Real-time predictors and consequences of binge eating among adults with type 1 diabetes

Ashley A. Moskovich¹, Natalia O. Dmitrieva², Michael A. Babyak¹, Patrick J. Smith¹, Lisa K. Honeycutt¹, Jan Mooney¹ and Rhonda M. Merwin¹*

Abstract

Background: Objective binge eating (OBE) is common among individuals with type 1 diabetes (T1D) and may have negative consequences for glycemic control. Recent studies have suggested that diabetes distress (i.e., emotional distress specific to diabetes and living with the burden of management) is a distinct emotional experience among individuals with diabetes. Preliminary studies have found diabetes distress is associated with eating disorder symptoms and poor glycemic control. The aim of the current study was to examine real-time emotional precursors and consequences of OBE in adults with T1D (i.e., general negative affect, specific emotional states and diabetes distress) using ecological momentary assessment methods. We also explore the impact of OBE on 2-h postprandial glycemic control relative to non-OBE eating episodes.

Methods: Adults with T1D (N = 83) completed 3-days of ecological momentary assessment assessing mood and eating behavior using a telephone-based survey system. Participants were prompted to rate momentary affect, including level diabetes distress, at random intervals and reported on eating episodes. Participants also wore continuous glucose monitors allowing for ongoing assessment of glycemic control. Multi-level modeling was used to examine between- and within-person effects of momentary increases in emotions prior to eating on the likelihood of OBE and the impact of OBE on postprandial blood glucose. Generalized linear mixed models examined whether change in post-meal affect differed between OBE and non-OBE episodes.

Results: Participants were predominately middle-aged (Mean = 42; SD = 12.43) Caucasian (87%) females (88%) reporting clinically significant eating disorder symptoms (76%). Nearly half of the sample (43%) reported OBE during the 3-day study period. The between-person effect for negative affect was significant (OR = 1.93, p < .05), indicating a 93% increased risk of OBE among individuals with higher negative affect compared to individuals with average negative affect. Between-person effects were also significant for guilt, frustration and diabetes distress (OR = 1.48–1.77, ps < .05). Analyses indicated that mean change in post-meal negative affect was significantly greater for OBE relative to non-OBE episodes (B = 0.44, p < .001). Blood glucose at 120 min postprandial was also higher for OBE than for non-OBE episodes (p = .03).

Conclusions: Findings indicate that individuals who tend to experience negative affect and diabetes distress before eating are at increased risk of OBE at the upcoming meal. Results also suggest that engaging in binge eating may result in greater subsequent negative affect, including diabetes distress, and lead to elevated postprandial blood glucose levels. These findings add to a growing literature suggesting diabetes distress is related to eating disordered behaviors among individuals with T1D.

Keywords: Type 1 diabetes, Eating disorders, Binge eating, Ecological momentary assessment, EMA

* Correspondence: rhonda.merwin@duke.edu
¹Duke University Medical Center, DUMC Box 3842, Durham, NC 27712, USA
Full list of author information is available at the end of the article

© The Author(s). 2019 Open Access This article is distributed under the terms of the Creative Commons Attribution 4.0 International License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The Creative Commons Public Domain Dedication waiver (http://creativecommons.org/publicdomain/zero/1.0/) applies to the data made available in this article, unless otherwise stated.
**Plain english summary**

Binge eating is common among individuals with type 1 diabetes (T1D) and may negatively impact glycemic control. Existing eating disorder treatments are less effective for individuals with T1D, suggesting the need to better understand factors that may contribute to binge eating in this population. Previous research indicates that people are more likely to binge eat when they are feeling negative emotions. However, whether there are different emotional antecedents or consequences for T1D patients is not known. The current study tested whether increases in negative affect, including diabetes distress (i.e., emotional distress specific to living with diabetes), increased the likelihood of binge eating among adults with T1D. Eighty-three adults with T1D provided information about their emotions and eating behavior throughout the day for 3 days using a telephone-based survey system. Findings indicated individuals who reported higher levels of guilt, frustration and diabetes distress before eating episodes were more likely to binge eat than individuals who reported average levels of these emotions. Results also indicated that people felt worse (generally and about diabetes) and had higher blood glucose levels after binge eating. Findings suggest that interventions focused on helping individuals cope with negative emotions and diabetes distress may be helpful to incorporate into treatments for binge eating.

**Background**

Eating problems are common among individuals with type 1 diabetes [1–3]. This includes binge eating, dietary restriction and compensatory behaviors observed in the general population (e.g., self-induced vomiting) along with the unique capacity to restrict insulin for weight control. Studies show that disordered behaviors are associated with poor metabolic control and diabetes complications even when full diagnostic criteria for an eating disorder is not met (e.g., binge eating disorder, bulimia nervosa) [1, 3–5].

Up to 45–80% of young women with type 1 diabetes report binge eating behavior [6, 7], and many engage in this behavior frequently [3]. For example, a recent study found that 56% of adolescents completing a national survey reported binge eating at least once during the past 14 days [3]. Objective binge eating (OBE), defined as a loss of control over eating while consuming an objectively large amount of food [8], makes it challenging to manage diabetes. Most notably, individuals may struggle to accurately count carbohydrate and estimate bolus insulin needs when eating is uncontrolled. Binge eating may also motivate the use of dangerous behaviors to compensate for excessive calories consumed, further disrupting glycemic control (e.g., intentionally restricting insulin to induce glycosuria; the excretion of glucose into the urine) [9]. Poor glycemic control is associated with an array of diabetes-related medical complications (e.g., neuropathy, retinopathy) [9, 10], highlighting the importance of addressing OBE in this patient population.

Despite the high prevalence and clinical significance of OBE in type 1 diabetes, it remains an understudied problem and effective treatments are lacking. Data suggests that conventional outpatient eating disorder treatments (developed for nondiabetic individuals) are less effective for individuals with type 1 diabetes [11–14]. One treatment study found that individuals continued to binge eat and restrict insulin, even when there were improvements in weight and shape concerns [14]. This indicates the need to better understand the factors associated with OBE in this unique patient population in order to develop more effective interventions.

A large body of empirical work in the general population suggests that negative affect is associated with OBE among individuals without diabetes [15, 16]. Previous studies have demonstrated that individuals who engage in OBE tend to report higher levels of depression and anxiety in general [16–18], and experience momentary increases in negative affect prior to binge eating episodes. When examining specific emotional states, guilt, sadness, and anger tend to be the strongest predictors of binge eating [19–22]. Studies examining affect post binge eating have mixed results. While some studies report that negative affect increases after binge eating [15, 21], others suggest that binge eating may actually temporarily decrease negative affect thereby functioning as a maladaptive emotion regulation strategy [19, 20, 22, 23].

At least one study has found individuals with type 1 diabetes with OBE report greater anxiety and depression than type 1 diabetes patients who do not engage in OBE [24]. However, there are no studies that have tested momentary changes in affect that may precede or follow an episode of binge eating in this high-risk patient population. Thus, whether emotional precursors or consequences of OBE are the same for individuals with type 1 diabetes as in the general population is unknown. This may include differences in general emotional states or more uniquely, diabetes distress (i.e., emotional distress specific to diabetes and living with the burden of management), which has been identified as a distinct emotional state experienced by individuals with diabetes [25–27].

For individuals with diabetes, maintaining control over eating is not only about controlling weight but also about preventing immediately life-threatening circumstances (e.g., diabetic ketoacidosis) and staying off future long-term diabetes-related complications. Thus, meal-times may be particularly emotionally evocative, evoking negative affect generally, and specifically feelings of fear, anger and guilt associated with diabetes and living with the burden of diabetes management. Diabetes distress is
increasingly recognized as a factor associated with poor management in type 1 diabetes [27, 28]. A few studies suggest diabetes distress is associated with eating disorder symptoms and taking less insulin than is needed [26, 29–31]. However, whether diabetes distress is functionally-related to OBE, increasing risk for this behavior in real-time, a consequence of OBE, or neither, has not been determined.

The current study examined real-time precursors and consequences of OBE in adults with type 1 diabetes using ecological momentary assessment methods. We examined general negative affect as a predictor of OBE, as well as specific emotional states and diabetes distress. We also established both the between- and within-person effects in each predictor (i.e., distinguished between individual differences in negative affect from potential additional impact of a momentary increase in negative affect) on OBE episode likelihood. Finally, we examined the impact of binge eating on glycemic control by examining blood glucose 2 h postprandial for OBE episodes versus non-OBE episodes. These findings may shed light on behavior patterns and treatment targets for this high-risk patient population.

**Methods**

**Participants**

Participants were recruited from two medical centers in the Southeast United States and the surrounding area as part of a larger study investigating eating disorder symptomatology among individuals with type 1 diabetes (see [31, 32]). Participants were adults between the ages of 18 and 65 years diagnosed with type 1 diabetes without hypoglycemic unawareness (as assessed via the Gold method [33]) or cognitive disabilities that interfered with their capacity to manage diabetes independently. Individuals with clinically significant eating disorder symptomatology (as indicated by a score of ≥20 on the Diabetes Eating Problems Survey-Revised (DEPS-R) [34] described in more detail below) were recruited first to answer primary research questions of the larger investigation (see Merwin et al., 2018 [32]). After the initial recruitment target was surpassed, enrollment was opened to individuals with DEPS-R scores below 20 to capture the full range of eating disorder symptomatology (see Merwin et al., 2015 [31]). The final sample consisted of 83 individuals, including 63 with DEPS-R ≥ 20.

**Procedure**

As described in previous papers (see [31, 32]), participants completed 3 days of ecological momentary assessment of mood and eating behavior using a telephone-based survey system. Interstitial glucose levels were monitored throughout the assessment period using blinded continuous glucose monitoring (CGM).

Eligible participants presented to the laboratory on two separate days. On Day 1, participants completed self-report measures of their illness history and had a blood draw to determine hemoglobin A1c (HbA1c). They had a glucose sensor placed and were then trained on the momentary assessment procedures which included completing surveys at random intervals throughout the day and initiating survey entries for meals/snacks (described in detail below). Participants returned to the laboratory 3 days later to have their glucose sensor removed and data downloaded using specialized software. They also completed additional self-report measures not relevant to the current study. Procedures were approved by the Duke University Health System Institutional Review Board (IRB) and all participants documented informed consent before participation in the study protocol.

**Assessments**

**Diabetes eating problems survey-revised (DEPS-R; [34])**

The DEPS-R is a 16-item self-report assessment of problematic eating attitudes and behaviors specifically tailored to individuals with diabetes. Items measure how often the individual has experienced each attitude and behavior over the past 4 weeks using a 6-point scale ranging from “Never” to “Always”. Sample items include “I feel that my eating is out of control”, “I would rather be thin than have good control of my diabetes” and “After I overeat, I skip my next insulin dose.” DEPS-R scores range between 0 and 80 and scores ≥20 have been associated with higher HbA1c [34]). The DEPS-R has demonstrated excellent internal consistency (Chronbach’s $\alpha = 0.86–0.89$), good construct validity as evidenced by associations with diabetes distress and eating disorder symptoms, and external validity [34, 35].

**Ecological momentary assessment (3 days)**

Participants received randomly generated phone calls from IfByPhone®, an automated telephone system, at the rate of 1–2 times an hour between the hours of 8 am and 10 pm. Participants also placed calls to the survey system to report meals/snacks and were asked to do so immediately after eating. At each call, participants completed brief surveys (taking less than 1–2 min to complete) on their current emotion or mood and eating and type 1 diabetes management behavior.

At each call, participants were asked to provide momentary ratings of their affective state (happy, sad, frustrated, angry, anxious or nervous, guilty or disgusted with yourself) using a scale from 1 to 6 (e.g., “On a scale from 1-6, how sad do you feel?”). Current level of diabetes distress was also assessed by the following question: “How upset do you feel about your diabetes or diabetes management?” (1 = Not at All, 6 = Very Much).
For calls reporting eating, participants were also asked to indicate the time they started eating and answer questions about their eating behavior. Relevant to the current study were questions assessing whether or not OBE was present including: “Did you eat a large amount of food, more than would be typical of others in a similar situation?” and “Did you experience a loss of control over your eating?” For the first item (Large amount of food), participants responded with key presses indicating 1 = Yes, I ate a large amount of food or 2 = No). For the second item (Loss of control), participants responded using a 6-point Likert scale (1 = Not at all, indicating no loss of control; 6 = Very much). Later, this item was changed to dichotomous for ease of administration and analysis (1 = Yes, loss of control present, 2 = No loss of control). OBE was determined to be present when participants indicated that “Yes” they had eaten a large amount of food for the situation and “Yes” they had experienced a loss of control over eating (i.e., reporting anything other than 1 = No loss of control for the scaled item; or “Yes” to the dichotomous item).

Participants received specific training on the study definitions of a “large amount of food” (i.e., an amount of food that is definitely larger than what most individuals would eat in a similar situation) and “loss of control over eating” (i.e., a feeling that one cannot stop or control eating) as defined by the Diagnostic and Statistical Manual of Mental Disorders – 5 [8]. The study coordinator reviewed the definitions with all individuals and provided examples. Participants received a training handbook that included the definitions and examples to refer to as needed throughout the 3-day assessment period.

**Continuous glucose monitoring (CGM)**

The Medtronic CGMS ® iPro™ or iPro2™ was used for CGM. Trained study staff inserted Medtronic glucose sensors under participants’ abdominal skin and then connected the sensor to small, lightweight monitors. Monitors lay flat on the skin of abdomen, attached by a small adhesive patch. Participants were able to engage in all normal activities after sensor placement, including swimming and bathing. Sensors sampled interstitial glucose levels continuously and transferred 5-min averages to the monitors for storage. Participants were blinded to their glucose values, but did continue to check their blood glucose with finger sticks a minimum of 3 times a day (as needed for CGM calibration and ongoing management of their diabetes) using a One Touch meter and strips that we provided. The mean absolute difference percentage of 9.9 indicated that CGM calibration accuracy was good. CGM data was downloaded by specialized software after completion of the 3-day assessment period.

**Data analytic strategy**

Eating reports, random prompts and CGM data were time synced for analyses.

**Level of participation**

Level of participation during the 3-day assessment period was determined by calculating the percentage of random calls completed and total number of eating episodes reported.

**Emotional predictors of binge eating**

We used multi-level modeling to examine the effects of momentary increases in emotions prior to eating on the likelihood of OBE episode. This allowed us to examine both within and between-person effects while also accounting for the nesting of observations [36–38]. Analyses were restricted to eating episodes with random prompt affect ratings within 60 min prior to eating. We controlled for the time between the affect report and start of eating. We created a composite negative affect variable by taking the mean responses of sad, frustrated, angry, anxious or nervous, and guilty or disgusted with self to first examine the overall effect of negative affect on OBE. All individual emotional states, including happiness and diabetes distress were then examined as independent predictors of OBE.

We used a two-level generalized linear mixed modeling (SAS GLIMMIX) strategy with random intercepts to predict the likelihood of the dichotomous OBE variable. Models were estimated with Maximum Likelihood adaptive Gauss-Hermite quadrature, the logit link function, binary distribution, between-within denominator degrees of freedom.

**Continuous glucose monitoring (CGM)**

The Medtronic CGMS ® iPro™ or iPro2™ was used for CGM. Trained study staff inserted Medtronic glucose sensors under participants’ abdominal skin and then connected the sensor to small, lightweight monitors. Monitors lay flat on the skin of abdomen, attached by a small adhesive patch. Participants were able to engage in all normal activities after sensor placement, including swimming and bathing. Sensors sampled interstitial glucose levels continuously and transferred 5-min averages to the monitors for storage. Participants were blinded to their glucose values, but did continue to check their blood glucose with finger sticks a minimum of 3 times a day (as needed for CGM calibration and ongoing management of their diabetes) using a One Touch meter and strips that we provided. The mean absolute difference percentage of 9.9 indicated that CGM calibration accuracy was good. CGM data was downloaded by specialized software after completion of the 3-day assessment period.

**Change in post-meal affect**

Generalized linear mixed models were used to examine whether change in post-meal negative affect differed significantly between OBE and non-OBE episodes. Analyses were constrained to eating episodes with random prompt affect ratings within 60 min before and after eating. We controlled for pre-meal levels of affect. We first compared OBE to non-OBE eating episodes on post-meal negative affect using the composite negative affect variable. Follow-up analyses for individual affect states, including diabetes distress, were then conducted.

**OBE and glycemic control**

We estimated a two-level linear mixed-model to examine the effect of OBE on 120-min postprandial blood glucose. Predictor variables included OBE (coded as present or absent) and pre-meal blood glucose, with the participant serving as the clustering variable. Thus, our analysis compared the impact of OBE to the impact of all other eating episodes, including normal eating,
overeating, and subjective binge eating (i.e., eating events during which an individual experiences a loss of control over eating, but does not consume an objectively large amount of food [39]).

Results
Sample characteristics
Eighty-three adults with type 1 diabetes participated in the current study. The sample was predominately female (88%) and Caucasian (87%) with a mean age of 41.9 (SD = 12.43; Range 18–68). See Table 1 for additional demographic information. Data analyses excluded nine individuals who either did not complete the 3-day assessment (n = 5) or had unusable data due to technical problems (n = 4).

Level of participation
Level of participation was high. Participants on average responded to 96% of the random prompts and reported 4 eating episodes per day. Participants reported eating 1002 eating episodes during the 3-day period, 80 (8%) of which were characterized as OBE episodes. Nearly half of the sample (44%) reported at least one episode of OBE during the 3 days.

Emotional predictors of binge eating
The current analyses examined the reported eating episodes with random prompt affect ratings within 60 min of eating (n = 659). This included 55 OBE episodes reported by participants. As demonstrated in Table 2,

| Parameter | B  | SE  | Odds Ratio | 95% CI |
|-----------|----|-----|------------|--------|
| Intercept | −3.63*** | 0.5 |            |        |
| Lag Time  | 1.02 | 0.7 | 2.7 | 0.7–11.2 |
| Negative Affect (BP) | 0.66* | 0.3 | 1.9 | 1.1–3.4 |
| Negative Affect (WP) | −0.43 | 0.3 | 0.7 | 0.4–1.1 |
| Intercept | −3.60*** | 0.5 |            |        |
| Lag Time  | 1.01 | 0.7 | 2.7 | 0.7–10.9 |
| Happy (BP) | −0.13 | 0.2 | 0.9 | 0.6–1.4 |
| Happy (WP) | 0.06 | 0.2 | 1.1 | 0.8–1.5 |
| Intercept | −3.65*** | 0.5 |            |        |
| Lag Time  | 1.03 | 0.7 | 2.7 | 0.7–11.3 |
| Sad (BP)  | 0.21 | 0.4 | 1.2 | 0.6–2.6 |
| Sad (WP)  | −0.42† | 0.2 | 0.7 | 0.4–1.0 |
| Intercept | −3.58*** | 0.5 |            |        |
| Lag Time  | 0.92 | 0.7 | 2.5 | 0.6–10.1 |
| Angry (BP) | 0.46 | 0.2 | 1.6 | 0.9–2.9 |
| Angry (WP) | −0.38† | 0.3 | 0.7 | 0.5–1.0 |
| Intercept | −3.62*** | 0.5 |            |        |
| Lag Time  | 1.00 | 0.7 | 2.7 | 0.7–10.9 |
| Frustrated (BP) | 1.35* | 0.4 | 1.7 | 1.1–2.6 |
| Frustrated (WP) | −0.23 | 0.2 | 0.8 | 0.6–1.1 |
| Intercept | −3.65*** | 0.5 |            |        |
| Lag Time  | 1.10 | 0.7 | 2.9 | 0.7–11.9 |
| Anxious/Nervous (BP) | 0.46† | 0.2 | 1.6 | 1.0–2.5 |
| Anxious/Nervous (WP) | −0.20 | 0.2 | 0.8 | 0.6–1.2 |
| Intercept | −3.62*** | 0.5 |            |        |
| Lag Time  | 1.02 | 0.7 | 2.8 | 0.7–10.9 |
| Guilty/Disgusted With Yourself (BP) | 0.57* | 0.2 | 1.8 | 1.1–2.8 |
| Guilty/Disgusted With Yourself (WP) | 0.07 | 0.2 | 1.1 | 0.8–1.4 |
| Intercept | −3.65*** | 0.5 |            |        |
| Lag Time  | 1.05 | 0.7 | 2.9 | 0.7–11.4 |
| Upset about Diabetes (BP) | 0.40* | 0.2 | 1.5 | 1.1–2.1 |
| Upset about Diabetes (WP) | 0.15 | 0.2 | 1.2 | 0.8–1.7 |

BP between persons effects, WP within-persons effects
†p < .10, *p < .05, **p < .01, ***p < .001

Table 1 Participant Demographics (N = 83)

| Characteristic | Mean (SD) or % |
|----------------|----------------|
| Age (yrs.)     | 41.89 (12.43)  |
| Sex (% female) | 88.00          |
| Race/Ethnicity (%) |
| Caucasian/White | 86.7          |
| African-American/Black | 10.8       |
| Asian/Pacific-Islander | 1.2         |
| Hispanic | 1.2         |
| Marital Status (%) |
| Never Married | 22.9          |
| Married | 63.9          |
| Separated/Divorced | 12.0      |
| Widowed | 1.2          |
| Highest Level of Education (%) |
| High school graduate or GED | 6.0         |
| Some college/technical school | 19.3        |
| Bachelor’s Degree | 54.2        |
| Graduate degree | 20.5         |
| Age at Type 1 Diabetes Diagnosis (Yrs.) | 18.5 (10.7) |
| Duration of Type 1 Diabetes (Yrs.) | 23.4 (13.4) |
| Treatment Regimen (%) |
| Insulin Pump Therapy | 62.7        |
| Multiple Daily Injections | 37.3        |
| HbA1c (mean (SD)) | 8.8 (2.3)    |
there was a between-person effect for negative affect 60 min prior to a meal predicting OBE \( (OR = 1.93, p = .02, 95\%\ CI = 1.09, 3.41) \), indicating a 93% increased risk of OBE among individuals with higher negative affect compared to individuals with average negative affect. The odds ratio indicates that for every 1-point increase in the negative affect score, the odds of OBE nearly doubled.

Analyses testing specific affect states as predictors of OBE indicated significant between-person effects for guilty or disgusted with yourself \( (OR = 1.77, p = .01, 95\%\ CI = 1.13, 2.77) \), frustrated \( (OR = 1.71, p = .01, 95\%\ CI = 1.13, 2.59) \), and diabetes distress \( (OR = 1.48, p = .02, 95\%\ CI = 1.07, 2.07) \).

There was not a significant within-person effect of negative affect on OBE \( (OR = 0.65, p = .11, 95\%\ CI = 0.39, 1.10) \), indicating that a momentary increase does not confer additional risk over and above the effect of individual differences in negative affect. In exploratory analyses, there were non-significant within-person trends for sad \( (OR = 0.66, p = .07, 95\%\ CI = 0.42, 1.04) \) and angry \( (OR = 0.69, p = .08, 95\%\ CI = 0.45, 1.04) \). See Table 2.

### Change in post-meal affect

Analyses were conducted with the 520 eating episodes that had affect reports within 60 min before and after eating. As shown in Table 3, results indicated that, after controlling for pre-meal negative affect, the increase in negative affect was greater when binge eating occurred than when it did not, \( B = 0.44, SE = 0.08 p < .001 \).

Analyses examining specific post-meal affective states indicated that changes in affect were significantly greater for OBE episodes relative to non-OBE episodes for all emotions except happiness. After controlling for pre-meal level of affect, individuals reported increased levels of sadness, anger, frustration, anxiety or nervousness, guilt or disgust with yourself, and diabetes distress following OBE compared to non-OBE episodes \( (Bs: 0.27–0.60, all ps < .05) \). The strongest effects were for frustrated \( (B = 0.60, SE = 0.16, p < .001) \) and guilty or disgusted with yourself \( (B = 0.59, SE = 0.12, p < .001) \). See Table 3.

### OBE and glycemic control

Blood glucose at 120 min postprandial was higher for OBE \( (M = 213 \text{ mg/dL, } 95\%\ CI = 191, 234) \), than for non-OBE episodes \( (M = 188 \text{ mg/dL, } 95\%\ CI = 179, 198) \), \( p = .03 \).

### Discussion

The current study examined real-time emotional predictors and consequences of binge eating during 3-days of ecological momentary assessment in adults with type 1 diabetes reporting a range of eating disorder symptomatology. Of the 1002 eating episodes reported by participants, 80 were classified as OBE episodes and 43% of participants engaged in binge eating at least once during the 3-day assessment period. Results indicated increased odds of OBE among individuals with higher levels of pre-meal negative affect and increased emotional distress and 2-h postprandial blood glucose following OBE relative to non–OBE episodes.

Elevated blood glucose levels may be the result of difficulty determining amounts of carbohydrate consumed and approximating insulin response to the carbohydrate load or intentional insulin restriction to compensate for calories consumed. Overall, results highlight the importance of helping individuals with type 1 diabetes develop skills to cope with emotional distress in order to manage diabetes and achieve optimal glycemic control.

---

**Table 3** Fixed Effect Estimates of OBE Episodes Predicting Mean Change in Affect Relative to Non-OBE Episodes

| Parameter | \( B \) | SE | DF | t |
|-----------|-------|----|----|---|
| Intercept | 1.21*** | 0.1 | 75 | 10.1 |
| Pre Negative Affect | −0.50*** | 0.1 | 442 | −9.4 |
| Post OBE \( \Delta \) Negative Affect | 0.44*** | 0.1 | 442 | −5.4 |
| Intercept | 1.63*** | 0.2 | 74 | 7.1 |
| Pre Happy | −0.57*** | 0.1 | 443 | −10.7 |
| Post OBE \( \Delta \) Happy | −0.13 | 0.2 | 443 | 0.8 |
| Intercept | 1.21*** | 0.1 | 75 | 9.4 |
| Pre Sad | −0.59*** | 0.1 | 443 | −12.9 |
| Post OBE \( \Delta \) Sad | 0.39*** | 0.1 | 443 | −3.6 |
| Intercept | 1.28*** | 0.1 | 75 | 9.4 |
| Pre Angry | −0.71*** | 0.1 | 443 | −15.3 |
| Post OBE \( \Delta \) Angry | 0.27* | 0.1 | 443 | −2.5 |
| Intercept | 1.60*** | 0.2 | 75 | 9.2 |
| Pre Frustrated | −0.59*** | 0.1 | 442 | −11.9 |
| Post OBE \( \Delta \) Frustrated | 0.60*** | 0.2 | 442 | −3.9 |
| Intercept | 1.06*** | 0.1 | 75 | 7.3 |
| Pre Nervous/Anxious | −0.52*** | 0.1 | 442 | −10.7 |
| Post OBE \( \Delta \) Nervous/Anxious | 0.27* | 0.1 | 442 | −2.2 |
| Intercept | 1.42*** | 0.2 | 75 | 9.0 |
| Pre Guilty/Disgusted With Yourself | −0.47*** | 0.1 | 442 | −10.1 |
| Post OBE \( \Delta \) Guilty/Disgusted With Yourself | 0.59*** | 0.1 | 442 | −4.8 |
| Intercept | 1.57*** | 0.2 | 75 | 7.4 |
| Pre Upset About Diabetes | −0.49*** | 0.1 | 442 | −8.1 |
| Post OBE \( \Delta \) Upset About Diabetes | 0.30* | 0.1 | 442 | −2.4 |

All models control for pre-meal levels of affect, OBE objective binge eating

*p < .05, **p < .01, ***p < .001
In the current study, individuals with type 1 diabetes who reported higher average levels of frustration, guilt and diabetes distress within 60 min of eating were more likely to engage in OBE than their peers who scored lower on negative affect. Individuals with elevated levels of negative affect before eating may be struggling to cope with managing a chronic illness that impacts every meal. For example, individuals may feel frustrated about their pre-meal blood glucose and their ability to control their blood glucose and eating well enough to achieve optimal glycemic targets. They may also feel as though they have to impose strict dietary rules to control blood glucose and may feel frustrated that diabetes prevents them from eating what they would like or feel guilt and distress about what they are planning to eat. These individuals may turn toward binge eating as a way to cope with these difficult feelings, or alternatively, give up and abandon efforts at managing diabetes altogether by eating unrestricted amounts of food. Evidence suggests that this leads to more, not less distress (including specifically about diabetes), which may in part be due to the negative impact losing control over eating and consuming large amounts of food (and/or engaging in compensatory weight control behaviors) has on glycemic control and/or one’s perceived ability to effectively manage their eating/diabetes.

Past studies have found that diabetes distress is associated with eating disorder symptoms among individuals with diabetes [26, 29–31]. The current study adds to this preliminary data, and expands what is known by suggesting that diabetes distress may not only be a factor that increases risk, but is also a consequence that may maintain these behavior patterns. This may mean that explicitly targeting diabetes distress in eating disorder treatment, rather than narrowly focusing on body weight and shape concerns, could have benefits for this unique patient population.

Diabetes distress was a between-person factor significantly associated with OBE, but momentary elevations in diabetes distress did not explain additional variance in OBE episode risk. In our previous study, we found that diabetes distress tends to have less variability than other negative emotional states with participants’ diabetes distress levels remaining relatively constant when assessed multiple times a day [31]. This may indicate that individuals are less sensitive to subtle changes in diabetes distress and may benefit from treatments that increase capacity to observe fluctuations influencing momentary behavior. Diabetes distress may also be conflated with or influence other negative emotional states (or other negative emotional states may influence perceptions of diabetes distress). For example, participants may have been reporting anger when, perhaps with less awareness, underlying distress about diabetes was generating such anger (e.g., feeling angry that pre-meal blood sugar was out of range).

The results of the current study should be considered in light of its limitations. First, the 3-day assessment period may not have been a sufficient amount of time to capture patterns of emotional antecedents and consequences of binge eating. It may be that with additional time and more episodes of binge eating to analyze (either due to decreases in participant reactivity or simply more opportunities for binge eating to occur), different patterns may emerge. Second, we characterized OBE episodes based on participant report of whether or not an objectively large amount of food was consumed. While participants were trained on parameters defining an objectively large amount of food, patient perception may still have biased results by inaccurately classifying eating episodes. For example, participants who feel a lot of shame for eating may describe an episode as an objectively large amount of food despite it not meeting the provided definition. Third, the impact of OBE on postprandial blood glucose may have been underestimated in this study. We examined the effect of OBE on postprandial blood glucose irrespective of whether or not insulin restriction also occurred. Elevations in postprandial blood glucose may be even higher when insulin restriction follows OBE, which might commonly occur among some individuals. We also compared the effect of OBE episodes on postprandial blood glucose relative to all non-OBE eating episodes combined (i.e., non-OBE episodes included normal eating, overeating and subjective binge eating episodes). This may have further mitigated the relative effects of OBE on postprandial blood glucose by elevating postprandial blood glucose of non-OBE episodes. While an objectively large amount of food is by definition not consumed during subjective binge eating episodes, the experience of losing control over eating may still increase the risk of using insulin restriction for weight control resulting in subsequent postprandial blood glucose elevations [40]. In our previous study, feeling of loss of control over eating (regardless of whether an objectively large amount of food was consumed) was associated with insulin restriction (see Merwin et al., 2015 [31]). Lastly, the sample consisted mostly of White women with type 1 diabetes who reported elevated DEPS-R scores and is not a representative sample. Thus, we cannot say anything about frequency of OBE in the general population of type 1 diabetes patients or whether these patterns would generalize to other type 1 diabetes patients with OBE. This may limit the generalizability of the findings.

Conclusions

Overall, findings indicate that individuals who tend to experience negative affect and diabetes distress before eating are at increased risk of binge eating at the...
upcoming meal. Engaging in binge eating may result in greater subsequent negative affect, including diabetes distress, and lead to elevated postprandial blood glucose levels. Although the current study cannot speak to causation, it is possible that the negative consequences of OBE may actually be a factor maintaining binge eating behavior. That is, individuals may engage in subsequent binge eating to cope with the emotional distress they experience following previous binge eating episodes (e.g., feeling distressed about elevations in blood glucose and/or their ability to effectively manage their eating/diabetes). These findings add to a growing literature suggesting diabetes distress is related to eating disordered behaviors among individuals with type 1 diabetes and further suggest that it may have a role in maintaining the problem [21, 24–26]. Interventions that focus on helping individuals cope with negative affect and specifically diabetes distress may be helpful to incorporate into treatments for type 1 diabetes patients.

Abbreviations
CGM: continuous glucose monitoring; DEPS-R: Diabetes Eating Problems Survey-Revised; OBE: objective binge eating; T1D: type 1 diabetes

Acknowledgements
Not applicable.

Funding
This study was funded by the National Institute of Diabetes, and Digestive and Kidney. Diseases (R01 DK089329; PI: Merwin).

Availability of data and materials
The datasets analyzed during the current study are available from the corresponding author on reasonable request.

Authors’ contributions
AM assisted in data collection and drafted the manuscript. ND, MB and PS conducted the analyses and reviewed/edited the manuscript. LH assisted in the development and execution of study protocols and assisted in manuscript preparation. JM assisted in manuscript preparation. RM developed the research idea, directed all research activities and drafted the manuscript. JM assisted in the development and execution of study protocols and assisted in manuscript preparation. RM conducted the analyses and reviewed/edited the manuscript. LH assisted in data collection and drafted the manuscript. PS conducted the analyses and reviewed/edited the manuscript. LH assisted in data collection and drafted the manuscript. PS conducted the analyses and reviewed/edited the manuscript. LH assisted in data collection and drafted the manuscript. PS conducted the analyses and reviewed/edited the manuscript.

Ethics approval and consent to participate
The study protocol was approved by the Duke University Health Systems Institutional Review Board. Participants documented informed consent for publication.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Publisher’s Note
Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Author details
1Duke University Medical Center, DUUMC Box 3842, Durham, NC 27712, USA.
2Northern Arizona University, Flagstaff, AZ, USA.

References
1. Toni G, Berioli M, Cerquiglini L, Ceccarini G, Grohmann U, Principi N, et al. Eating disorders and disordered eating symptoms in adolescents with type 1 diabetes. Nutrients. 2017;9(9):906–15.
2. Young V, Eiser C, Johnson B, Brierley S, Elliott J, Heller S. Eating problems in adolescents with type 1 diabetes: a systematic review with meta-analysis. Diabet Med. 2013;30:189–98.
3. Araia E, Hendreecue C, Skinner T, Pouwer F, Speight J, King RM. Gender differences in disordered eating behaviors and body dissatisfaction among adolescents with type 1 diabetes: results from diabetes MILES youth—Australia. Int J Eat Disord. 2017;50(10):1183–93.
4. Reinehr T, Diers B, Galler A, Teufel M, Berger G, Stachow R, et al. Worse metabolic control and dynamics of weight status in adolescent girls pointing to eating disorders in the first years after manifestation of type 1 diabetes mellitus. Findings from the Diabetes Patienten Verlaufs/documentation registry. J Pediatr. Available online 20 December 2018. DOI: https://doi.org/10.1016/j.jpeds.2018.11.037.
5. Wisting L, Reas DL, Bang L, Skirvinhaus T, Dahl-Jorgensen K, Re Ø. Eating patterns in adolescents with type 1 diabetes: associations with metabolic control, insulin omission, and eating disorder pathology. Appetite. 2017;114:226–31.
6. Colton PA, Rydall AC, Olmsed MP, Rodin GM, Daneman D. Disturbed eating behavior and eating disorders in preteen and early teenage girls with type 1 diabetes: a case-controlled study. Diabetes Care. 2004;27(7):1654–9.
7. Bryden KS, Neil A, Mayou RA, Younou MA, Peveler RC, Fairburn CG, Dungar DB. Eating habits, body weight, and insulin misuse. A longitudinal study of teenagers and young adults with type 1 diabetes. Diabetes Care. 1999;22(12):1956–60.
8. American Psychiatric Association. Diagnostic and statistical manual of mental disorders. 5th ed. (DSM-5®). Am Psychiatric Pub. 2013. p. 350.
9. Crow S, Keel P, Kendall D. Eating disorders and insulin-dependent diabetes mellitus. Psychosomatics. 1998;39:233–43.
10. Nathan DM, DCCT/Edic Research Group. The diabetes control and complications trial/epidemiology of diabetes interventions and complications study at 30 years: overview. Diabetes Care. 2014;37(1):9–16.
11. Rodin G, Olmsed MP, Rydall AC, Mahanaj SI, Colton PA, Jones JM, et al. Eating disorders in young women with type 1 diabetes mellitus. J Psychosom Res. 2002;53(4):943–9.
12. Custal N, Arcelus J, Anguera Z, Bove FI, Wales J, Granero R, et al. Treatment outcome of patients with comorbid type 1 diabetes and eating disorders. BMC Psychiatry. 2014;14(1):140–4.
13. Peveler RC, Fairburn CG. The treatment of bulimia nervosa in patients with diabetes mellitus. Int J Eat Disord. 1992;11(5):445–53.
14. Olmsed MP, Daneman D, Rydall AC, Lawson ML, Rodin G. The effects of psychoeducation on disturbed eating attitudes and behavior in young women with type 1 diabetes mellitus. Int J Eat Disord. 2002;32(2):230–9.
15. Haedt-Matt AA, Keel PK. Revisiting the affect regulation model of binge eating: a meta-analysis of studies using ecological momentum assessment. Psychol Bull. 2011;137(4):660–81.
16. Heatherton TF, Baumeister RF. Binge eating as escape from self-awareness. Psychol Bull. 1991;110(1):86–108.
17. Bulik CM, Sullivan PF, Kendler KS. Medical and psychiatric morbidity in obese women with and without binge eating. Int J Eat Disord. 2002;23(1):72–8.
18. Antony MM, Johnson WG, Carr-Nangle RE, Abel JL. Psychopathology correlates of binge eating and binge eating disorder. Compr Psychiatry. 1994;35(5):386–92.
19. Berg KC, Crosby RD, Cao L, Crow SJ, Engel SG, Wonderlich SA, et al. Negative affect prior to and following overeating-only, loss of control eating-only, and binge eating episodes in obese adults. Int J Eat Disord. 2015;48(6):641–53.
20. Smyth JM, Wonderlich SA, Heron KE, Silwinski MJ, Crosby RD, Mitchell JE, et al. Daily and momentary mood and stress are associated with binge eating and vomiting in bulimia nervosa patients in the natural environment. J Consult Clin Psychol. 2007;75(4):629–38.
21. Wegner KE, Smyth JM, Crosby RD, Wittrock D, Wonderlich SA, Mitchell JE. An evaluation of the relationship between mood and binge eating in the natural environment using ecological momentary assessment. Int J Eat Disord. 2002;32(3):352–61.
22. Berg KC, Crosby RD, Cao L, Peterson CB, Engel SG, Mitchell JE, et al. Facets of negative affect prior to and following binge-only, purge-only, and binge/purge events in women with bulimia nervosa. J Abnorm Psychol. 2013;122(1):111–8.

23. Munsch S, Meyer AH, Quarter V, Wilhelm FH. Binge eating in binge eating disorder: a breakdown of emotion regulatory process? Psychiatry Res. 2012;195(3):118–24.

24. Takii M, Komaki G, Uchigata Y, Maeda M, Omori Y, Kubo C. Differences between bulimia nervosa and binge-eating disorder in females with type 1 diabetes: the important role of insulin omission. J Psychosom Res. 1999;47(3):221–31.

25. Fisher L, Mullan JT, Arean P, Glasgow RE, Hessler D, Masharani U. Diabetes distress and not clinical depression or depressive symptoms is associated with glycemic control in both cross-sectional and longitudinal analyses. Diabetes Care. 2009;33(1):23–8.

26. Polonsky WH, Anderson BJ, Lohrer PA, Welch G, Jacobson AM, Aponte JE, et al. Assessment of diabetes-related distress. Diabetes Care. 1995;18(8):754–60.

27. Martyn-Nemeth P, Quinn L, Hacker E, Park H, Kujath AS. Diabetes distress may adversely affect the eating styles of women with type 1 diabetes. Acta Diabetol. 2014;51(4):683–6.

28. Goebel-Fabbri AE, Fikkan J, Franko DL, Pearson K, Anderson BJ, Weinger K. Insulin restriction and associated morbidity and mortality in women with type 1 diabetes. J Diabetes Complicat. 2015;29(4):572–7.

29. Hoffman L, Stawski RS. Persons as contexts: evaluating between-person and within-person effects in longitudinal analysis. Res Hum Dev. 2009;6(2–3):97–120.

30. Curran PJ, Bauer DJ. The disaggregation of within-person and between-person effects in longitudinal models of change. Annu Rev Psycho. 2011;62:583–619.

31. Fairburn CG. The Eating Disorder Examination (12th edition). In: Fairburn CG, Wilson GT, editors. Binge eating: Nature, assessment, and treatment. New York: Guilford Press; 1993. p. 317–60.

32. Mond J, Hay P, Rodgers B, Owen C, Crosby R, Mitchell J. Use of extreme weight control behaviors with and without binge eating in a community sample: implications for the classification of bulimic-type eating disorders. Int J Eat Disord. 2006;39(4):294–302.