage of this approach is that an individual's membership in a group is probabilistic rather than certain. Conventional statistical tests that examine group differences assume no error in group classification. The estimates that we report are similar to regression coefficients; they are changes in log odds ratio of being in one trajectory versus the other, given a one-unit increase in the risk factor. Coefficients more than 0 indicate an increased probability of the risk factor in the target group compared with the reference group, whereas coefficients less than 0 indicate a decreased probability of the risk factor in the target group compared with the reference group.

Results

Descriptive Information

To determine whether the collection of HbA1cs was related to attrition, we compared participants who had had completed all waves of the TT study and the first wave of REACH to those who did not and found no difference on any demographic variable or psychosocial predictor variable. However, those who completed all waves of the TT study and the first wave of REACH had a lower baseline HbA1c ($M = 7.71$, $SD = .99$) than those who missed one or more measures ($M = 8.61$, $SD = 1.35$). We also addressed this issue by correlating the number of HbA1cs we collected with baseline HbA1c and continuous predictor variables and conducting *t*-tests on the number of HbA1cs by categorical demographic variables. In terms of demographic variables, a greater number of HbA1cs was related to higher social status ($r = .18$, $p < .05$) and to be using an insulin pump ($t\ [130] = -2.75$, $p < .01$). Having a greater number of HbA1cs over the course of the study also was related to a lower baseline HbA1c ($r = -.38$, $p < .001$). Number of HbA1cs was only related to one psychosocial predictor, unmitigated communion, such that those who scored higher on unmitigated communion had fewer HbA1cs ($r = -.27$, $p < .01$).

Identification of Trajectories

The six-group model had the lowest BIC, but the change in BIC was much smaller moving from the five-group to the six-group model than any other model comparison (see Supplementary Table SII). In addition, the six-group model contained two groups with less than 10 persons; one had only three participants. Thus, we selected the five-group model because it had the next lowest BIC, trajectories that were distinct from one another, and groups that contained at least 10 participants.

Next, we examined the nature of the trajectory for each group, beginning with cubic trends. If the cubic parameter was not significant, we dropped it and examined the quadratic parameter. If the quadratic parameter was not significant, we dropped it and retained the linear parameter. These changes in parameters also improved model fit.

The five-group model is shown in Figure 1. Group 1 (*stable on target*) consists of 39 participants, has an average HbA1c of 7.4%, and has a significant quadratic trajectory that starts with a below target HbA1c at 7.2% that shows a slight increase over adolescence to 7.8%, which then returns to target in the early 20s (7.1%). Group 2 (*stable above target*) consists of 46 participants, has a significant cubic trajectory that starts with a higher HbA1c just below 8%, which then increases in early adolescence to nearly 9% and remains a bit elevated at 8.4%. Group 3 (*volatile late peak*) is the smallest ($n = 10$) and most volatile group, with a significant cubic trend, starting with an HbA1c at 7.4% (not much higher than the stable on target group), but then increases dramatically in the later

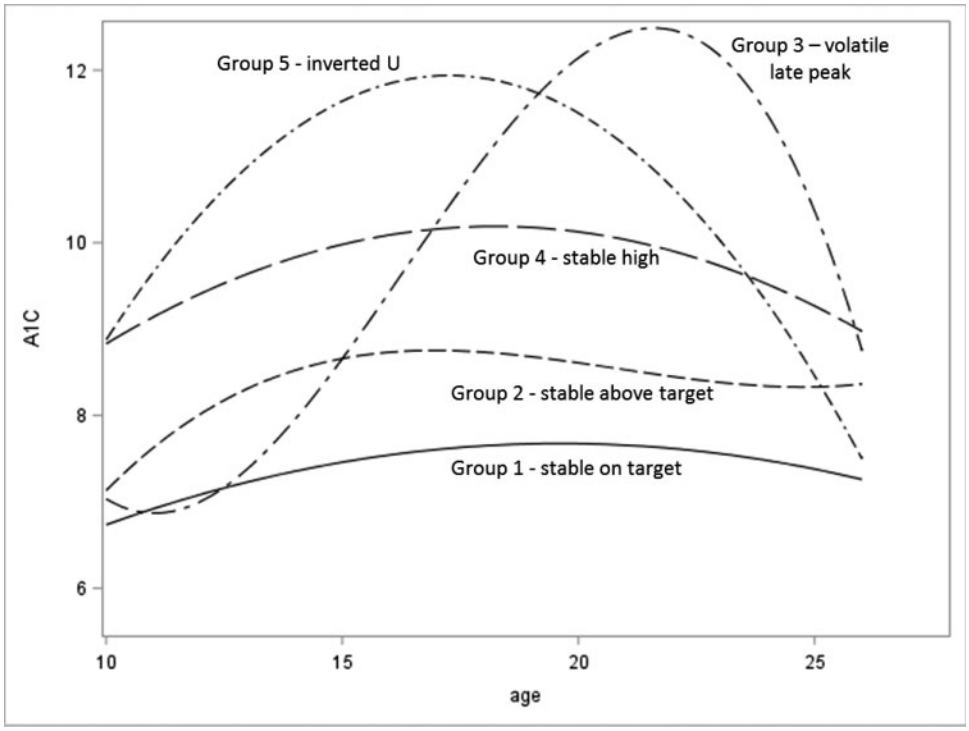

Figure 1. Trajectories of glycemic control over adolescence and emerging adulthood.

teen years to exceed 12% and shows signs of some lowering in the early 20s. Group 4 (*stable high*) consists of 23 individuals, has a significant quadratic trajectory, begins with a high HbA1c of between 8.5–9% that steadily increases over adolescence, peaking at just over 10%, and then steadily decreases. Group 5 (*inverted U*) consists of 13 individuals that start with the same high HbA1c as the stable high group, has a significant quadratic trajectory that shows a large increase in early and middle adolescence nearly reaching 12%, but also a large drop in HbA1c over the later teen years and into the 20s to below 10%. The volatile late peak and inverted U groups both show large increases in HbA1c, but the increase occurs earlier for the inverted U than the volatile late peak group.

Distinguishing Trajectories

We present descriptive information on each of the demographic and psychosocial risk factors for the five trajectory groups in Table II.

Demographics

We used the *stable on target* group (Group 1) as our reference group because these participants had levels of glycemic control that were on target and remained stable over the 11 years. Sex, race, duration of diabetes, and age at diagnosis did not distinguish any of the four trajectories from the stable on target group. Social status, however, distinguished the stable on target group from the volatile late peak group (coeff $-.09$, SE $= .04$, $p < .05$) and the stable high group (coeff $= -.07$, SE $= .03$, $p < .05$), such that the stable on target group came from higher social status families than the other two groups. Household structure distinguished the stable on target group from the volatile late peak group (coeff $= 2.63$, SE $= .92$; $p < .01$), the stable high group (coeff $= 1.46$, SE $= .77$, $p < .10$), and the inverted U group (coeff $= 1.75$, SE $= .85$; $p < .05$), such that the stable on target group was more likely to come from two-parent families than the other three groups. Whether youth were using an insulin pump also distinguished three of the groups from the stable on target group: the stable above target group (coeff $= -1.24$, SE $= .51$, $p < .05$), the stable high group (coeff $= -2.25$, SE $= .81$, $p < .01$), and the inverted U group (coeff $= -2.41$, SE $= 1.10$, $p < .05$) were less likely to be on an insulin pump at age 12.

Psychosocial Risk Factors

Because social status and household structure distinguished the trajectories, we statistically controlled for those two variables before testing psychosocial risk factors against the stable on target group. Results are shown in Table III. First, we examined whether relationship variables distinguished the trajectories. Neither parent relationship quality nor friend support distinguished the trajectories. Friend conflict distinguished the inverted U group from the stable on target group, such that the inverted U group showed more friend conflict than the stable on target group.

Table II. *Descriptives for Study Variables (Means and Standard Deviations or Percent) by Trajectory Group*

Measure	Stable on Target	Stable above Target	Volatile Late Peak	Stable High	Inverted U
Age	12.05 (.76)	12.05 (.78)	12.85 (.85)	12.05 (.60)	12.06 (.65)
Parent social status	45.68 (11.68)	42.30 (10.72)	36.35 (8.89)	38.67 (9.29)	41.31 (11.2)
Age at diagnosis	7.01 (3.02)	6.94 (3.00)	8.78 (3.81)	6.88 (3.07)	8.26 (2.04)
Diabetes duration	5.04 (2.98)	5.11 (2.96)	4.07 (3.95)	5.17 (3.05)	5.17 (3.05)
Sex (% male)	49	50	30	44	54
Race (% white)	100	96	80	96	69
Ethnicity (% non-Hispanic)	97	96	100	100	77
% Live with biological mother and father	87	80	40	65	62
% Pump	46	22	30	9	8
Parent relationship quality	4.12 (.49)	3.99 (.56)	4.09 (.56)	4.05 (.59)	3.99 (.65)
Friend support	3.57 (.73)	3.72 (.71)	3.69 (.62)	3.90 (.49)	3.63 (.64)
Friend conflict	1.69 (.51)	1.78 (.49)	1.63 (.38)	1.71 (.49)	2.63 (1.09)
Unmitigated communion	2.77 (.73)	2.69 (.54)	2.48 (.66)	2.93 (.62)	3.33 (.66)
Psychological distress	−.02 (.58)	−.17 (.66)	−.06 (.85)	.07 (.77)	.65 (1.08)
BASC Externalizing	47.79 (6.80)	51.68 (10.16)	56.7 (16.24)	56.35 (16.9)	57.75 (14.17)
BASC Internalizing	50.00 (8.74)	53.86 (11.09)	58.2 (12.66)	59.13 (10.87)	56.17 (12.09)
Self-Care Inventory	4.13 (.46)	3.96 (.44)	4.04 (.29)	4.00 (.35)	3.77 (.54)

Table III. *Psychosocial Predictors of Trajectory Group Membership Controlling for Parent Social Status and Household Structure: Comparisons With Stable on Target Group (Group 1)*

Risk factor	Stable Above Target Group 2	Volatile Late Peak Group 3	Stable High Group 4	Inverted U Group 5
Friend conflict	n.s.	n.s.	n.s.	1.99*** (.62)
Psychological distress	n.s.	n.s.	n.s.	.93** (.43)
Internalizing problems	n.s.	.08** (.04)	.09*** (.03)	.06* (.04)
Externalizing problems	n.s.	n.s.	.08† (.03)	.07** (.03)
Unmitigated communion	n.s.	n.s.	n.s.	1.56*** (.57)
Self-care behavior	n.s.	n.s.	n.s.	−1.74** (.79)

Note. n.s. = not significant; $^{\dagger}p < .10$; $^{*}p < .1$; $^{**}p < .05$; $^{***}p < .01$.

Numbers indicate the changes in log odds ratio of being in the trajectory versus the reference group, given a one-unit increase in the risk factor. Here the reference group is the stable on target group. Coefficients that are more than 0 indicate there is an increased probability of the risk factor in the target group compared with the reference group, whereas coefficients that are less than 0 indicate that there is a decreased probability of the risk factor in the target group compared with the reference group. Numbers in parentheses are standard errors.

Next, we examined psychological distress indicators. The psychological distress index distinguished the inverted U group from the stable on target group, indicating that the inverted U group was more distressed at study start than the stable on target group. Internalizing problems distinguished three of the groups from the stable on target group: the volatile late peak group, the stable high group, and the inverted U group. Externalizing problems distinguished the stable high and inverted U groups from the stable on target group. All effects were in the direction of the stable on target group having fewer internalizing and externalizing problems than other groups.

Unmitigated communion distinguished the inverted U group from the stable on target group, suggesting the inverted U group had higher levels of unmitigated communion than the stable on target group. Self-care behavior distinguished the inverted U group from the stable on target group, such that the stable on target group had better self-care than the inverted U group.

Discussion

This was the first study to examine the continuous changes in glycemic control over the entire course of adolescence extending into emerging adulthood, spanning an 11-year period. Although one other study examined 11 continuous years (Schwandt et al., 2017), it did not capture the early years of emerging adulthood. Unlike the vast majority of previous research, we identified more than two or three distinct trajectories of glycemic control. But consistent with a recently published study, we identified five distinct trajectories of glycemic control that nearly parallel the ones that they found (Schwandt et al., 2017). In addition to demographic and disease variables, we also examined a wider array of psychosocial risk and resistance variables than has been explored by previous research. Below we describe how the results of this study compare with those from previous studies.

Previous research has documented that glycemic control deteriorates over the course of adolescence

(Helgeson et al., 2009), but few studies have identified distinct patterns of change. The results of this study showed that three groups started out with a similar level of on-target glycemic control, but their trajectories diverged over the course of adolescence and emerging adulthood. The stable on target and stable above target groups comprised over half of the sample, both showing deteriorations in glycemic control over the course of adolescence that began to taper off by emerging adulthood. The only difference between the two groups is that the stable above target group started with a higher HbA1c and had a larger initial increase such that they remained higher than the stable on target group over the duration. The volatile late peak group consisted of a small group of youth who started with a similar level of glycemic control as the stable on target and stable above target groups, but their HbA1c dramatically increased in late adolescence, with hints of a trend toward lowering in their 20s. The final two groups—the stable high and inverted U groups—both began adolescence with a high HbA1c but diverged in their trajectories. The stable high group showed slight increases in HbA1c that tapered off in emerging adulthood but remained high, whereas the inverted U group showed a much sharper increase in HbA1c in middle and late adolescence with a substantial drop in HbA1c in emerging adulthood—also remaining high. Although all of our groups showed some level of increase in HbA1c over the course of adolescence, most groups showed some decline in HbA1c by emerging adulthood. This decline is of some reassurance to practitioners. The question remains, however, as to what the impact on long-term complications is for having a period of poor control during adolescence, even if improvement is noted in emerging adulthood. Poor control during this time may increase chances of developing chronic complications later. It could also have been associated with more emergency room visits, hospitalizations, and repeated clinic visits, which would translate into considerable economic costs.

The five trajectories that we identified in this study are remarkably similar to the five trajectories identified over the ages of 8 to 19 in the recently published study on German and Austrian youth (Schwandt et al., 2017). Our stable on target and stable above target groups are reflected in the Schwandt et al. (2017) data, with these two groups capturing nearly two-thirds of youth—65% in our study and 67% in Schwandt et al. (2017). Our stable high group is also reflected in these data, capturing 17% of our youth and 15% of their youth. The Schwandt et al. (2017) study identifies two trajectories with large increases in glycemic control over adolescence that are somewhat reflective of our inverted U and volatile late peak groups, but differ in their overall shape from our trajectories because of differences in timeframe. We have evidence that glycemic control begins to decrease in both the inverted U and volatile late peak groups in early emerging adulthood. These effects are not captured by Schwandt, but their study ends at age 19.

Our findings also are consistent with those of Luyckx and Seiffge-Krenke (2009) in obtaining groups that vary in their level of control and isolating a group that deteriorates in glycemic control. But our findings make further differentiations within these patterns of control to show that some groups have relatively stable control that varies in level but other groups vary more substantially in their changes in glycemic control over adolescence and emerging adulthood. Luyckx and Seiffge-Krenke (2009) did not identify a group whose level of HbA1c increased during adolescence but then decreased during emerging adulthood (inverted U).

Our second study goal was to distinguish the more problematic trajectories of glycemic control from the stable on target glycemic control group. With respect to demographic variables, both parent social status and household structure emerged as significant predictors. They not only distinguished the high HbA1c groups from the lowest HbA1c group but also distinguished the volatile late peak group from the lowest HbA1c group, suggesting that these demographic factors play a role in predicting which youth begin adolescence in good control but show a dramatic deterioration over the course of adolescence. These results suggest that health-care practitioners should be especially sensitive to the characteristics of the family and family structure when identifying early adolescents who may need more attention. To do this may require extending the time that practitioners can spend with families or garnering additional health-care resources to be directed toward identifying high-risk youth.

As predicted, psychological distress indices in early adolescence emerged as significant predictors of glycemic control trajectories and characterized groups with more problematic trajectories of HbA1c, but findings differed depending on whether the report was from youth or their parents. Youth's report of psychological distress only distinguished the inverted U group from the stable on target group. Parents' report of youth internalizing problems, however, distinguished the three groups with the most problematic courses of HbA1c from the stable on target group. Taken collectively, screening for depressive symptoms in early adolescence not only among youth but also among parents may help to identify youth who will face difficulties in the later teen years. These findings indicate that parents might have some insight into children who are at risk for deteriorations in glycemic control over the course of adolescence and suggest that practitioners obtain screening information from parents as well as youth.

In terms of relationship variables, overall parent relationship quality did not distinguish any of the trajectories from the stable on target group as anticipated. Parent relationship quality may fluctuate too much over these years to be a stable predictor of changes in glycemic control. One aspect of friend relationships, however, did distinguish the trajectories. Consistent with our hypotheses and the findings in a previous report (Helgeson et al., 2010), conflict with friends distinguished the group that maintained the highest levels of HbA1c for the longest period (inverted U) from the stable on target glycemic control group. Given that friendships are likely to change over the course of adolescence and emerging adulthood, it is unlikely that conflict with specific friends at age 12 is having an effect on glycemic control over the subsequent 11 years. However, conflict with friends may be a proxy for general social difficulties, which could be linked to the next predictor we discuss.

We examined a personality trait, unmitigated communion, that is relevant to social difficulties, and found that it differentiated the group that maintained the highest levels of HbA1c over adolescence (the inverted U group) from the stable on target group. Youth characterized by unmitigated communion are likely to be overly involved in their relationships with friends and may neglect themselves, including diabetes care, because of immersion in friend relationships. These findings regarding unmitigated communion are consistent with the social processing model of adjustment (Crick & Dodge, 1994), which suggests that youths' self-care difficulties may stem in part from inaccurate thoughts and beliefs about others. Like the research on extreme peer orientation (King et al., 2012) and negative attributions for friends' reaction to self-care (Hains et al., 2007), those characterized by unmitigated communion may have inaccurate beliefs about their peer relationships. Given the central role that friendship plays in the lives of adolescents and emerging adults, this should be a subject of inquiry by health-care practitioners.

As we hypothesized, self-care behavior distinguished the group with the highest level of HbA1c over adolescence (inverted U) from the stable on target glycemic control group. These findings support the vast literature that has linked self-care to glycemic control (Lewin et al., 2009), and extend that research by showing self-care behavior also predicts a deterioration of glycemic control over the course of adolescence. However, self-care did not distinguish the other trajectories of glycemic control from the stable on target group. Self-care at age 12 may not be a stable resistance factor, limiting its ability to differentiate many patterns of HbA1c over adolescence and emerging adulthood.

Taken collectively and returning to the risk and resistance framework (Wallander et al., 1989), these findings show that characteristics of one's family growing up—specifically, lower parent social status and lack of two-parent household structure—are risk factors, whereas being on an insulin pump was a resistance factor for problematic trajectories of glycemic control over adolescence and emerging adulthood. It is interesting that insulin pump at age 12 variable had such predictive power, as insulin pump usage increased over the course of the study (see Table I). Because youth are not randomly assigned to be on an insulin pump, we must consider the possibility that those on an insulin pump at age 12 had other advantages. Our data showed a trend for those on an insulin pump at age 12 to come from higher social status families ($p = .05$).

Among the psychosocial variables we examined as risk and resistance factors, the one that had the most predictive power in distinguishing trajectories was a marker of youth's psychological distress as reported by parents, specifically internalizing problems. Thus, indications of internalizing problems among youth in early adolescence appear to be a risk factor for increases in HbA1c and fluctuations in HbA1c over the course of adolescence. A second set of risk factors that we identified might be considered markers of social difficulties—conflict with friends and unmitigated communion. These variables, however, were limited in their predictive power, as they only distinguished the group that maintained the highest HbA1c over adolescence and emerging adulthood from the group that maintained the lowest and most stable HbA1c over that same period.

These findings have both clinical implications for health-care practitioners who work with youth and emerging adults with type 1 diabetes and implications for future research that is conducted in this area. Many intervention studies that target youth with type 1 diabetes span early to middle to late adolescence (Harris, Freeman, & Beers, 2009)—no doubt because it is difficult to identify large number of adolescents within a small age-range to have the power to test the effectiveness of an intervention. However, there are different patterns of change in HbA1c that occur over adolescence and emerging adulthood, and spikes in HbA1c occur at different ages. In other words, it cannot be anticipated that all youth deteriorate over adolescence at the same rate and at the same time. Thus, an intervention that is aimed at a 12-year-old may not be the same as that required by a 17-year-old or a 20-year-old. The resources needed to address the difficulties faced by a teenager whose HbA1c remains somewhat elevated over the course of adolescence may not be the same as the resources needed by a teenager whose HbA1c drastically increases in early adolescence or the teenager whose HbA1c drastically increases in later adolescence, perhaps after college graduation. These findings speak to the importance of clinical trials that are able to tailor the resources provided to the individual needs of the patient. Trial such as the FL3X behavioral

intervention (Mayer-Davis et al., 2015), in which youth's HbA1c is tracked continuously and resources provided on an "as needed" basis, may be especially promising given our findings.

Before concluding, we note several study limitations and suggestions for future research. First, we have varying frequencies of glycemic control measurements for participants over the course of adolescence and emerging adulthood, which has important clinical and methodological implications. Youth from higher social status families had higher numbers of HbA1cs recorded, which likely reflects greater clinic attendance and adherence. Trajectories are likely to be less precise for those participants who have fewer measures of glycemic control. Although the number of measures ranged from 4 to 27 for an individual, the average number of measures for the five trajectory groups was fairly similar. The stable on target group did not have the lowest or the highest number of measures (18 measures). With the development of better HbA1c kits, future research might entice youth who are not attending the clinic regularly to test their glycemic control on their own. This would not only be useful from a research point of view but also could be helpful to health-care practitioners if youth are willing to return the results to the clinic.

Second, we were not able to distinguish all of the trajectories from the stable on target group. In addition, the groups with the largest increases in HbA1c (volatile late peak, inverted U) contained smaller numbers of participants. The volatile late peak is a particularly interesting group, as their HbA1c is especially high during emerging adulthood rather than adolescence. It is especially important for future research to replicate these findings by following larger samples of youth over adolescence and emerging adulthood. Larger numbers of people in these two groups would provide added power to identify the youth who are likely to end up with these trajectories.

Other study limitations include the fact that these data are based on HbA1c readings that were taken from more than one laboratory, which is likely to introduce some error in measurement. The vast majority of youth remained at Children's Hospital throughout adolescence, but some youth saw other physicians after high school graduation. In REACH, we used the DCA Vantage Analyzer to measure HbA1c, which is a common method used in adult care. A study that evaluated a number of point-of-care instruments showed that the DCA Vantage met the requirements for assay conformance with the National Glycohemoglobin Standardization Program (Lenters-Westra & Slingerland, 2010). Note that the trajectories were already diverging in adolescence when youth were at Children's Hospital and the same laboratory was used. It is extremely unlikely that the large differences in trajectories that occurred after that fact could be attributed to laboratory variance alone. In addition, these data are based on a largely white non-Hispanic sample, which limits the generalizability of the findings. Finally, we note that the majority of our risk and resistance factors were not diabetes-specific. For example, we measured general psychological distress and general characteristics of relationships. Diabetes-specific measures, such as the Diabetes Distress Scale (Polonsky et al, 2005), might have provided added discriminatory power in distinguishing the trajectories.

In sum, this is the first study to follow the course of glycemic control through adolescence and the early stage of emerging adulthood for 11 consecutive years among a cohort of early adolescents with type 1 diabetes. We identified five distinct patterns of glycemic control and showed that demographic and psychosocial factors distinguished the poorest control and most volatile control groups from the most stable on target glycemic control group. Although youth generally show some level of increase in HbA1c over the course of adolescence, many youth show improvements in HbA1c by the early years of emerging adulthood. One question for future research is to examine the cost to future physical health of having a poor but limited period of poor glycemic control during adolescence.

Supplementary Data

Supplementary data can be found at: http://www.jpepsy.oxfordjournals.org/.

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