Brief Report: Trajectories of Glycemic Control over Early to Middle Adolescence

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Objectives To identify distinct patterns of glycemic control over early to middle adolescence, and to determine whether psychosocial variables predicted those patterns. Methods We used trajectory analysis to examine glycemic control over 5 years among adolescents with type 1 diabetes who were of age 12 on average at study start (n = 132). Well-being, relationships, and self-care behavior were assessed with in-person interviews. Blood glucose testing was determined from blood glucose meters, and missed clinic appointments and glycosolated hemoglobin were obtained from medical records. Results We identified two distinct clusters of individuals, a stable good glycemic control group and a poorer deteriorating glycemic control group. Individuals in the deteriorating control group were characterized by higher peer conflict, more negative diabetes emotions, fewer blood glucose tests, and more missed clinic appointments. Conclusion Psychosocial variables and behavioral markers of self-care may predict the course of glycemic control over early to middle adolescence.

Key words adolescence; diabetes; glycemic control.

A great deal of research has documented that glycemic control deteriorates over the course of adolescence (Greening, Stoppelbein, Konishi, Jordan, & Moll, 2007; Helgeson, Siminerio, Escobar, & Becker, 2009). In a previous paper, we used longitudinal growth curve modeling to show that hemoglobin A1c increased over early to middle adolescence (Helgeson et al., 2009). Growth curve analyses enable examination of individual variation in rates of change, but ultimately provide estimates for the average growth and variance in growth in a population. That is, this statistical procedure assumes that population members follow a common pattern of either increasing or decreasing growth on the dependent variable of interest. With respect to HbA1c, the finding is that the common pattern over adolescence is one of an increase. However, health care professionals recognize that not all adolescents experience a deterioration in glycemic control. Thus, the question remains as to whether there are distinct “patterns of change” in glycemic control over the course of adolescence. We address this question in this article with the use of trajectory analysis.

Trajectory analysis is a statistical tool used to determine whether there are groups or clusters of individuals with distinct developmental trajectories (Nagin, 2005). For example, some adolescents may maintain a relatively stable pattern of good or poor glycemic control, other adolescents may fluctuate, and yet others may show a steady deterioration or improvement. In the past, researchers have tried to capture distinct patterns of change by placing adolescents into groups, such as good control, satisfactory control, and poor control, based on a single assessment of glycemic control or an average of several assessments.
(Seiffge-Krenke, 1998). We took advantage of the fact that we had collected five years of longitudinal data on markers of glycemic control (i.e., an average of 13 measures of glycosylated hemoglobin) that spanned early and middle adolescence to see if we could identify distinct patterns of change with trajectory analysis. Trajectory analysis is a relatively new statistical technique that has been used to identify distinct patterns of adjustment to breast cancer (Helgeson, Snyder, & Seltman, 2004; Henselmans et al., in press) and, most recently, to examine changes in glycemic control from later adolescence to emerging adulthood (Luyckx & Seiffge-Krenke, 2009). Trajectory analysis is particularly applicable to the period of early and middle adolescence as a great deal of change in glycemic control is expected to occur at this time. It is important to examine glycemic control changes during adolescence because research has shown that good glycemic control during adolescence in the DCCT, like in adults, predicts the development of diabetes-related complications (Diabetes Control and Complications Trial, 1993).

In addition to identifying trajectories of glycemic control, we also examined whether we could predict trajectory membership with demographic, medical, and psychosocial variables. In an earlier report on this same sample, we determined that poor self-care behavior, disturbed eating behavior, depressive symptoms, and peer conflict were related to poor glycemic control (Helgeson et al., 2009). Another study of older adolescents and young adults that examined trajectories of glycemic control showed that a good family climate was related to the trajectory of optimal control (stable good control), and a negative self-concept was related to the trajectory of deteriorating control (Luyckx & Seiffge-Krenke, 2009). Here, we examined whether psychosocial variables differentially discriminated among patterns of glycemic control over early and middle adolescence. We hypothesized that adolescents who showed better glycemic control profiles would have higher well-being, better peer and parental relations, and better self-care.

**Methods**

**Participants**

We enrolled 132 children with type 1 diabetes (5th, 6th, or 7th grade) into a 5-year longitudinal study. Recruitment procedures are described in detail in Helgeson et al. (2009). Age at study start ranged from 10.73 to 14.21 years ($M = 12.10$). The majority of participants were white (93%), and parents scored 41.97 ($SD = 11.05$) on the Hollingshead (1975) index, reflecting the lower end of technical workers, medium business, and minor professionals. The average glycemic control at study start was 8.04 ($SD = 1.32$). Three of these children were eliminated from the present analyses because they visited the clinic less than three times over the 5 years, such that only 1 to 3 glycemic control measures were available.

**Procedure**

The study was approved by the appropriate Institutional Review Boards. Children were interviewed annually before or after their regular clinic appointment in the hospital’s General Clinical Research Center. Parental consent and child assent were obtained prior to the start of the first interview. The instruments, described below, were administered at the initial interview. Children also brought blood glucose meters to the interview so that the research assistant could download these data. Information on glycemic control was abstracted from medical records.

**Instruments**

**Demographic and Illness-related Variables**

Demographic variables included age, sex, social status [four factor Hollingshead index (1975)], pubertal status [Carskadon & Acebo’s (1993) self-report measure], body mass index (BMI), and household structure (living with two parents or not). Diabetes-related variables included illness duration and insulin delivery method (pump vs. injection).

**Psychological Well-being**

We administered the abbreviated form of the Children’s Depression Inventory (Kovacs, 1985, 2001) to measure depressive symptoms ($\alpha = .76$), and two subscales from the Self-Perception Profile for Children (Harter, 1985) to tap global self-worth ($\alpha = .75$) and social acceptance ($\alpha = .73$). We developed a 3-item measure of diabetes well-being by asking participants how often they felt (a) scared, (b) sad, and (c) angry in connection with their diabetes (1 = never; 5 = very often; $\alpha = .78$). Although the measure is face valid, its use is exploratory as it was created specifically for this study.

**Relationship Variables**

We used Stattin and Kerr’s (2000) parent relationship measure to assess overall quality of the relationship with mother (alpha = .79) and father (alpha = .88). We averaged the two scales because they were highly correlated. We created a measure of parent diabetes-specific support ($\alpha = .85$) based on five emotional support items (e.g., How often do your parents listen to your problems about having diabetes?) and three instrumental
support items (e.g., How often do your parents suggest things that might help you take care of your diabetes?) contained in Schafer, McCaul, and Galsgow’s (1986) and McKelvey et al.’s (1993) measures. We used the Berndt and Keefe (1995) friendship scale to develop a measure of friend support (average of companionship, intimacy, instrumental support, self-esteem enhancement; \( \alpha = .90 \)) and friend conflict (average of dominance, conflict; \( \alpha = .84 \)).

Self-care Behavior
We updated the 14-item Self-Care Inventory (La Greca, Swales, Klemp, & Madigan, 1988) with eight more contemporary items as described in Helgeson et al. (2009). The internal consistency was high (\( \alpha = .78 \)). We also calculated the average number of meter readings taken per day over the past 2 months by downloading data from meters when available (70%) or using meter logs (20%). We calculated the number of missed clinic appointments over the 5 years by defining a period of 4.5 months without clinic attendance as a missed appointment, thus allowing some leeway due to scheduling difficulties or illness. The clinic recommends that adolescents see their physician every 3 months (i.e., 4 times a year).

Glycemic Control
Glycemic control was measured with hemoglobin A1c (HbA1c) obtained from each clinic appointment measured by HPLC (Tosoh Instruments) with normal range of 4.6–6.1%. HbA1c indicates the average blood glucose level over the past 1–2 months.

Results
Background Information
The average number of HbA1c levels recorded over the 5 years was 13 (\( SD = 3.79 \); range = 4 to 17).

Model Selection
We used the SAS procedure called procedure trajectory 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 (1999, 2005) to identify the number of groups representing relatively homogenous clusters of trajectories of HbA1c over the 5 years. We began by examining the raw data graphically. We plotted each individual’s HbA1c trajectory and examined the individual plots for distinct patterns of change. Based on this inspection, we identified four potential groups: a group with little change in HbA1c, a group with a slight decrease in HbA1c, a group with a slight increase in HbA1c, and a group with a large increase in HbA1c. In addition to identifying the number of trajectory groups, we also were identifying the pattern of each trajectory (i.e., quadratic, linear). We tested several models, starting with four groups, and selected the final model by examining the significance of the parameters and by comparing each model’s Bayesian Information Criterion (BIC) value. A decrease in BIC signifies an improvement in model fit. The BIC is used for model selection (Jones et al., 2001; Nagin, 1999, 2005).

Based on the BIC criterion, we selected the model with two trajectory groups, the first of which was a linear group (intercept = 7.95; slope = .01; \( SE = .002, p < .001 \)) and the second of which was a quadratic group (intercept = 10.00; slope = .03; \( SE = .006, p < .001 \)), both having random intercepts and slopes. This model is shown in Figure 1. Group 1 is a cluster of individuals with a very slight increase in HbA1c over time and whose initial HbA1c was lower than Group 2. We refer to this group as the “stable good” glycemic control group.

**Figure 1.** Trajectory analysis reveals two distinct clusters of individuals, a group who has relatively stable good metabolic control (group 1) and a group who has poorer metabolic control that deteriorates over time (group 2).
group. Group 2 is a cluster of individuals with a higher initial HbA1c reading and HbA1c’s that continue to rise substantially over the course of the five years. We refer to this group as the “deteriorating” glycemic control group. Two-thirds (63.7%) of adolescents were characterized by the stable good trajectory, whereas one-third (36.3%) was characterized by the deteriorating trajectory.

Rather than examine trajectories of HbA1c over time, we could have identified trajectories of HbA1c over age [although individuals began the study with differing ages (10.7–14.1 years)]. We repeated the above analyses using age rather than time as our growth parameter. The findings were virtually identical to those reported above; a two-trajectory model revealed the best fit, looked the same as that shown in Figure 1, and revealed the same significant parameters. Using time rather than age as a growth parameter revealed a slightly better BIC.

Demographic and Illness Predictors of Trajectory Groups

Once the distinct trajectories are identified, procedure trajectory can model the effects of covariates on 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. First, we examined whether demographic and illness-related variables distinguished the two trajectories. The estimates that we report are similar to regression coefficients; they are the change in log odds ratio of being in one trajectory versus the other, given a one-unit increase in the risk factor. Coefficients that are more than 1 indicate that there is an increased probability of the risk factor in Group 2 (deteriorating group), whereas coefficients that are less than 1 indicate that there is a decreased probability of the risk factor in Group 2.

Social status, pubertal status, and BMI distinguished the trajectories (−.04, p < .05; .71, p < .01; .17, p < .01). Individuals in the deteriorating group began the study with lower social status, higher pubertal status, and a higher BMI. Puberty distinguished the trajectories even controlling for age. Household structure distinguished the trajectories (1.76, p < .05), indicating that children who did not live in two-parent households were more likely to be in the deteriorating control group than the stable good control group. Age and gender did not distinguish the trajectories. Because girls reach puberty earlier than boys, we examined whether gender predicted the trajectories adjusted for age or whether gender interacted with age to predict the trajectories. Neither was significant. Length of diabetes did not distinguish the trajectory groups, but method of insulin delivery at study start did (−1.88, p < .05), indicating that individuals on insulin pumps were less likely to be in the deteriorating group than individuals taking injections. We were concerned that this finding was confounded with initial HbA1c, as better controlled patients may choose or be prescribed an insulin pump. Indeed, when we controlled for initial HbA1c, the effect of insulin delivery method disappeared (−.46, p = .61) and the effect of initial HbA1c remained significant (2.41, p < .001). As shown in Figure 1, the two trajectory groups differ in initial HbA1c. Thus, when examining whether psychosocial and behavioral risk factors distinguished the two groups, we statistically controlled for social status, pubertal status, BMI, and household structure in all analyses.

Psychosocial and Behavioral Risk Factors

Controlling for social status, pubertal status, BMI, and household structure, four psychosocial variables significantly distinguished the trajectories—friend conflict (1.13, p < .05), negative diabetes emotions (.59, p < .05), average number of meter readings taken per day (−.81, p < .01), and number of missed appointments over the 5 years (.22, p < .01). The deteriorating group was characterized by higher peer conflict (M = 2.11) than the stable good group (M = 1.67); had more negative emotions (M = 2.33) than the stable good group (M = 1.84); had fewer meter readings per day (M = 3.24) than the stable good group (M = 4.28); and more missed appointments (M = 5.81) compared to the stable good group (M = 2.50). Friend support, parent support, depressive symptoms, self-worth, and the self-care behavior index did not significantly distinguish the trajectories.

Discussion

This is the first study to examine whether there are distinct patterns of glycemic control over early through middle adolescence among those with type 1 diabetes. With 5 years worth of HbA1c readings, we were able to identify two distinct trajectories. One reason that we were not able to identify additional trajectories is that there was a large amount of fluctuation in glycemic control over this period of time. The period of adolescence is one in which numerous changes are experienced in relationships (parents, friends), school, and bodies (Holmbeck, Friedman, Abad, & Jandasek, 2006). All of these changes are likely to affect glycemic control. Nonetheless, there were clearly two distinct trajectories of glycemic control—one showing rather good control, starting off with HbA1c below 8.0% (clinic average 8.1% <13 years of
and increasing to about 8.0% five years later. It is worth noting that this trajectory characterized the vast majority of participants. However, one-third of participants were characterized by a much more dangerous trajectory of glycemic control, starting off significantly worse at nearly 9.0% and ending up at about 10.5%. It is important to identify who might be at risk for membership in this trajectory.

From our data, we identified several risk factors. The first risk factor was initial HbA1c. Those who started with poor control were the ones who ended with the worst control. Although initial age did not predict trajectory membership, pubertal status did, such that those who were more advanced physically were most likely to be in the deteriorating group. Early hormonal fluctuation may account for part of this relation but cannot fully explain it. There may be other factors that co-occur with early pubertal status that pose a risk for poor glycemic control.

Many studies have linked social relations to glycemic control (see Ryan, 2003, for a review), but most of those studies have focused on parental relationships rather than relationships with friends. Peer relationships are likely to be especially important during adolescence. When we examined changes in metabolic control via growth curve modeling, we found that peer conflict played a role; specifically, that adolescents who reported more peer conflict showed worse glycemic control. These data expand on those findings and suggest that peer conflict at the outset (average age 12) predicts a trajectory of declining control over the next 5 years. Although the traditional markers of well-being—depressive symptoms and self-esteem—did not predict trajectory membership, the single measure of diabetes-related well-being did. Adolescents who said that they experienced negative emotions in conjunction with diabetes at study start were more likely to experience a decline in glycemic control over time.

Finally, self-care influenced trajectory membership. Although the self-care behavior index did not predict trajectory membership, two more concrete markers of self-care did. First, more frequent blood sugar testing was associated with a more stable trajectory of HbA1c. Second, regular clinic appointment attendance was associated with a more stable trajectory of HbA1c. There are many reasons that people fail to attend clinic appointments. Families may have competing demands and/or have difficulty taking time off from work. Many of the families who attend this clinic live a fair distance away, as it is the only children’s diabetes clinic in the Western Pennsylvania area. It is interesting, however, that clinic appointments predicted trajectory membership even when social status was statistically controlled, so it is not only a lack of resources that is affecting clinic attendance, but also may be the case that a deterioration in HbA1c leads families to miss clinic appointments, possibly because they feel uncomfortable having to confront the issue with the health care team. However, the hope and expectation is that clinic attendance will provide guidance to prevent a deterioration in glycemic control.

Because Luyckx and Seiffge-Krenke (2009) also addressed trajectories of glycemic control in a recent paper, it is important to compare our findings to those that they reported. There were a number of differences, one of which is that their sample was drawn from Germany and our sample was drawn from the United States. In addition, the two studies focused on different phases of adolescence. Luyckx and Seiffge-Krenke (2009) found that self-concept distinguished the trajectories but only at the point of older adolescence, on average age 16, which is at the upper end of the age spectrum for our study participants. Their measure of self-concept also was more global (included body image, impulse control) than our specific measure of self-esteem. We found that peer relationships distinguished the trajectory groups but parental support did not. Luyckx and Seiffge-Krenke did not examine peer relationships but found that family climate distinguished the trajectory groups. However, their family climate variable focused on family organization and control which is different from our parent relationship quality and support measures. Having a predictable and organized family environment may be particularly important to effective management of diabetes. We identified two distinct trajectory groups, whereas they identified three groups. However, they noted that patterns of glycemic control did not differ substantially until after the age of 16.

Thus, we might observe a more varied pattern of glycemic control in our participants in the years to come.

Before concluding, we should note several study limitations. First, we did not measure other psychosocial variables that might have distinguished the trajectories, such as family organization or control. Second, we did not examine how psychosocial variables changed over the course of the 5 years which could have impacted trajectories of glycemic control. Third, our sample was fairly homogenous in terms of social status and race and ethnicity. There may be additional patterns of glycemic control or a larger deteriorating control group among lower social status groups or minority groups who have less access to health care and a less positive view of the health care system. In addition, the predictors of trajectory membership may differ across race and ethnicity, as some ethnic groups, such as African-Americans, place greater emphasis on the family than Caucasians (Gaines, 1997). Finally, further investigation is needed to understand why family organization and control might be particularly important to glycemic control.
although the study was longitudinal, there is the potential for reverse causality. For example, more negative diabetes emotions may lead to a deteriorating trajectory of glycemic control over adolescence, or a poor level of glycemic control may lead to an increase in negative diabetes emotions. It is likely that the process is reciprocal, with emotions affecting glycemic control and glycemic control affecting emotions.

To conclude, we found that early adolescents who have more conflict with peers, more negative emotions attached to diabetes, and monitor blood glucose and visit the physician less frequently are at risk for sharp declines in glycemic control over the next 5 years. These results suggest that early intervention with at-risk individuals is needed. Health care professionals need to attend to early adolescents who seem to be having difficulties with peer relations and seem to be unhappy about their diabetes before problems in self-care begin to arise. Health care professionals should consider discussing peer relationships with their patients, and researchers should consider interventions that involve peers or are directed at peer relations.

Missed clinic visits should be immediately addressed as they could be a harbinger of diabetes-related difficulties. Although it can be difficult to target at-risk individuals for an intervention, Wysocki and colleagues (Wysocki et al., 1997, 2000) targeted at-risk adolescents (ages 12–16 years) and their families for a family-based intervention, found that these adolescents evaluated the treatment positively, and that younger adolescents benefited more from the intervention than older adolescents. Our recommendations are consistent with those of Wysocki and colleagues—that intervention efforts ought to be aimed at preventing problems among younger adolescents rather than remedying problems among older adolescents.

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References


