ABSTRACT

Objective: To explore the experiences of adolescents with type 1 diabetes mellitus (T1DM) and their parents taking part in an overnight closed loop study at home, using qualitative and quantitative research methods.

Research design and methods: Adolescents aged 12–18 years on insulin pump therapy were recruited to a pilot closed loop study in the home setting. Following training on the use of a study insulin pump and continuous glucose monitoring (CGM), participants were randomized to receive either real-time CGM combined with overnight closed loop or real-time CGM alone followed by the alternative treatment for an additional 21 days with a 2–3-week washout period in between study arms. Semistructured interviews were performed to explore participants’ perceptions of the impact of the closed loop technology. At study entry and again at the end of each 21-day crossover arm of the trial, participants completed the Diabetes Technology Questionnaire (DTQ) and Hypoglycemia Fear Survey (HFS; also completed by parents).

Results: 15 adolescents and 13 parents were interviewed. Key positive themes included reassurance/peace of mind, confidence, ‘time off’ from diabetes demands, safety, and improved diabetes control. Key negative themes included difficulties with calibration, alarms, and size of the devices. DTQ results reflected these findings. HFS scores were mixed.

Conclusions: Closed loop insulin delivery represents cutting-edge technology in the treatment of type 1 diabetes. Results indicate that the psychological and physical benefits of the closed loop system outweigh the practical challenges reported. Further research from longitudinal studies is required to determine the long-term psychosocial benefit of the closed loop technology.

Key messages

- Closed loop insulin delivery represents cutting-edge technology in the treatment of type 1 diabetes.
- The psychosocial aspects of a closed loop require investigation to ensure minimal burden on participants and support with managing expectations.
- The psychological benefits of closed loop technology show promising benefits in terms of important patient-centered and family-centered outcomes.

Severe hypoglycemia can potentially lead to seizures and coma and may play a role as a precipitating factor in cardiac arrhythmias resulting in the ‘dead in bed’ syndrome.4

Nocturnal hypoglycemia is a special concern in the pediatric population, where a high incidence has been reported.5 6

Intensification of insulin treatment and strict glycemic control have been shown to cause further increases in rates of hypoglycemia in this population.5 7 8 Risk of hypoglycemia represents a major obstacle to the achievement of optimal blood glucose levels.9

The development of the artificial pancreas (AP), a system that combines glucose monitoring with computer-based algorithm-dictated insulin delivery, may provide a solution and represent an additional realistic treatment option for people with T1DM. The vital component of a closed loop system is a computer-based algorithm. Other components include a real-time continuous glucose monitor and an infusion pump to titrate and deliver insulin.10

Fear of hypoglycemia, particularly nocturnal, is common1 2 and a serious complication of insulin treatment in people with type 1 diabetes mellitus (T1DM). It represents a critical problem in the management of the disease and poses psychological distress for many parents of children with T1DM.3
There has been no previous prolonged evaluation of a closed loop under free-living conditions. The purpose of this study, alongside the assessment of the safety and efficacy of an overnight closed loop at home setting, was to explore the experiences of adolescents and their parents taking part in the study, using qualitative and quantitative research methods.

PARTICIPANTS AND METHODS
Sixteen adolescents with T1DM aged 12–18 years were recruited to an open-label, single-center, randomized two-period crossover study.11 This assessed the efficacy, safety, and utility of real-time continuous subcutaneous glucose monitoring (FreeStyle Navigator, Abbott Diabetes Care, Alameda, California, USA) combined with an overnight closed loop glucose control in the home setting in comparison with real-time continuous subcutaneous glucose monitoring alone in adolescents with T1DM on subcutaneous insulin infusion pump therapy (Dana R Diabecare, Sooil, Seoul, South Korea). Participants connected to the system in the evening and disconnected on waking in the morning. Closed loop technology was not used during the day or for meals. Every 12 min, the treat-to-target algorithm calculated a new insulin infusion rate, which was automatically set on the study pump.11

A mixed methods psychosocial evaluation was conducted to determine the utility of the device in terms of participants’ perceptions of lifestyle change, diabetes management, and fear of hypoglycemia. Participants aged 16 years and older and parents or guardians of participants aged younger than 16 years signed informed consent; assent was received from minors.

As part of the study, participants received prestudy training on the use of a study insulin pump and study real-time continuous glucose monitoring (CGM), and then a minimum of 7 days of masked CGM data was recorded over a training period and used to optimize insulin therapy. Participants underwent two interventions: overnight closed loop combined with real-time CGM for 21 nights and the real-time CGM alone for 21 days with a 2–3 week washout period. The order of the two interventions was random.

Qualitative methods
Semistructured interviews to explore participants’ perceptions of the impact of the closed loop technology on their lived experience were designed in collaboration with the clinical research team. The interview schedule was then piloted on four potential participants for usability, relevance, and acceptability. These participants were not included in the study. The feedback was positive with minor revisions suggested, and the interview schedule was revised in line with this. All adolescents taking part in the closed loop study were invited to participate in the qualitative interview study as well as one/both of their parents, and 15 of the 16 participants elected to do so.

On completion of the study, participants/parents were invited to partake in an audio-recorded telephone interview conducted by KDB. All interviews were conducted within 2 weeks of the end of the trial. Audiotapes were transcribed with all identifying details removed.

A thematic approach was used to analyze the data, informed by the method of constant comparison, and involved concurrent data collection and analysis.12 Following transcription, KDB and TT performed independent analyses, reading each participant’s interview in full before performing cross-comparisons to identify continuities and differences between accounts. A joint thematic analysis was used to compare interpretations and resolve any differences in interpretation to reach agreement on recurrent themes and findings.12 This analysis was used to develop a coding framework which captured original research questions and emerging findings.

Content analysis focused on the number/frequency of ‘instances’, their context, meaning, and whether they were common across participants. Thematic analysis concentrated on identifying key themes arising with a view to understanding the experiences of adolescents and their parents, exploring connections between themes, and identifying how closed loop technology affects everyday living and factors important to quality of life in ways that are important to adolescents and their parents.

Quantitative methods
At study entry and again at the end of two interventions, each adolescent completed the Diabetes Technology Questionnaire (DTQ). This is a 30-item measure of the impact of, and satisfaction with, technological tools that may be used in the management of T1DM.13 Participants were asked to rate their agreement or disagreement with statements regarding the specific component of diabetes technologies (ie, meter, pump, continuous glucose monitor, closed loop AP). Items related to ‘current’ satisfaction and impact as well as ‘change’ in satisfaction and impact since the new technology was added to the participant’s regimen and administered at the end of the two 21-day crossover periods.

The DTQ yields separate scores for ‘current’ (How much is this a problem now?) and ‘change’ (How has it changed compared to before the study?) subscales. After reverse scoring of some items, higher scores are indicative of more favorable satisfaction and impact ratings of the technology. Unpublished psychometric data based on a sample of 115 youths enrolled in a CGM trial indicate that the internal consistency (Cronbach’s α) was 0.96 for parents and 0.94 for adolescents, split half reliability was 0.87 for parents and adolescents, 3-month test–retest reliability was 0.68 for parents and 0.59 for adolescents, and parent–adolescent agreement was 0.61.

Parents and adolescents also completed the Hypoglycemia Fear Survey (HFS).14 a 23-item measure
that assesses the frequencies of certain behaviors that are designed to avoid hypoglycemia (10 items) and of sources of worry or anxiety about hypoglycemia (13 items). Numerous studies have supported the instrument’s psychometric properties.  

RESULTS

Qualitative interviews

Fifteen adolescent participants agreed to be interviewed along with 13 parents (12 mothers; 1 father). The two eldest participants did not wish for their parent to be interviewed. Interview duration ranged from 14 to 28 min for adolescents (mean 22 min) and from 25 to 65 min for parents (mean 36 min). Parent interviews always lasted longer than those of their child; boys’ interviews were shorter than girls’ interviews. Only one parent from each family chose to be interviewed. Participants included nine males and six females, age 15.6 (2.1) years; diabetes duration 7.2 (4.3) years; glycated hemoglobin 8.0 (0.9) % (63.9 (9.3) mmol/mol); body mass index (BMI) 22.4 (3.7) kg/m²; BMI z-score 0.8 (0.8); insulin pump therapy duration of 3.0 (2.3) years.

Twelve adolescents directly commented on having perceived improved blood glucose levels as a result of using the closed loop system, which was mirrored by seven of the parents. Twelve parents and adolescents reported feeling safe using the closed loop system; a negative incidence for one parent–adolescent pair resulted in a loss of this confidence in the system. On one occasion, the closed loop was connected when the participant had a very high blood glucose level. The participant assumed that it would regulate to within the target; however, it did not do so and no alarm sounded, so no manual correction insulin dose was given, resulting in high blood glucose until the next morning (the high overnight glucose was retrospectively explained by the missed alarm insulin dose, resulting in high blood glucose). Twelve parents and adolescents reported that it would regulate to within the target; however, it did not do so and no manual correction insulin dose was given, resulting in high blood glucose until the next morning (the high overnight glucose was retrospectively explained by the missed alarm insulin dose, resulting in high blood glucose).

Six adolescents spoke directly about their improved sleep and how it led to ‘waking up normal’ and facilitated improved diabetes control during the day. Six parents also commented on sleep, but focused on reduced anxiety and increased confidence that their child would wake up with ‘normal’ blood glucose levels. Seven parents commented that the closed loop system enabled them to feel less anxious about their child’s diabetes.

Difficulties with calibration, alarms, and size of the device were key concerns. Key aspects of closed loop technology are included in table 1.

There was 100% agreement between parents and adolescents on the key benefits of the closed loop system. Agreement focused on safety, improved blood glucose control, trust in the device, and reassurance without having to get up in the night to do a blood test. Tables 2 and 3 present the details of key positive and negative themes.

Deeper exploration showed additional benefits and downsides; for example, one parent reported on the alarms being a downside (004). Additional downsides were reported by participant 004 who explained that “it [the CGM transmitter] was uncomfortable to lie on, so he had to keep it up to the system.” Parent 002 and their parent commented on the ‘constant blood sugar level’ and ‘numbers were perfect’ and the parent of participant 002 added that they didn’t want to give it back and would definitely keep it.

The concept of feeling ‘normal’ as opposed to ‘diabetic’ was raised by two adolescent participants, perhaps reflecting the stigma associated with diabetes and the challenges of living with it.1 No parent commented on this. Hope for the future was expressed by several participants, for example, ‘I liked the idea of how good it could be’ (003) as well as satisfaction that they were taking part in an important clinical research trial that would ultimately benefit other people with diabetes.

Ten parents and 15 adolescents would recommend the closed loop technology. There was agreement between the 10 parent–adolescent pairs in their recommendation.

Diabetes Technology Questionnaire

The DTQ measure completed by adolescents covers similar content as the qualitative interviews, albeit with a forced choice questionnaire format. Results for the ‘current’ subscale showed that, at baseline, 21% of answers indicated either ‘very much’ or ‘some’ in response to the question “Is this a problem now?” compared with 14.7% following the closed loop treatment. Corresponding proportions of answers indicative of ‘Not much at all’ were 57.7% and 59.1%, respectively. Results for the ‘change’ subscale indicated that 8.7% of responses were indicative of ‘Worse or Much Worse’ following the closed loop treatment with 20.5% responses for ‘Better or Much Better’. The small number of
participants precluded inferential statistical analyses of these results.

As an alternative method of exploring the DTQ results in greater detail, table 4 summarizes the five DTQ ‘change’ subscale items that reflected the most improvement and the five items reflecting the most worsening relative to the participants’ circumstances prior to the study. As table 4 shows, the top four items reflecting improvement clustered around reduced anxiety related to hyperglycemia and hypoglycemia (both with 66.7% of responses of ‘Much Better’ or a ‘Little Better’) and around effort to prevent these glycemic excursions (60% and 53.3%, respectively). The remaining item reflecting the patient-reported benefit of the closed loop system concerned ensuring that the right insulin dose is given when meals are skipped or delayed (40% positive responses). No other DTQ item received more than 33.3% of responses in these positive categories and, for 12 of the 30 items, fewer than 10% of respondents indicated that their closed loop experience had been ‘Much Better’ or ‘A Little Better’ when compared with their prestudy experiences on those same dimensions.

Conversely, table 4 also shows that a sizable minority of participants reported worsened outcomes relative to their past experience regarding certain aspects of the closed loop experience. The items that were most likely to engender responses of ‘Much Worse’ or ‘A Little Worse’ were concerned with carrying and using several devices (40%), trouble sleeping (33.3%), perhaps...
associated with the alarms; however, in the interviews, many participants and parents reported better sleep, reacting to alarms (33.3%), pain or discomfort (21.4%), and feeling that devices run one’s life (20%). Negative outcomes of closed loop use were reported somewhat less often by participants than were the benefits, and all had to do with various forms of intrusion into daily life.

**Hypoglycemia Fear Survey**

Means±SD HFS total scores obtained from adolescents declined very slightly from the baseline level of 60.1±1.2 to 58.0±0.9 after the closed loop phase and 54.8±1.1 after the open loop phase. For parents, mean HFS total scores increased from 65.7±1.4 at baseline to 68.2±1.5 after the closed loop phase and 70.4±1.6 after the open loop phase. Time spent in hypoglycemia below 70 mg/dL was low in both periods. The number of nights when the glucose was below 63 mg/dL for at least 20 min was lower during closed loop (10% vs 17% nights; p=0.01).

**DISCUSSION AND CONCLUSIONS**

Closed loop technology represents cutting-edge technological research in the treatment of T1DM. Restricted to hospital-based trials until recently, technological advancements have facilitated a progression to home-based trials, where it is possible to determine, alongside clinical and cost-effectiveness, the impact on everyday living and experiences of participants in terms of impact, trust, and safety.

Participation in the study was reported as a positive experience for all participants, with several expressing hope for the future of diabetes management associated with the closed loop technology. A key benefit reported in the interviews by many participants was the positive impact on their sleep, which somewhat contradicts the questionnaire responses. This may reflect the reduced anxiety at the same time as sometimes being disturbed in the night by the alarms of the technology. Furthermore, the disparity may reflect the forced choice on the questionnaire compared with the reflective nature of the interviews.

Parental fear of hypoglycemia is common, with nocturnal hypoglycemia being a particular problem. Many parents wake up in the night to check their child’s blood glucose level, with a subsequent impact on sleep patterns. This affects anxiety levels and daily functioning. The visual affirmation of stable blood glucose levels throughout the night was reassuring for participants. Many commented that waking up on a ‘good number’ set them up for the rest of the day and the improved glucose control lasted well into the next morning, thus aiding concentration and enhancing well-being at school. Poorer educational attainment for children with diabetes is reported and poor sleep may be a contributing factor to this.

The downsides reported by families were practical difficulties with calibrating the device, insulin infusion set canula insertions, and inconvenience of the size of the device. These issues are not related to the closed loop system but to sensor augmented insulin pump therapy per se. This perhaps reflects the technological world that we live in and general lack of mechanical sympathy but, more interestingly, it reflects the underlying belief by all participants that the algorithm would work and that they had faith in it to do so. One participant and their family found participation challenging and frightening at times; however, they were still pleased that they had taken part.

It is noteworthy that so many adolescent participants commented on the improved blood glucose control as a key benefit of the closed loop technology and the potentially reduced risk of long-term complications. A common misconception suggests that social life is prioritized over diabetes at this age; however, the results of this study do not support this. It may be a consequence...
intrusive for families and facilitated separate and private interviews for adolescents and parents. Similarly, the sample was based on the availability of participants from the clinical trial, and so it is not possible to know whether saturation of views was reached.

The qualitative and quantitative methods converged in supporting the observation that closed loop treatment carries with it promising benefits in terms of important patient-centered and family-centered outcomes, but that integration of closed loop use in daily life will require advances that reduce the intrusiveness of this technology.

In conclusion, closed loop insulin delivery represents cutting-edge technology in the treatment of T1DM. Results indicate that the psychological and physical benefits of the closed loop system outweighed the practical challenges reported. These qualitative results were largely confirmed using a quantitative measure, the DTQ. Further research from longitudinal studies is required to determine the long-term benefit of the closed loop technology.

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Competing interests RH reports having received speaker honoraria from Minimed Medtronic, Lifescan, Eli Lilly, BBraun, and Novo Nordisk; serving on the advisory panel for Animas, Minimed Medtronic, and Eli Lilly; receiving license fees from BBraun and Beckton Dickinson; and having served as a consultant to Beckton Dickinson, BBraun, Sanofi, and Profil. RH and DBD report patent applications.

Ethics approval The study was approved by the local research ethics committee and Cambridge National Research Ethics Service (NRES).

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