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Sleep Habits in Adolescents with Type 1 Diabetes: Variability in Sleep Duration Linked with Glycemic Control

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Abstract

Objective—To describe adolescents' sleep on school and weekend nights using multiple methods, and to examine the links between sleep variability, quality and duration with diabetes indicators.

Methods—Adolescents with type 1 diabetes (N=65, mean age=15.0, 52.3% female, mean HbA1c=8.9% or **74 mmol/mol)** wore an actigraph and kept daily diaries recording sleep, activities, and blood glucose monitoring (BGM) habits for at least 7 days. Average daily BGM and blood glucose levels (BG) were obtained through glucometer downloads. HbA1c was obtained as part of clinic visits. Adolescents completed a sleep quality questionnaire (PSQI), and adolescents and caregivers reported on adherence to diabetes treatment.

Results—Adolescents reported a mean PSQI global score of 5.37, which is above the clinical cutoff for poor sleep quality. Actigraphy data revealed that mean adolescent total sleep time was 06:54 (hh:mm), and participants slept more on weekend nights than on school nights (P<.001). Additionally, variability in sleep duration was significantly related to HbA1c, frequency of BGM, and average BG. Total sleep time and self-reported sleep quality were not significantly associated with adherence or glycemic control.

Conclusions—Few adolescents with type 1 diabetes met recommendations for sleep duration, and many reported poor sleep quality. We identified significant associations between variability in sleep duration with poorer glycemic control and less frequent BGM, supporting the need to consider sleep patterns as a modifiable factor that may affect adherence and glycemic control.

Keywords

Sleep; Type 1 Diabetes; Adolescence; Adherence

Introduction

Insufficient sleep is a public health problem that affects the majority of adolescents in the United States (1, 2). Many adolescents have difficulty meeting the recommended sleep duration of 8–10 hours/night (3) due to greater extracurricular activities (e.g. homework,

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sports, work), (4, 5) earlier school start times, and increased social commitments (6) during this developmental stage. In addition to these academic and social changes, adolescents experience shifts in circadian rhythms that cause them to stay awake later (7). While adolescents in the general population face many demands that may interfere with healthy sleep habits, adolescents with type 1 diabetes (T1D) also experience challenges associated with the intensive treatment regimen, which includes daily blood glucose (BG) monitoring and frequent insulin administration (8). Recent data from a national sample indicated that only 17% of adolescents were meeting the target goal for glycemic control (i.e. glycosylated hemoglobin (HbA1c) ≤ 7.5% (58 mmol/mol)) (9). Thus, it is essential to identify modifiable barriers to achieving optimal glycemic control, and sleep may be an important factor to consider.

A recent meta-analysis revealed that children and adolescents with T1D obtain significantly less sleep than those without diabetes (10). This is likely due to sleep disturbances unique to T1D, which include awakenings caused by rapid fluctuations in glucose levels (11), the need to treat low BG levels overnight (12), and interruptions due to diabetes-related technology (e.g., alarms) (13). For adolescents with T1D, sleep disturbances have been linked with poorer glycemic control (14, 15) related to increased insulin resistance (16), as well as poorer diabetes management (14). In one recent study, an increase of 15–20 minutes of sleep in adolescents was associated with an additional BG check and insulin bolus (17). The majority of these studies used subjective measures of sleep (questionnaire data or diaries), and therefore further investigation into specific sleep habits related to diabetes management and glycemic control is warranted.

More recently, researchers have examined not just the duration of sleep, but the timing and regularity of sleep. For example, when people sleep less on school nights (i.e. accumulate a sleep debt) and compensate by sleeping more on weekend nights, they may experience what is known as “social jetlag,” or daytime tiredness related to sleep inconsistency (18). This practice of weekend bedtime delay and oversleeping, or variability in sleep timing and duration, has been associated with mood problems, poor academic performance, and obesity (19) in adolescents in the general population, as well as poorer glycemic control in adults with T1D (20). In one of the only studies to examine this phenomenon in adolescents with T1D, social jetlag (the difference between school night and weekend night sleep duration) was not associated with glycemic control, but social jetlag was significantly associated with insulin requirements (21), suggesting that variability in sleep is related to insulin resistance. However, these studies relied on self-report of sleep patterns, and more objective measures of sleep timing and duration are likely to offer greater insight.

To address the gaps in the literature, the current study provides an in-depth description of sleep in adolescents with T1D, using a multi-method approach (actigraphy, questionnaire, and daily diary self-report), to characterize and identify differences in sleep patterns on school nights and weekend nights. In addition, we sought to examine the relationship of inconsistent and insufficient sleep with diabetes indicators, including adherence and glycemic control. We hypothesized that shorter total sleep time and greater variability in sleep duration would be related to poorer glycemic control and more problems with adherence.

Methods

Participants

This study included 65 adolescent-caregiver dyads. Adolescents were eligible for the study if: 1) they were between the ages of 13–17 years; 2) they had been diagnosed with T1D for at least 12 months; 3) they had not been diagnosed with any sleep disorders; 4) they were not currently participating in any intervention studies; and 5) they were able to read/speak English. Caregivers were eligible if they were able to read/speak English.

Procedures

All study protocols and materials were approved by the university's Institutional Review Board/Human Research Protection Program. A trained research analyst (RA) approached participants during their regular scheduled clinic appointment to screen for diagnosed sleep disorders (e.g. sleep apnea, restless legs, narcolepsy). For eligible adolescents, a study visit was scheduled before or after their diabetes clinic appointment, or on a different day near their appointment (based on participant preference). Of the 92 families approached, 27 refused, yielding a participation rate of 71%. After providing informed consent/assent, adolescents and caregivers completed questionnaires in REDCap (Research Electronic Data Capture) (22) and received training on using the actigraph watch. Adolescents were instructed to wear the watch continuously for at least 7 days, and to press the event marker at "lights out" and "lights on" times to demarcate time in bed. Additionally, adolescents were asked to complete a daily sleep diary, in the morning and evening for the corresponding 7 days. Participants were provided detailed written directions, and the RA followed up the following day to resolve any issues with the actigraph watch or completing the diary. Participants returned the watch and sleep diary in a pre-paid envelope (one participant did not wear the atigraph watch). Adolescents and caregivers were compensated for their time to complete questionnaires and received additional compensation for returning the watch and sleep diary.

Measures

Demographics—Caregivers provided demographic information about themselves and their teens on variables such as age, sex, race/ethnicity, household income, duration of diabetes, and treatment type (i.e. insulin pump or injections).

Sleep characteristics and quality—Actigraphy data, collected with the Phillips Actiwatch Spectrum Plus, were used as an objective measure of adolescents' sleep. Based on previous work (23), we configured actigraph watches using a 1-minute epoch, with a sleep interval of 10 epochs for onset of sleep, and an awake threshold setting of 40 (medium). Data from the watch were analyzed using Philips Actiware software to calculate sleep efficiency (ratio of total sleep time to time in bed, recommended range is 85–100%), sleep latency (time from bedtime to sleep onset, recommended duration is <30 minutes), and sleep duration (total sleep time). Furthermore, adolescents completed the Pittsburgh Sleep Quality Index (PSQI), a widely-used and validated self-report measure, consisting of 19 items on sleep quality (24). Items are scored on a scale ranging from 0 (no difficulty) to 3 (severe

difficulty) to produce a global score. The clinical cutoff for poor sleep quality is a score of 5 or higher.

Sleep habits—Adolescents tracked their sleep habits using a daily sleep diary, including daytime sleep-related behaviors (e.g., caffeine use, daily activity level, electronics in room) and nocturnal sleep characteristics (e.g., bedtime, wake time, night awakenings), as well as diabetes-specific factors that may influence sleep (e.g., blood glucose monitoring (BGM) by the adolescent at bedtime, overnight, and in the morning). They also recorded nap activity (quantity and duration), school start times, stress and mood levels (single item scaled from 1–10), afterschool activities (e.g., sports practice, work) and any abnormalities in routine that may have affected their sleep (e.g. sleepovers, snow days, use of cold medications).

Adherence—Adolescents and caregivers completed the Self-Care Inventory (SCI), which measures adherence to diabetes treatment, such as diet, exercise, blood glucose monitoring, insulin administration, and attending medical appointments (25). The overall adherence score is determined using the mean of seven items, rated from 1 (never do it) to 5 (always do this as recommended without fail). Higher scores indicate better adherence. Cronbach's alpha was .80 for adolescents' self-report and .80 for parent report. In addition, we obtained average daily blood glucose monitoring (BGM) by downloading adolescents' glucometer readings from the previous 30 days to serve as an objective measure of adherence. Bedtime and overnight BGM was based on self-report from each day of the sleep diary.

Glycemic control—Adolescents' HbA1c values were collected as part of their regular diabetes clinic visit using the point-of-care Bayer Diagnostics DCA2000® Analyzer. HbA1c provides a percentage of glycosylated hemoglobin over the previous 3 months. Higher levels indicate poorer glycemic control, and the target for adolescents is ≤ 7.5% (58 mmol/mol) (8) In addition, data from adolescents' glucometers were used to determine average BG levels, and percent of BG readings within target range (70–140 mg/dL) over the previous 30 days.

Analysis Plan

Statistical analyses were performed using IBM SPSS Statistics 23. We conducted descriptive analyses were conducted to describe the characteristics of the study population and sleep habits in our sample. To examine differences between school and weekend nights, we conducted paired *t*-tests to compare sleep data (from both actigraphy and sleep diary) for school nights (typically Sunday-Thursday night) and weekend nights (typically Friday and Saturday night) for each participant, using the average values across school nights and weekend nights. Paired *t*-tests were also conducted to compare differences between school nights and weekend nights on sleep-related behaviors (i.e., mean number of caffeinated drinks, mean number of bedtime and morning BGM, and number of nights with electronic use). Further, bivariate analyses were conducted to determine the associations between variability in sleep duration, total sleep time, and self-reported sleep quality with diabetes-related outcomes. For these analyses, total sleep time (from actigraphy data) was averaged across 7 nights. Similar to prior research, variability in sleep duration was calculated using the standard deviation of total sleep time across 7 nights, representing the variation within-subjects in sleep from night to night (26). Finally, we conducted a series of multivariable

linear regression analyses to determine whether total sleep time or variability in sleep duration were significant predictors of glycemic control (HbA1c, average blood glucose, percent of readings within range) and diabetes management (average blood glucose checks/day, parent- and self-reported adherence).

Results

Participants were mostly White, Non-Hispanic (80%), and had diabetes for approximately 6 years (± 3.75). More than half the participants used an insulin pump for treatment (59%), but only 2 participants (3%) used continuous glucose monitors. Average HbA1c in our sample was 8.9% (74 mmol/mol) (± 1.47%), which is similar to rates observed in a nationally representative sample of youth with T1D (M = 8.5% at 12 months) (27). During the 30 days prior to sleep data collection, frequency of BGM was 3 times per day on average, mean BG level was 221.03 mg/dL (± 61.13) and about 24% of BG levels were within the target range. Actigraphy data were available for 64 participants, and usable data was available for 4–11 nights. See Table 1 for additional participant characteristics.

Description of Sleep

Adolescents reported a mean PSQI score of 5.37 (±2.50), which is above the clinical cutoff for poor sleep quality. Across 7 nights, actigraphy data revealed that mean total sleep time was 06:54 (hh:mm), mean onset latency was 17.8 minutes, and mean sleep efficiency was 84.6%. Based on sleep diary data, adolescents reported mean duration as 08:18. Across the 7 nights, adolescents reported a mean and median bedtime of 11:15 PM and 11:00 PM, respectively, with a range of reported bedtimes between 7:00PM – 5:00AM. The mean and median wake times reported were 7:34 AM and 7:00 AM, respectively, and reported wake times ranged from 4:10 AM to 1:44 PM. Only 23% of adolescents reported obtaining sufficient sleep (≥ 8 hours) on school nights. Sleep variability ranged from 21.2 minutes to 164.8 minutes, with a mean of 73.0 minutes. There were no significant differences in sleep characteristics between adolescents who were homeschooled and those who attended institutional schools (all $P > .05$).

Sleep Habits

Based on diary data, the median number of electronics powered on in the room while sleeping was one device, with a range of 0–3 devices (cell phone was most common device). Daily caffeine intake ranged from 0–6 caffeinated drinks; the mode was 0 and the mean was 0.97 drinks. The mean stress level reported was 3.16 (with lower numbers indicating less stress on a scale from 1–10) and mean mood level was 7.31 (with lower numbers indicating worse mood on a scale from 1–10). The range of number of nighttime blood glucose checks (the last check before sleep, and any checks between bedtime and wake time) was 0–4. On each night, the percentage of teens who performed overnight BG checks was 6.3 – 15.6%. The percentage of participants who reported BGM at bedtime and in the morning was 72.3% and 85.5%, respectively.

School Nights vs. Weekend Nights

On school nights, actigraphy revealed that the mean bedtime was significantly earlier than on weekend nights (10:53 PM vs. 11:57 PM, $t = -6.18$, $P < .001$). Similarly, the average wake time on school nights was 6:32 AM, significantly earlier than weekend wake time of 8:39 AM (t = −11.00, $p < .001$). Paired *t*-tests indicated that participants slept significantly more on weekend nights than on school nights, according to both actigraphy (mean total sleep time was 7:16 on weekends, 6:28 on school nights; $P < .001$) and daily diaries (mean total sleep time was 8:45 on weekend nights, 7:45 on school nights; $P < .005$). In other words, we observed an average social jetlag of approximately 1 hour. Additionally, the percentage of participants who reported BGM at bedtime was greater on weekend nights than on school nights (72.3% vs 60%) and the same pattern appeared for morning BGM (83.1% on weekend nights and 76.9% on school nights); however, there was not a statistically significant difference in frequency of BGM between school nights and weekend nights. Further, there was not a significant difference in use of caffeine or electronics between school nights and weekend nights.

Associations between Sleep Characteristics and Diabetes-Related Outcomes

Bivariate analyses were conducted to determine the association between variability in sleep duration, total sleep time, and self-reported sleep quality with diabetes-related outcomes (see Table 2). We identified a significant association between greater variability in sleep duration and less frequent BGM ($r = -0.27$, $P < 0.05$) and between sleep variability and HbA1c ($r = 0.34$, $P < 0.01$). In addition, our data revealed a significant association between sleep variability and average BG levels ($r = 0.30$, $P < 0.05$) and percent of BG levels within range ($r = -0.26$, $P < 0.05$). However, total sleep time and sleep quality were not significantly associated with any diabetes-related outcomes. Further, there was no significant association between sleep variability and parent- or self-reported adherence.

Multivariable Analysis

We conducted multivariable linear regression analyses to test sleep variability as a predictor of frequency of BGM, HbA1c, average BG, and percent of BG readings within target range. Each model was adjusted for demographic and clinical variables, including adolescent race/ethnicity, age, treatment type (pump vs. injections), and duration of diabetes. The model predicting frequency of BGM was significant ($F(5, 53) = 3.22$, $P = .013$), accounting for 16.1% of the variance. In this model, diabetes duration ($\beta = -.30$, $P = .018$) and variability in sleep duration ($\beta = -.25$, $p = .045$) were significant predictors, and the addition of sleep variability explained 6.1% of the variance in frequency of BGM. The model predicting HbA1c was also significant ($F(5,54) = 4.21$, $P = .003$), and accounted for 21.4% of the variance. Analyses revealed that two variables were significant predictors of HbA1c: diabetes duration ($\beta = .37$, $P = .003$) and variability in sleep duration ($\beta = .29$, $P = .016$); the addition of sleep variability to the model explained 8.2% of the variance in HbA1c. The model predicting average BG levels was also significant ($F(5, 54) = 2.96$, $P = .020$), accounting for 14.3% of variance. In this model, two variables were significant predictors of BG: adolescent age ($\beta = -.32$, $P = .014$) and variability in sleep duration ($\beta = .26$, $P = .040$). The addition of sleep variability explained 6.4% of the variance in average glucose levels.

Finally, the model predicting percent of BG readings within range was not significant (F (5,53) = 2.06, P = .085).

Discussion

The current study reveals novel findings relating sleep variability to diabetes indicators among adolescents with type 1 diabetes. The majority of our sample did not meet sleep recommendations, and many reported poor sleep quality. Based on both actigraphy and sleep diary data, adolescents slept longer and later on weekend nights than on school nights, indicating social jetlag, and variations in sleep duration were significantly related to poorer diabetes-related outcomes. Specifically, variability in sleep duration was associated with poorer glycemic control (HbA1c, average BG levels) and diabetes management (frequency of BGM).

While there is accumulating evidence regarding the importance of obtaining sufficient and good quality sleep for adolescents, (2) this study is one of the few to examine sleep habits in adolescents with T1D using both objective and subjective measures. We found many similarities between our sample and the general adolescent population, as well as some sleep disturbances unique to adolescents with T1D, such as overnight BGM and the need to treat nocturnal hypoglycemia. Similar to the general population, the majority of the adolescents in our sample were not meeting recommendations for sleep duration (28). Further, many of our participants reported electronic devices powered on while sleeping and caffeine consumption during the day, with some reporting as many as 6 caffeinated drinks/day (the American Association of Pediatrics recommends no more than 100 milligrams per day, or about 1 cup of home-brewed coffee (29)). Caffeine consumption and electronic use have been shown to interfere with sleep in the general adolescent population (30), and our results suggest they may have a negative impact on sleep in the T1D population as well.

The current study is unique in providing insight into school night and weekend night sleep habits in this population. According to both actigraphy data and sleep diaries, adolescents in our sample slept significantly longer on weekend nights than on school nights, with an average difference of about 1 hour. This finding supports the phenomenon of social jetlag, in which adolescents compensate on weekend nights for insufficient sleep on school nights (18). The difference in our sample was somewhat less than what was recently reported in by Von Schnurbein et al., who found an average of 2.5 hours of social jetlag in adolescents with T1D (based on self-report) (21). In addition, we found that adolescents indicated more regular BGM at bedtime on weekend nights than on school nights, but the difference in frequency was not statistically significant. Although the difference was non-significant, it could be a reflection of having a more rushed schedule during the school week, or that that insufficient sleep on school nights negatively impacts adolescents' ability to effectively engage in diabetes management, similar to findings from previous studies (14, 17). Another strength of our study is that by taking a multi-method approach, we were able to explain some of the disturbances observed in the actigraphy data; for example, several of the participants had night wakings that we could match to reports in the sleep diaries of treating low BG values overnight.

Finally, one of the contributions of our study was the focus on variability in sleep duration, and the novel finding that inconsistent sleep patterns among adolescents with T1D were associated with less frequent BGM, higher HbA1c, and increased average BG levels, after adjusting for demographic variables. In contrast, sleep duration (total sleep time) and self-reported sleep quality were not significantly associated with any of these outcomes. Our results are in line with findings from a recent study of adults with T1D, (20) but the current study is the first, to our knowledge, to demonstrate these relationships in the adolescent population. In addition, the lack of a significant association between sleep duration and glycemic control may explain why sleep has not been consistently associated with glycemic control in other studies of children and adolescents with T1D (10). Our findings suggest that, although obtaining sufficient sleep is important for good overall health, it may be even more valuable to consider consistency and timing of sleep in adolescents with T1D (31). Maintaining a stable sleep schedule over school nights and weekend nights to avoid social jetlag may have the potential to improve diabetes management and glycemic control. Therefore, we suggest that clinicians ask adolescents about their typical weekend and weeknight sleep patterns and encourage regularity in sleep timing.

Several limitations of the current study must be noted. First, although we avoided enrolling participants during school breaks, some participants experienced aberrations in their sleep routine during the study period, including snow days or sleepovers, which may have affected their sleep habits or diabetes management. Further, the study design was cross-sectional, so we cannot determine causality of the relationships observed. For example, BG data and sleep data were not collected concurrently, so we cannot conclude the directionality of the relationship between variability in sleep duration and glycemic control. The associations between sleep and glycemic control are likely to be bidirectional, such that poor glycemic control increases the likelihood of nocturnal hypo- and hyperglycemia, which can disrupt sleep (12. Finally, it is possible that overscheduling or lack of family routines could have a negative impact on both sleep habits and diabetes management.

The current study further supports the need for clinicians to assess adolescents' sleep habits, which was recently recommended by the ADA (8). Findings from the current study suggest that variability in sleep timing and duration may be more detrimental than insufficient sleep in relation to adherence and glycemic control, and therefore encouraging earlier weekend bedtimes and a more consistent sleep schedule could improve diabetes outcomes. Future studies are needed to obtain a more comprehensive understanding of the role of sleep in diabetes management, including longitudinal studies, studies examining the use of diabetes devices, such as continuous glucose monitors, which have the potential to disturb sleep with alarms (13), as well as qualitative studies to understand barriers to obtaining consistent sleep in this population. In addition, more work is needed to determine if these findings generalize to younger children and emerging adults with T1D.

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SJ conceptualized and designed the study, assisted with data analyses, drafted the initial manuscript, and approved the final manuscript as submitted.

NP and KS collected data, conducted data analyses, reviewed and revised the manuscript, and approved the final manuscript as submitted.

SK, LW and GL reviewed and revised the manuscript, and approved the final manuscript as submitted.

BM aided in the interpretation of sleep data, reviewed and revised the manuscript, and approved the final manuscript as submitted.

SJ is the guarantor of the manuscript, and had full access to all the data in the study and takes responsibility of the integrity of the data and accuracy of data analysis.

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Abbreviations

BGM	Blood glucose monitoring
BG	Blood glucose
HbA1c	Glycosylated hemoglobin
PSQI	Pittsburgh Sleep Quality Index
SCI	Self-Care Inventory
P-SCI	Parent report of Self-Care Inventory
A-SCI	Adolescent report of Self-Care Inventory
ADA	American Diabetes Association

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Table 1

Sample Demographics and Clinical Characteristics (n=65)

	Range	Mean (SD)
Age (years)	13 – 17	15.1 (1.3)
Duration of Diabetes (years)	1 – 15	5.8 (3.7)
A1C (%)	5.9 – 12.5	8.9 (1.5)
Daily BGM (checks per day)	0 – 8	3.2 (1.6)
Average Glucose	107.5 – 416.0	221.0 (61.1)
Percent Within Range	1.3 – 84.9	23.9 (15.6)
PSQI Global Score	2 – 13	5.4 (2.5)
		N (%)
Adolescent Sex		
Male		31 (47.7)
Female		34 (52.3)
Adolescent Race/Ethnicity		
White, Non-Hispanic		51 (79.6)
Other		13 (20.3)
Treatment Type		
Insulin Pump		38 (58.5)
Injection		27 (41.5)
Annual Household Income (USD)		
≤ 39,999		14 (21.5)
40–79,999		18 (27.7)
≥ 80k		32 (49.2)
Parental Marital Status		
Non-Married/Partnered		13 (20.0)
Married/Partnered		52 (80.0)
Schooling		
Institutional School		55 (85%)
Homeschool		10 (15%)

Note. Daily BGM= Average daily blood glucose checks from meter download.

Abbreviations: PSQI = Pittsburgh Sleep Quality Index.

Table 2

Bivariate Correlations between Sleep Characteristics and Diabetes-Related Outcomes

	1	2	3	4	5	6	7	8	9	10	11
1. Sleep Variability	--										
2. Total Sleep Time	.04	--									
3. PSQI	.10	−.14	--								
4. HbA1c	.34**	−.10	−.03	--							
5. % Within Range	−.26*	.08	−.07	−.55***	--						
6. Average Glucose	.30*	−.02	.00	.71***	−.64***	--					
7. BGM	−.27*	.08	−.22	−.45***	.21	−.42***	--				
8. P-SCI	−.05	.12	−.10	−.38**	.22	−.38**	.19	--			
9. A-SCI	−.05	.08	−.23	−.37**	.17	−.19	.53***	.39**	--		
10. Diabetes Duration	.02	−.23	.25	.35**	−.22	.10	−.22	−.23	−.45***	--	
11. Age	−.15	−.41***	.06	−.18	.13	−.27*	−.11	−.09	−.08	.10	--

Abbreviations: PSQI = Pittsburgh Sleep Quality Index; BGM = Blood Glucose Monitoring (average checks per day); P-SCI = Parent report of Self-Care Inventory; A-SCI = Adolescent report of Self-Care Inventory.

* = $P<.05$

** = $P<.01$

*** = $P<.001$.