A Sleep Intervention to Improve Glycemic Control and Reduce Diabetes Distress in Working Adults with Type 1 Diabetes

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ABSTRACT

Insufficient sleep and sleep irregularity (variability in sleep duration) are increasingly recognized as important contributors to glycemic control and diabetes distress in type 1 diabetes (T1D). Up to 40% of adults with T1D had a sleep duration < 6-6.5 hours per night, either by self-report or objectively assessed actigraphy. Diabetes distress is reported (40% prevalence) in individuals with T1D and is associated with poor glycemic control. Despite findings that sleep disturbances are common in T1D, our present understanding of the effects of sleep optimization on sleep, diabetes distress, and glycemic control is limited. The purpose of this pilot and feasibility trial is to evaluate the effects of a T1D-specific sleep optimization intervention (Sleep-Opt-In) on the outcomes of sleep, diabetes distress and glycemic control in individuals with T1D and habitual short sleep. We specifically aim to determine if Sleep-Opt-In will: 1) be feasible and acceptable to the target population; 2) result in improved sleep duration and regularity; 3) result in improved glycemic control; and 4) lower diabetes distress. To achieve these aims, we propose a randomized controlled trial in 20 adults aged 18 to 65 years with T1D. Participants will be screened for habitual sleep duration < 6.5 hours per night. Eligible subjects will be randomized to the T1D-Sleep-Opt-In group or attention control group. A one-week run-in period is planned, with baseline measures of sleep (duration and regularity), glycemia (A1C, fructosamine, glycemic variability), and diabetes distress (Diabetes Distress Scale). The T1D-Sleep-Opt-In will entail a novel technology-assisted behavioral sleep extension intervention that we recently developed to leverage rapidly increasing public interest in sleep tracking by consumers (+500% in 3 years). Our technology employs four elements: a wearable sleep tracker, didactic content, an interactive smartphone application, and brief telephone counseling. For this proposal, we will further optimize our intervention to be T1D-specific by addressing T1D-related sleep issues such as nocturnal hypoglycemia. The attention control group will participate in a healthy living information program. At completion (Week 8) and post-program), baseline measures will be repeated to determine differences between the two groups (Week 12) and sustainability of the intervention (intervention group week 24). Findings from this proposed pilot study will serve as the foundation for a larger clinical trial to improve sleep, reduce diabetes distress, and improve glycemic control.

Specific Aims

In 2015, 1.2 million people in the U.S. had diagnosed type 1 diabetes (T1D).[1] Maintenance of glycemic control is necessary to reduce complications in T1D. Despite improvements in treatment regimens and technology, less than 31% of adults with T1D achieve glycemic targets.[2] Insufficient sleep and sleep irregularity are increasingly recognized as important contributors to glycemic control and diabetes distress in T1D.[3-5] High levels of diabetes distress negatively impact self-management behaviors.[6] The 2017 American Diabetes Association Standards of Medical Care in Diabetes incorporated sleep, including sleep duration and pattern, as an important component of medical evaluation in persons with diabetes.[7] This is the first time sleep has been included in these national guidelines. Despite findings that insufficient sleep is common in T1D, our present understanding of the effects of sleep optimization on glycemic control and diabetes distress is limited.

The primary aim of this pilot trial is to evaluate the feasibility, acceptability, and preliminary efficacy of a **T1D-specific sleep optimization intervention "T1D-Sleep-Opt-In"** on the outcomes of sleep (duration and regularity), glycemic control (A1C, fructosamine, glycemic variability), and diabetes distress (Diabetes Distress Scale)[8] in working-age adults with T1D and habitual short sleep duration. **This proposal is based on recent observations and a newly developed sleep optimization intervention from our group. (1)** Working-age adults with T1D who reported sleeping < 6h had significantly higher A1C (vs. ≥ 6h). **(2)** Sleep irregularity in T1D was associated with poor glycemic control and increased glycemic variability. **(3)** Sleep irregularity was associated with diabetes distress in T1D. **(4)** A pilot study of a 2-week behavioral sleep optimization in adults without diabetes who had habitual short sleep duration led to improved fasting insulin resistance. **(5)** A pilot trial of our newly developed technology-assisted behavioral sleep optimization intervention in adults with short sleep duration demonstrated a clinically significant increase in sleep duration (median 35 minutes)**. Therefore, this proposal seeks to improve glycemic control and lower diabetes distress by improving sleep duration and regularity in T1D using T1D-Sleep-Opt-In under a randomized controlled design.**

Our novel sleep optimization intervention employs: a wearable sleep tracker, didactic content, an interactive smartphone application, and brief telephone counseling.[9] For this proposal, we will adapt the intervention to be T1D-specific. We will then test preliminary efficacy. We hypothesize T1D-Sleep-Opt-In will be feasible and acceptable and increase sleep duration and regularity; results will serve as pilot data for a larger trial (RFA-DK-17-028 *Treating Diabetes Distress to Improve Glycemic Outcomes in T1D).* This pilot study will randomize 20 working adults with T1D (18-65 years) who report habitual short sleep duration to eight-week T1D-Sleep-Opt-In or attention control. **Specific aims** are to determine:

Aim 1: Feasibility and acceptability of T1D-Sleep-Opt-In. Rationale: Analysis of recruitment, retention, and participant program evaluation will provide feasibility and acceptability data. Hypothesis: T1D-Sleep-Opt-In will be feasible and acceptable to the target population. Approach: Feasibility will be determined through analysis of recruitment and retention. Acceptability will be determined through participant evaluation.

Aim 2: Preliminary efficacy of T1D-Sleep-Opt-In on sleep duration and regularity. Rationale: Our sleep optimization intervention resulted in increased sleep duration in non-T1D individuals. Hypothesis: T1D-Sleep-Opt-In will result in clinically significant increased sleep duration and regularity. Approach: Sleep duration and regularity will be measured by actigraphy at baseline, Week 4, Week 8, and post-program at Weeks 12 for both groups (and Week 24 T1D Sleep-Opt-In only).

Aim 3: Preliminary efficacy of T1D-Sleep-Opt-In on glycemic control. Rationale: Short sleep duration and sleep irregularities were associated with poor glycemic control in T1D. Sleep optimization in short-sleeping individuals without diabetes resulted in improved insulin resistance. Hypothesis: T1D-Sleep-Opt-In will result in improved glycemic control. Approach: A randomized controlled trial of an 8-week T1D-Sleep-Opt-In compared to an information control group on glycemic control, measured by A1C, fructosamine, and glucose variability from continuous glucose monitoring assessed at baseline, Weeks 4, 8, and post-program Week 12 for both groups (and Week 24 T1D Sleep-Opt-In only).

Aim 4: Preliminary efficacy of T1D-Sleep-Opt-In on diabetes distress. Rationale: Short sleep and sleep irregularities are associated with diabetes distress. Hypothesis: T1D-Sleep-Opt-In will lower diabetes distress. Approach: A randomized controlled trial of the effects of an 8-week T1D-Sleep-Opt-In compared to a healthy living information attention control group on diabetes distress assessed at baseline, Week 4, Week 8, and post-program at Week 12 for both groups (and Week 24 T1D Sleep-Opt-In only).

The long-term goal of our research is to develop an effective and scalable T1D-Sleep-Opt-In that can be easily deployed to those with T1D to improve glycemic control and reduce distress.

Research Strategies

A. Significance

In 2015, 1.2 million people in the U.S. had T1D.[1] Unfortunately, less than 31% achieved glycemic targets.[2] While advances in insulin formulations and technologies can help improve glycemic control, sleep and diabetes distress are emerging as potentially modifiable factors affecting glycemic control in T1D.

A.1 Insufficient and irregular sleep are predictors of poor glycemic control T1D.

Up to 40% of adults with T1D had sleep duration < 6-6.5 h/night either by self-report or objectively assessed.[3,10-17] In adolescents, 20-30% reported insufficient sleep.[12,18,19] Insufficient sleep is associated with insulin resistance,[20] risk for incident diabetes,[21] and poorer glycemic control in patients with T2D.[22] It recently emerged as a predictor of poor glycemic control in T1D.[3] Increased insulin resistance likely plays a central role; one-night experimental sleep restriction (4 hours) in 7 patients with T1D was associated with decreased peripheral insulin sensitivity, compared to normal sleep duration (7.8 hours).[23] In our recent meta-analysis, adults with T1D who reported sleeping > 6 hours had 0.24% lower A1C levels than those sleeping ≤ 6 hours.[3]

Irregular sleep schedules can lead to circadian disruption. The circadian system plays an important role in glucose metabolism, and experimental circadian misalignment results in impaired glucose tolerance.[24,25] Thus, variability in sleep timing could be detrimental to glycemic control in T1D. In our study, 41 working-age adults with T1D increased variability in sleep duration had significantly higher A1C than those with less variability (median 7.2% vs. 7.8%, $p = 0.008$). Variability in sleep duration was also associated with increased daily insulin requirement, suggesting more insulin resistance in these individuals. Similarly, in a study of 221 German adolescents, greater variability between work and free days was associated with higher insulin requirements.[26] T1D patients lack endogenous insulin secretion; varying degrees of insulin resistance could lead to increased glycemic variability (within-day glucose fluctuations), a factor reported to be associated with increased microvascular complications in T1D.[27,28] In a cohort of 30 patients with T1D, we found that sleep variability strongly correlated with glycemic variability (Martyn-Nemeth, preliminary data).

These data strongly suggest that insufficient and irregular sleep affects glycemic control in T1D, with the effect size similar to some standard treatments for T1D.[29,30] **Despite recognition from the American Diabetes Association that sleep patterns should be assessed in individuals with diabetes,[7] no studies to date explored the effects of sleep optimization (strategies to improve sleep duration and regularity) on glycemic control in T1D.** These data are urgently needed and can potentially have a large clinical impact given the current state of suboptimal glycemic control and an increasing incidence of T1D.

A.2 Sleep is related to diabetes distress in patients with T1D

Diabetes distress, defined as emotional distress surrounding the management of diabetes,[31] was found to be significantly higher in adults with T1D who reported poor sleep quality.[5] Our team conducted focus groups with T1D adults to examine contemporary challenges of diabetes self-management. Qualitative reports indicated that sleep was a major source of distress. Participants attributed sleep disturbances to fear of hypoglycemia (and waking to check glucose levels) as well as hyperglycemia (and waking to urinate).[32]

A.3 Diabetes distress has an impact on glycemic control in patients with T1D

Our data and others' reveal that diabetes distress is associated with higher A1C and glycemic variability in T1D.[6,33] Diabetes distress is associated with poor self-care behaviors such as dietary/medication non-compliance[34,35] and physical inactivity.[35] Thus, diabetes distress can be a barrier in improving glycemic control.[36] Interventions using diabetes-self management education or in a combination with psychological components reported reductions in diabetes distress and improved glycemic control in some[6,37-40] but not all studies.[6,41] No studies to date explored the effects of sleep intervention on diabetes distress.

A.4 Sleep optimization is feasible and shown to improve glucose metabolism in short sleepers.

The goal of this application is to examine the feasibility and preliminary efficacy of a sleep optimization intervention for glycemic control and diabetes distress in T1D. Despite strong data to support a causal relationship between insufficient sleep and abnormal glucose metabolism, few studies have explored sleep interventions as a means to improve metabolic outcomes. Only one published study examined the effects of home sleep extension on glucose metabolism in healthy volunteers ($n = 16$) who were chronic short sleepers.[42] After six weeks of sleep extension (average increase by 44 minutes/day), there was a robust correlation between the increase in sleep duration and improvement in fasting insulin sensitivity. In our randomized cross-over sleep extension study of 21 short-sleeping non-diabetic working-age adults, those who extended their sleep to > 6h/night for 2 weeks had significant improvement in fasting insulin resistance, early insulin response to glucose, and β-cell function. Another RCT of 42 normal-weight, healthy, short sleepers showed a 21-minute increase in sleep duration for the intervention group. This was associated with decreased intake of fat,

carbohydrates, and free sugars.[43] Perfect et al. conducted an RCT using a sleep extension in 79 adolescents with T1D. Participant retention was 100%, and sleep duration increased by one hour in 33% of participants.[44] In summary, sleep extension is feasible in both adolescents and adults and may improve glycemic control.

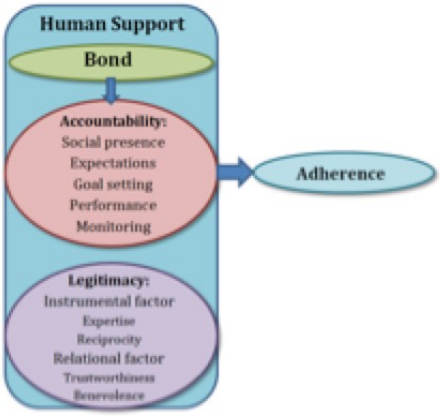
A.5 Wearable sleep trackers provide a critical opportunity to engage short sleepers

Over the past few years, the public's interest in monitoring sleep has skyrocketed, providing an important opportunity to affect sleep in public health. Marketing research reported a 500% annual growth in the wearable fitness tracker market for the past three years.[45] In 2016, over 12% of U.S. adults owned a fitness monitor,[46] and sleep was rated as the most popular feature to track.[46] Our intervention uses data from a wearable sleep tracker (Fitbit) to personalize feedback and promote interaction with remote coaches. Given that individuals often need to forgo other potentially more rewarding activities to extend sleep, sleep-tracking devices provide a way to make sleep extension insightful and rewarding. Companies including Fitbit and Apple have released features such as bedtime reminders and sleep goals. This suggests that consumers are interested in improving sleep but the impact on sleep and health is unknown.

A.6 Enhancing adherence to technology-assisted behavioral interventions is key to improvements

Many technology interventions suffer from high rates of non-adherence.[47] Coached interventions typically show larger effect sizes than unguided interventions, likely due to improved adherence.[48] The process by which human support enhances adherence to behavioral intervention technologies has been termed "Supportive Accountability," (**Figure 1**),[49] which draws on broad empirical literature including clinical and organizational psychology[50,51] and motivation theory.[52,53] This model suggests that behavioral intervention technology users are more likely to adhere if they are accountable to another person. Accountability is defined as knowing that one will have to justify use or non-use to another individual at some future time.[50] The effects of accountability are enhanced when goal setting and progress are known to another person, goals are process- rather than outcome-focused, and expectations are defined in advance. The model involves qualities of the coach, including legitimacy (the person the user is accountable to has some expertise[51] and is viewed as trustworthy and benevolent). We designed and tested a coaching protocol around these principles[54] that demonstrated the capacity to enhance adherence in a sleep extension intervention (see C.2.8).

Figure 1. Supportive Accountability



A.7 The proposed work will test the feasibility, acceptability, and preliminary efficacy of a T1D-specific sleep optimization intervention "T1D-Sleep-Opt-In" on sleep (duration and regularity), glycemic control (A1C, fructosamine, glycemic variability) and diabetes distress (Diabetes Distress Scale) in working-age adults with T1D and habitual short sleep duration under a randomized controlled design. Working-age adults often encounter social obligations that affect their sleep duration, especially on weekdays, and were shown to have less sleep regularity than older individuals.[55] The conceptual framework underlying our proposal is that three key variables (sleep, glycemic control, diabetes distress) are related and affect each other in T1D.

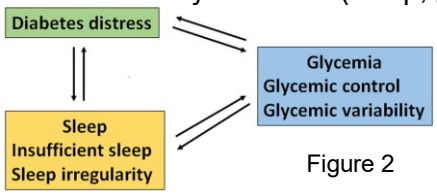


Figure 2

In this proposal, we will further optimize our intervention to be T1D-specific by addressing T1D-related sleep issues (e.g. nocturnal hypoglycemia). Feasibility and acceptability will be determined. We will then evaluate effectiveness of this 8-week T1D-Sleep-Opt-In. We hypothesize that T1D-Sleep-Opt-In will be feasible and acceptable and show preliminary efficacy in improving sleep, glycemia, and diabetes distress. To determine durability of the intervention, follow-up will be performed at week 12 for both groups (and Week 24 T1D Sleep-Opt-In only).

This innovative study will provide insights into the causal relationship between sleep and glycemic control and diabetes distress in T1D individuals. Results will serve as pilot data for a larger trial and could have a wide clinical implication for health care providers caring for persons with T1D.

B. Innovation

Our proposed study will be innovative in that it will study T1D-Sleep-Opt-In on working-age adults with T1D: (1) Optimizing the intervention to be T1D-specific is unique. **(2) Effects on glycemic control.** Insufficient and irregular sleep contributes to poor glycemic control and glycemic variability. A sleep

optimization program to improve glycemic outcomes is novel. **(3) Effects on diabetes distress.** Diabetes distress is common and contributes to poor glycemic control and reduced quality of life. Sleep optimization offers a unique and practical treatment to reduce diabetes distress. **(4) Durability as determined by a follow-up period.** No data exist regarding the durability of sleep optimization. Understanding the long-lasting effects will lead to designing a reinforced intervention with proper timing and optimize the effects of T1D-Sleep-Opt-In.

T1D Sleep-Opt-In is unique, practical, and scalable. The proposed intervention is based on a theoretical model focused on motivating long-term behavior change. It uses technologies desirable to patients and already part of their daily lives. Using this combination of technology and well-validated behavior change strategies, we can engage patients to learn their behavioral patterns and make lasting changes in their sleep habits. The use of technology and automated support could result in a highly scalable and cost-effective intervention.

Approach

C.1 Preliminary Studies

C.1.1 Insufficient and irregular sleep are associated with poorer glycemic control in adults with T1D. Dr. Reutrakul, co-PI of this study, published a meta-analysis exploring the role of sleep in T1D. In a pooled analysis of 533 adults, those reporting sleeping < 6h had a higher A1C level by 0.24% than those sleeping ≥ 6 h.[3]. Dr. Reutrakul's subsequent study explored the role of sleep variability using 5-day actigraphy in 41 adults with T1D.[10] Those with higher sleep variability (standard deviation, SD, of sleep duration > 60 minutes) had significantly higher A1C levels than those with lower sleep variability (median 7.8% vs. 7.2%). In addition, higher sleep variability significantly correlated with higher daily insulin requirement (r = 0.386, p = 0.01), suggesting higher insulin resistance. Dr. Martyn-Nemeth, co-PI, studied 30 adults with T1D and found that variability of sleep duration as measured by actigraphy was significantly related to glycemic variability (glucose SD) measured by continuous glucose monitoring (CGM), r = 0.458, p = 0.01).

C.1.2 Sleep irregularity was associated with diabetes distress in T1D. In the same sample of 30 adults, greater sleep irregularity (sleep duration SD) significantly associated with diabetes distress (r = .600, p<.001).

C.1.3 Sleep optimization in short-sleeping non-diabetic adults resulted in improved glucose metabolism. Dr. Reutrakul performed a randomized cross-over study using two-week behavioral sleep optimization aimed at extending sleep duration and promoting sleep hygiene, including sleep regularity, in 21 non-diabetic adults with habitual short sleep (mean 5.3h/night by actigraphy). Participants who extended their sleep duration to >6 h/night (N = 8, mean 6.6h/night) had significantly improved fasting insulin resistance (HOMA-IR; adjusted mean difference, MD, -0.50, p = 0.013), increased early insulin response to glucose (insulinogenic index; MD 0.39, p = 0.001), and improved β-cell function (disposition index; MD 1.07, p = 0.02).

C.1.4 Our newly developed sleep optimization intervention in adults with short sleep duration demonstrated a clinically significant median sleep increase of 35 minutes.

Table 1. Pilot trial, 6 weeks	Median sleep change	Interquartile Range Sleep change
Intervention, N = 7	**+0:35:47**	**+0:31:14**
Control, N = 3	**+0:09:07**	**+0:32:24**

The technology-assisted intervention included use of a Fitbit, weekly didactic content, interactive tools (e.g., reminders) and feedback, including graphs of the target behavior (sleep duration and regularity). The team developed and tested a coaching protocol based on behavior change principles. Our research team conducted a randomized pilot study of 10 adult participants followed for six weeks with a protocol similar to what is proposed. Based on this experience, we refined our content and coaching protocol and assessed effects of our intervention on sleep duration at 6 weeks. All participants completed 2 periods of actigraphy. Participants in the intervention group wore the Fitbit for 85-100% of study days and completed 90% of coaching sessions. Results from the intervention (n = 7) and control (n = 3) groups showed that the intervention was effective at improving sleep duration by at least 30 min (Table 1).

C.1.5 Our research team consists of investigators from multiple disciplines with expertise that will facilitate successful completion of the project. This application brings together an interdisciplinary team with shared (T1D, sleep, CGM technology and glycemic variability measures, chronic illness, and clinical practice) and complementary (behavioral coaching, technology-assisted behavior change, statistical modeling, and Certified Diabetes Educator [CDE®]) expertise. Collectively, the team's research strengths span conceptual, methodological, clinical, statistical, and research in self-management and chronic disease.

C.2 Research plan

		Actigraphy/ sleep questionnaire	CGM, fructosamine, HbA1c	Diabetes Distress	Feasibility/ Acceptability
20 T1D subjects	Baseline	X	X	X	
Randomization	4-week	X	X	X	
	8-week	X	X	X	X
Follow up	12-week	X	X	X	
	24-week	X	X	X	

Table 2: Study Overview

C.2.1 Proposed study overview. Table 2 illustrates the proposed study. We will first adapt our current sleep optimization to be T1D-specific (see C.2.8). We will then recruit 20 non-shift-working adults aged 18-65 years with a clinical diagnosis of T1D for at least one year who reported habitual sleep duration < 6.5h/night during work- or weekdays. After informed consent is obtained, participants will have a baseline assessment during a 1-week run-in phase. Subjective sleep (see C.2.3) and objective sleep assessment by wrist actigraphy (see C.2.4) will be performed. Diabetes distress will be assessed (see C.2.5). Glycemic assessments will be performed by A1C, serum fructosamine, and 1-week CGM (see C.2.6) and height, weight and waist circumference will be obtained The participants will then be randomized 3:2 to either T1D-Sleep-Opt-In (see C.2.8) or attention control group for 8 weeks (see C.2.9). At Weeks 4 and 8, participants will have assessments of subjective and objective sleep, 1-week CGM, serum fructosamine, and diabetes distress. *Additionally, stool samples will be collected at week 0 and week 8 to measure the gut microbiome.* These measurements will be repeated at 12 for both groups- (and 24-week T1D Sleep-Opt-In only) follow-up visits to evaluate the program's durability. At the end of the intervention (Week 8), feasibility and acceptability will be determined (see C.2.7).

C.2.2 Participants. We plan to recruit 20 subjects. Inclusion criteria: working-age adults, 18-65 years with a clinical diagnosis of T1D for at least one year who reported habitual sleep duration <6.5h/night during work- or weekdays with a desire to sleep longer; own a smartphone compatible with Fitbit. Exclusion criteria: A1C ≤ 10%, Insomnia symptoms defined as severe as assessed by the Insomnia Severity Index (score ≥22), being at high risk for obstructive sleep apnea as assessed by Berlin Questionnaire,[56] history of severe hypoglycemia (defined as hypoglycemic episodes that result in loss of consciousness within the last 6 months, seizures, or requiring help from others), being treated with insulin pump with a hybrid closed-loop feature, rotating shift or night shift work, significant renal impairment (estimated glomerular filtration rate < 45 ml/min/1.73 m^2), significant medical morbidities, such as congestive heart failure, cirrhosis, chronic obstructive pulmonary disease requiring oxygen, active treatment for cancer or psychiatric problem, history of stroke with neurological deficits,pregnant or planning pregnancy. Inclusion/exclusion criteria will be obtained by participant self-report on all criteria except the estimated glomerular filtration rate and A1C which will be obtained by a blood draw. Subjects will be recruited through the UIC medical center and local diabetes websites and organizations, using flyers, e-announcements, and recruitment letters. UIC endocrinology clinic serves approximately 4,000 patients with diabetes per year.

C.2.3 Subjective sleep assessment Participants will complete standardized questionnaires. The Pittsburgh Sleep Quality Index (PSQI) assesses sleep quality in the past month,[57] Epworth Sleepiness Scale (ESS) assesses daytime sleepiness,[58] Insomnia Severity Index (ISI) assesses insomnia symptoms,[59] and the Berlin questionnaire assesses risk of obstructive sleep apnea.[56] ISI and Berlin questionnaires will be used to screen for eligible participants. PSQI and ESS will be administered at baseline and Weeks 4, 8, 12 for both groups, (and week 24 T1D Sleep-Opt-In only).

C.2.4 Wrist actigraphy to measure behavioral sleep Participants will wear an Actiwatch Spectrum Plus (Respironics, USA) on their non-dominant wrist for one week during baseline assessment, and Weeks 4, 8, 12 for both groups (and week 24 T1D Sleep-Opt-In only). Data will be collected in 30-sec epochs. Subjects will be asked to keep a daily sleep log and press an event marker on the Actiwatch at bedtime and wake-up time. Data will be downloaded and reviewed with each participant to clarify inconsistencies when the Actiwatch is returned. Rest intervals will be set using reported try-to-fall-asleep times and wake-up times on daily sleep logs or event markers if these times are missing. Using the Immobile Minutes algorithm in the Actiware 6 software, we will derive the following outcome variables: sleep onset, sleep offset, sleep duration, sleep efficiency (a measure of sleep quality), mid-sleep time (time point between sleep onset and wake time), and standard deviation (SD) of sleep duration, an indicator of sleep regularity which we previously showed to be related to glucose metabolism.[10]

C.2.5 Diabetes distress assessment. Diabetes distress will be measured with the Diabetes Distress Scale.[60] Additional related variables measured will be the CES-D, a measure of depression, the GAD-7, a

measure of general anxiety,[62] Fatigue PROMIS short-form 1a, Hypoglycemia Fear Survey and the Diabetes Self-Management Questionnaire. These variables will be measured at baseline, weeks 4, 8, 12 both groups (and 24 T1D Sleep-Opt-In only). Subjects who score 16 or greater on the CES-D will be offered a list of mental health resources (See Mood Score Script, Ver 1, 2-14-19 and Health Resources, Ver 1, 2-14-19.

C.2.6 Glycemic assessment Glycemic control will be primarily assessed by hemoglobin A1c (A1C; Quest Diagnostics), a gold standard marker of glycemic control in T1D reflecting average glucose levels in the previous 90 days. Secondary measures will include serum fructosamine (Quest Diagnostics) and CGM. Serum fructosamine is a glycated albumin that reflects glucose levels in the preceding three weeks and allows assessment of changes in glucose values in a shorter term than A1C. CGM (blinded) will be conducted using FreeStyle Libre Pro glucose sensor (FDA-approved). The sensor tracks glucose concentrations in the interstitial fluid over 24 h using a thin flexible filament (< 0.4 mm thick) inserted into the upper arm (5 mm depth). The system captures glucose levels every 1 minute and records the data every 15 minutes. Outcome variables derived from the CGM are mean glucose level, standard deviation (SD), coefficient of variation (CV), percentage of time spent < 70 mg/dl, and percentage of time spent ≥ 180 mg/dl.[63] Interstitial glucose measurements with FreeStyle Libre were found to be accurate compared with capillary blood glucose reference values.[64] Glycemic measures will be obtained for one week at baseline and Weeks 4, 8, 12 for both groups, (and week 24 T1D Sleep-Op-In group only). A small amount of serum or plasma (2 tsp) will be frozen and stored in a freezer at the College of Nursing for later analysis by UIC researchers.

C.2.6.1 Microbiome *Stool samples to measure the gut microbiome will be collected at week 0 and week 8. Changes in sleep may alter the gut microbiome and potentially influence glycemia. Participants will be provided a collection device (Easysampler®, ALPCO, Inc.) and return the specimen at a subsequent visit.* Remaining stool samples will be stored in a freezer at the College of Medicine for later analysis by UIC researchers.

C.2.7 Feasibility and acceptability of T1D-Sleep-Opt-In Feasibility will be determined through analysis of recruitment (number recruited, screened, eligible, and consented) and retention (% session participation, program completion rates). Acceptability will be determined through participant evaluation (written evaluation and interview at program completion). See Appendix B.

C.2.8 Intervention Description: T1D-Sleep-Opt-In. The goal of T1D-Sleep-Opt-In is to increase sleep time by ≥ 30 minutes. Participants randomized to the intervention will receive: (1) a wearable sleep tracker; (2) a smartphone application with interactive feedback and tools; (3) didactic content including weekly email lessons, reminders, and notifications; and (4) brief telephone coaching. The components are described below.

C.2.8.1 Wearable sleep tracker: A Fitbit Alta HR wearable sleep tracker allows participants to track their sleep and share results with the coach, not for the main study outcome (measured with actigraphy). Consumer sleep trackers provide an estimation of sleep but are less precise than actigraphy devices.[65,66] Therefore, our main outcome will be measured with actigraphy, which is validated but does not provide real-time feedback to the wearer.[67] Fitbit data will be used in coaching sessions and for providing weekly reports. The coach will have access to participants' sleep tracker data through a dashboard using the Fitabase platform.

C.2.8.2 Smartphone application: Participants will download the Fitbit smartphone application on their smartphone and participate in brief training in the intervention orientation session. Participants will be trained to review and edit their Fitbit sleep log each day, increasing the data validity. Though the application has the ability to enter sleep goals, these features will not be set on participants' applications.

C.2.8.3 Intervention content: Participants will receive automated content, including didactic lessons (weekly), individualized progress reports (weekly), and bedtime reminder text messages (30 min before scheduled bedtime; can be disabled for Weeks 4-8). The intervention content was developed by psychologists with advanced training in sleep and behavior change (Drs. Baron and Duffecy) and has been piloted in initial user testing. The 8 weekly didactic lessons (estimated duration 8-10 min), of written and video didactic content will be delivered via email and can be viewed on a smartphone, desktop, or tablet. Content from the lessons will be reinforced in the telephone coaching sessions (see Appendix A). Participants will receive an automatically generated report each week detailing their days of device usage, average bedtime, wake time, sleep duration, and an encouraging statement linked to weekly didactic content.

C.2.8.4. Coaching: All participants will be assigned to a sleep coach to monitor their progress during the study and provide weekly telephone coaching sessions related to their sleep-related goals*. Dr. Duffecy will act as coaches for this pilot.* The coaching protocol, developed by Dr. Duffecy, is based on the principles of Supportive Accountability.[68] The coach will establish **legitimacy** by their knowledge of sleep and basic

counseling principles. They will establish **goals** with the participants based on the participants' values and beliefs, including sleep-related goals and usage goals (e.g., number of days wearing the sleep tracker). **Performance monitoring** will be completed through an online dashboard visible to the coach (Fitabase Inc.). The dashboard will contain data from sleep diaries and the wearable sleep tracker. The first coaching session will be a 20-min engagement session, which includes introductions, rationale for the program, roles of the coach, and the participants' goals for the program. Coach will provide feedback to the participant based on wearable sleep tracker data. For coaching sessions 2-8, the coach and participant will also have weekly brief (5-10 min) follow-up support calls to review progress, problem solve barriers to progress, and set goals for the following week. Between sessions, coach will be available to troubleshoot any problems. The use of coaching has been demonstrated to improve adherence to technology-based interventions.[69,70] Dr. Duffecy has extensive experience in the use of coaching to improve adherence to technology-based interventions.[54,69,71,72]

C.2.9 Attention control: Health Education. Use of a control group is to control for the coach contact in the intervention group. Participants assigned to the control group will be provided weekly health education emails (e.g., nutrition, stretching exercises; Appendix A). They will be instructed to maintain their sleep schedule but not monitored with diaries or coaching, a technique that produces little change in sleep timing.[43] Participants will receive weekly brief telephone contact from the coach (≤ 5 min) to answer questions. After the final follow-up, control participants will receive a Fitbit fitness tracker and PDF files of the 8 didactic lessons by mail.

C.2.10 Statistical Analysis

For these pilot data, we will emphasize descriptive statistics such as means, standard deviations, effect sizes, medians, interquartile ranges, frequencies, and percentages to demonstrate the feasibility of recruitment, adherence, retention, acceptability, and treatment effects of change in outcomes between T1D-Sleep-Opt-In and attention control. Our statistical approach for a full trial of these hypotheses will be a mixed-effect model for repeated measures (MMRM), recommended for primary analysis of clinical trials with continuous endpoints.[73] Using this model on pilot data will allow us to assess if the statistical plan will need modification and will help with sample size calculations for a future R01 submission. Confidence intervals will be used to estimate a plausible range of values for feasibility and effect size estimates.

Sample size. This feasibility pilot study is not powered to detect significant effects for improvement in sleep, glycemic control, or diabetes distress. Our sample of 20 participants will be adequate for gaining experience using this protocol with a T1D population and for calculating mean and variability confidence intervals for sleep and diabetes-related measures.[74]

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