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Six months of hybrid closed loop in the real-world: An evaluation of children and young adults using the 670G system

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Abstract

Objective: To describe glycemic and psychosocial outcomes in youth with type 1 diabetes using a hybrid closed loop (HCL) system.

Subjects: Youth with type 1 diabetes (2–25 years) starting the 670G HCL system for their diabetes care were enrolled in an observational study.

Methods: Prospective data collection occurred during routine clinical care and included glycemic variables (sensor time in range [70–180 mg/dL], HbA1c), and psychosocial variables (Hypoglycemia Fear Survey [HFS]; Problem Areas in Diabetes [PAID]). Mixed models were used to analyze change across time.

Results: Ninety-two youth (mean age 15.7 ± 3.6 years, 50% female, HbA1c $8.8\% \pm 1.8\%$) started HCL for their diabetes care. Youth used Auto Mode $65.5\% \pm 3.0\%$ of the time at month 1, which decreased to $51.2\% \pm 3.4\%$ at month 6 ($P = .001$). Sensor time in range increased from $50.7\% \pm 1.8\%$ at baseline to $56.9\% \pm 2.1\%$ at 6 months ($P = .007$). HbA1c decreased from $8.7\% \pm 0.2\%$ at baseline to $8.4\% \pm 0.2\%$ after 6 months of use ($P = .0001$), with the greatest HbA1c decline in participants with high baseline HbA1c. Increased percent time in auto mode was associated with lower HbA1c ($P = .02$). Thirty percent of youth discontinued HCL in the first 6 months of use. There were no changes in the HFS or PAID scores across time.

Conclusions: HCL use is associated with improved glycemic control and no change in psychosocial outcomes in this clinical sample. The decline in HCL use across time suggests that youth experience barriers in sustaining use of HCL. Further research is needed to understand reasons for HCL discontinuation and determine intervention strategies.

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AUTHOR CONTRIBUTIONS

C.B. designed the study, researched data and wrote the manuscript. H.M. designed the study, contributed to the introduction and the discussion and reviewed/edited the manuscript. T.V. completed statistical analysis, contributed to the methods and reviewed/edited the manuscript. B.I.F. contributed to the introduction and reviewed/edited the manuscript. L.P. completed statistical analysis and reviewed/edited the manuscript. R.P.W. reviewed/edited the manuscript. K.A.D. designed the study, researched data, and reviewed/edited the manuscript. G.F.P. designed the study, contributed to the discussion and reviewed/edited the manuscript. C.B. is the guarantor of this work.

Keywords

pediatrics; artificial pancreas; automated insulin delivery; continuous glucose monitor

1 | INTRODUCTION

Type 1 diabetes management presents a significant challenge for adolescents and young adults with a marked pattern of deterioration in glycemic control beginning in early adolescence and continuing through young adulthood.^{1–3} This extended period of suboptimal glycemic control is associated with increased risk of microvascular and macrovascular complications later in life.⁴ Challenges with glycemic control and self-management in this difficult developmental period also negatively impact psychological well-being, leading to a mutual deterioration of glycemic control and quality of life in this vulnerable population.^{5,6}

The use of diabetes technology is a promising treatment strategy to improve diabetes outcomes in youth. Use of insulin pumps and continuous glucose monitors (CGM) are associated with reduction in HbA1c, both when used separately and together.⁷ The most advanced technology currently available for diabetes care is a hybrid closed loop (HCL) insulin delivery system. HCL technology automates basal insulin delivery in response to CGM glucose trends while users deliver bolus doses for carbohydrate consumption. The MiniMed 670G is the first HCL device to be commercially available, which consists of the 670G insulin pump and the Guardian 3 CGM.

The 670G operates in two modes, both as a standard insulin pump (“Manual Mode”), and as HCL (“Auto Mode”).⁸ When using the 670G system in Auto Mode, the basal insulin delivery is calculated every 5 min by the pump’s HCL algorithm, based on sensor glucose data.⁹ To maintain Auto Mode use, the user must wear the CGM consistently, calibrate the CGM sensor at least twice per day, and respond to alerts in a timely manner. The system exits users from Auto Mode to Manual Mode if: (a) there is prolonged hyperglycemia (ie, sensor glucose >250 mg/dL for 3 h or >300 mg/dL for 1 h); (b) the pump has delivered a minimum or maximum insulin rate for 1–3 h; or (c) sensor glucose data are missing or inaccurate. Users often receive a “BG required” alert, requiring a blood glucose (BG) value to be entered into the pump to return to Auto Mode.

The single-arm 670G pivotal trial demonstrated safety and showed significantly lowered HbA1c and increased sensor glucose time in range (TIR, 70–180 mg/dL) compared to baseline in children (7–13 years), youth (14–21 years), and adults (22–75 years).^{10–12} A sub-analysis of adolescent and young adult participants (14–26 years) during the first 3 months of use revealed that total daily dose and basal to bolus ratio did not change, but adjustments were needed for carbohydrate to insulin ratios requiring ongoing clinical guidance from providers.¹³

Although data from clinical trials are promising, longitudinal, prospective real-world studies of HCL use in youth are needed to assess the clinical implications of HCL for everyday diabetes care and should include assessment of both glycemic and psychosocial outcomes.

There have been a few studies of youth and parents using HCL as part of clinical trials that found reduced hypoglycemia worry and diabetes care burden after using HCL,^{14,15} however, research on the psychosocial impact of HCL is limited, and has not been examined in the context of usual clinical care.¹⁶ The purpose of this study is to examine prospective, real-world data on 670G use in a clinical population of youth and young adults with type 1 diabetes (collectively referred to as “youth”), and to describe the glycemic and psychosocial outcomes, specifically changes in hypoglycemia worry and diabetes distress, for these youth using HCL therapy for 6 months.

2 | METHODS

2.1 | Study design

Patients from an academic, pediatric clinical center starting the 670G system for their routine type 1 diabetes care participated in an observational study. Patients and their caregivers were trained on the 670G system per the clinic’s standard of care, described in detail elsewhere.¹⁷ Standard training included 1–2 weeks using the 670G system in Manual Mode, followed by HCL training on use of Auto Mode and follow-up via phone after starting Auto Mode. Prospective data collection occurred during Manual Mode use (up to 14 days prior to starting Auto Mode), 1 month after starting Auto Mode (during a training follow-up call), and during routine clinic visits, occurring approximately every 3 months, during the first 6 months of Auto Mode use.

Glycemic variables and measures of Auto Mode use were collected from the participants’ electronic medical record and from 670G device downloads, which contained data from the 2 weeks prior to each clinic visit. To gather data on fear of hypoglycemia and diabetes distress, youth and caregivers completed questionnaires prior to Auto Mode training, and during routine clinic visits or on-line via REDCap for the first 6 months using the 670G system in Auto Mode.¹⁸ This study was approved by the University of Colorado Multiple Institutional Review Board.

2.2 | Participants

Eligible participants were youth aged 2–25 years with type 1 diabetes, who were prescribed the 670G system for their diabetes care by their health care provider between September 2017 and May 2018, and were scheduled to complete training on the system, along with their caregiver(s). Although the 670G is only FDA approved for youth ages 7 and older, youth as young as 2 years old were eligible in case any providers prescribed the device off label to the younger age group. Participants were excluded if they did not read or speak English, as study questionnaires were only validated in English. Participants age 7–17 years old provided assent for the study, and participants or caregivers 18 years’ old provided informed consent. In two-parent households, the parent who identified as the primary diabetes caregiver was included in the study.

2.3 | Measures

2.3.1 | Descriptive characteristics—Participants’ age, sex, race, ethnicity, and insurance status in addition to history of insulin pump and CGM use were collected via the

electronic medical record at the time of study enrollment. To analyze differences in outcomes based on age, participants were stratified into the following three age groups at study enrollment: child (<14 years), adolescent (14–17 years), and young adult (18 years).

2.3.2 | Participant use of Auto Mode—Auto Mode data were collected from the “Assessment and Progress Report” of the commercially available CareLink software after 1 month of Auto Mode use (during the training follow up call), and during clinic visits after starting Auto Mode (approximately 3 and 6 months post Auto Mode start). Metrics included percent time using Auto Mode, percent time wearing CGM, mean number of blood glucose checks per day, mean number of sensor calibrations per day, mean total daily insulin dose, mean percentage of total daily insulin delivered as bolus or basal insulin, mean number of system exits from Auto Mode each day, and reasons for Auto Mode exits. For this analysis, exit reasons were categorized as either related to hyperglycemia (high sensor glucose exit and maximum insulin delivery), hypoglycemia (minimum insulin delivery), manual exit (user manually disabled Auto Mode feature), and other (including no sensor calibration, BG required, or unknown). Participants were defined as discontinuing use of Auto Mode, if there was <10% time in Auto Mode at the visit.

2.3.3 | Glycemic outcomes—HbA1c values were obtained from the electronic medical record at baseline (ie, HbA1c result closest to Auto Mode training date) and at routine clinic visits, approximately 3 and 6 months after starting Auto Mode. HbA1c was measured with a point-of-care Siemens DCA Vantage Analyzer 2000 (Siemens Healthcare Diagnostics, Elkhart, IN), calibrated every 3 months using International Federation of Clinical Chemistry reference standards. To evaluate differences in outcomes based on baseline HbA1c, participants were stratified into three groups: low HbA1c (baseline HbA1c <7.5%), middle HbA1c (baseline HbA1c 7.5%–8.9%) and high HbA1c (baseline HbA1c ≥9.0%). Sensor glucose data were obtained from the Carelink “Assessment and Progress Report” at baseline, while using the 670G system in Manual Mode, and at routine clinic visits following Auto Mode start. The mean sensor glucose was recorded and sensor glucose values were classified as percent time <55, <70, 70–180, >180, and >250 mg/dL.¹⁹ Glycemic metrics were analyzed for all participants using Auto Mode at each visit (defined as >10% Auto Mode use).

2.3.4 | Psychosocial outcomes—To evaluate the impact of 670G use on psychosocial outcomes, study participants and their primary caregiver completed two questionnaires: (a) Hypoglycemia Fear Survey (HFS; Worry subscale) and (b) Problem Areas in Diabetes (PAID).

The HFS is a self-reported questionnaire of behavior and worry related to hypoglycemia and its negative consequences.^{20,21} Only the Worry subscale was used for this study as this metric has been used in the past for other diabetes technology studies.²² In addition the worry subscale has demonstrated acceptable factor structure in pediatrics whereas the behavior subscale has been called into question.²³ Validated versions of the HFS exists for children (CHFS; 15 items; Worry subscale score = 0–60) ages 6–18 years, caregivers of children with type 1 diabetes (PHFS; 15 items; Worry subscale score = 0–60), and young adults (HFS-II; 18 items; Worry subscale score = 0–72). Questions address concerns related

to hypoglycemia where respondents indicate how often they worry about each concern on a scale from 0 = never to 4 = almost always with higher scores indicating more hypoglycemia worry. After summing Worry subscale scores, a z-score was computed to provide a standard scale for scoring for caregivers (Cronbach's α = .87-.92), children (.83-.87), and young adults (not calculated due to small sample size).

The PAID is a self-report questionnaire of the emotional distress and psychosocial burden associated with management of type 1 diabetes. Validated versions of the PAID were administered to children (PAID-Peds; 20 items; Cronbach's α = .91-.94) ages 8–17 years old and young adults (PAID; 20 items; Cronbach's α not calculated due to small sample size) with type 1 diabetes, and caregivers (PAID-PR; 18 items; Cronbach's α = .87-.92).^{24–27} Questions address burdens or concerns related to managing diabetes where respondents indicate how much they agree on a 5-point scale of 0 = agree to 4 = disagree. For the PAID-Peds and PAID-PR, items are reverse scored and a mean score of all items is calculated and multiplied by 25, resulting in a total score of 0–100, with higher scores indicating more perceived burden. The PAID contains 20 items, which are summed and multiplied by 1.25, resulting in a total score of 0–100, with higher scores indicating more perceived burden.

2.4 | Statistical analyses

All system use, glycemic, and psychosocial variables were assessed for normality using the Kolmogorov-Smirnov test. Descriptive statistics reported are mean $\pm$ SD, median (25th, 75th percentile), or frequencies (%). Continuous variables were compared using t tests or Kruskal-Wallis Rank Sum tests, and Chi-squared or Fisher's exact tests were used for categorical variables.

Linear mixed effects models were used to examine change across time and were chosen to account for the correlation of repeated measures within a participant and because of their robustness to missing data. Time was treated as a categorical variable and all models included a random intercept for subject. The HbA1c model included an interaction term for baseline HbA1c group with time point, but the CGM variable models did not. The interaction effect of age and time point on HbA1c was examined, but it was not significant. Differences between time points for each baseline HbA1c group were compared using linear contrasts. The effect of age group on Auto Mode use was assessed with a linear mixed effects model adjusted for time point with random intercept for subject. The interaction effect of age group and time point on Auto Mode use was examined, but it was not significant. The effect of Auto Mode use on HbA1c was also assessed using a linear mixed effects model with random intercept for subject but did not include a time variable, as this relationship was assumed to be stable across visits. Results from mixed models are reported as least squares means $\pm$ SE.

HFS scores were Z-transformed prior to analysis. Parent and child responses were analyzed separately due to potential correlation between parent and child responses. All tests performed were two-sided and a P value <0.05 was considered statistically significant. P values were adjusted for multiple comparisons using the false discovery rate (FDR) method, treating baseline to the first clinic visit (approximately 3 months of Auto Mode use) and

baseline to the second clinic visit (approximately 6 months of Auto Mode use) as separate families of hypotheses. Analyses were performed using R version 3.6.0 and descriptive statistics were compared using the “tableone” package.

3 | RESULTS

Of the 113 eligible youth approached, 107 agreed to participate, resulting in a recruitment rate of 96% (Figure 1). The final sample of individuals who consented for the study, started Auto Mode, and completed 6 months of follow-up included 92 youth and 89 caregivers.

Youth were 15.7 ± 3.6 years, 50% male, with type 1 diabetes duration of 7.0 ± 4.0 years (Table 1). Thirty-three percent of the sample was 13 years old, 30% of the sample were 18 years old, and the remaining 37% of youth were 14–17 years old. The mean HbA1c at baseline was $8.8\% \pm 1.8\%$, collected 39 (8, 64) days prior to starting Auto Mode. Seventy-two percent of youth had been using an insulin pump for 3 years and 61% had been using CGM for 1 year prior to starting the 670G system.

Participants completed their one-month training follow-up phone call $30^{7,32}$ days after starting Auto Mode. The first clinic visit was approximately 3 months (95 [71,12] days) after starting Auto Mode, and the second clinic visit was approximately 6 months (189 [169, 210] days) after starting Auto Mode. Twenty-eight participants (30%) completed one clinic visit within the first 6 months after starting auto mode and 59 (64%) completed two clinic visits. Five participants (6%) completed a 1-month training call but no clinic visits within the first 6 months of starting auto mode.

3.1 | Participant use of the 670G system

After 1 month, Auto Mode use was $65.5\% \pm 3.0\%$. Use of Auto Mode declined to $56.2\% \pm 3.2\%$ at 3 months ($P = .008$), and again to $51.2\% \pm 3.4\%$ at 6 months after starting Auto Mode ($P < .001$ for change from month 1 to month 6). Likewise, CGM use decreased from $80.2\% \pm 2.6\%$ at baseline (11 [7, 14] days prior to starting Auto Mode), to $72.4\% \pm 3.0\%$ at 3 months ($P = .03$) and $68.1\% \pm 3.1\%$ at 6 months ($P = .001$ for change from baseline to month 6). There was a difference in Auto Mode use by age group, with youth less than 14 years spending $17\% \pm 6\%$ more time in Auto Mode, on average, compared to those age 14–17 years ($P = .005$) and $13\% \pm 6\%$ more time in Auto Mode compared to those age 18–25 years ($P = .045$). Participants experienced an average of 0.9 ± 0.05 exits from Auto Mode each day, and nearly 40% of these exits were related to hyperglycemia (Table 2).

Ten youth discontinued Auto Mode within the first 3 months of use. By 6 months, an additional 18 youth discontinued Auto Mode, resulting in a total of 28 youth (30% of participants) discontinuing Auto Mode in the first 6 months of use. Of the 28 youth who discontinued Auto Mode, 21 also stopped using the CGM.

3.2 | Glycemic outcomes

For individuals who used Auto Mode, sensor glucose TIR (70–180 mg/dL) changed from $50.7\% \pm 1.8\%$ at baseline, to $58.7\% \pm 2.0\%$ at 3 months ($P < .001$), to $56.9\% \pm 2.1\%$ at month 6 ($P = .01$ for change from baseline to month 6). Prevalence of hypoglycemia was

low, with less than 3% of sensor glucose values <70 mg/dL. There was no difference in percent sensor glucose values <70 mg/dL or percent sensor glucose values <55 mg/dL across time points (Table 2).

Mean HbA1c decreased from $8.7\% \pm 0.2\%$ at baseline to $8.2\% \pm 0.2\%$ after 3 months ($P < .001$) and $8.4\% \pm 0.2\%$ after 6 months of use ($P = <.001$ for change from baseline to month 6). Mean sensor glucose decreased from 185.7 ± 3.2 mg/dL at baseline to 175.7 ± 3.5 mg/dL after 3 months ($P = .002$) and 177.5 ± 3.7 mg/dL after 6 months of use ($P = .01$ for change from baseline to month 6). There was no significant interaction between HbA1c outcomes and age group, but there was a significant difference between HbA1c outcomes and baseline HbA1c group (Figure 2). There was no change in HbA1c after 6 months of Auto Mode use for the low baseline HbA1c group (mean baseline HbA1c $6.9\% \pm 0.2\%$). The middle HbA1c group (mean baseline HbA1c $8.3\% \pm 0.2\%$) experienced an initial decrease in HbA1c of $0.5\% \pm 0.1\%$ after 3 months of use, but after 6 months of use, there was no difference in HbA1c compared to baseline. Mean HbA1c for those in the high HbA1c group (mean baseline HbA1c $10.7\% \pm 0.2\%$) decreased to $9.7 \pm 0.2\%$, after 3 months of use ($P = <.001$), and to $9.3\% \pm 0.3\%$ after 6 months of use ($P = .001$ for change from baseline to month 6). After controlling for baseline HbA1c, there was an association between auto mode use and HbA1c. For each 10% increase in auto mode use, HbA1c decreased by 0.07% ($P = 0.02$) (Figure 3).

3.3 | Psychosocial outcomes

Youth and their caregivers completed baseline questionnaires 97¹³ days before starting Auto Mode and then at 76 (48, 107) days after starting Auto Mode, and again 182 (158, 210) days after starting Auto Mode. There was no change in HFS worry z-scores for youth or caregivers in the first 6 months of Auto Mode use (Table 2). Baseline PAID scores for caregivers was 44.7 ± 2.0 and PAID scores for youth was 35.8 ± 2.4 . There were no changes in PAID scores for either youth or caregivers, after using Auto Mode for six months (Table 2).

4 | CONCLUSIONS

This is one of the first studies to prospectively examine the use of HCL in the real-world, and the first study to examine HCL use in an exclusively pediatric sample, providing both clinical and psychosocial outcomes during a 6-month period. These results present a mixed picture of opportunities and challenges for HCL use in a youth population, identifying key issues for consideration in future studies and clinical practice.

These data show that glycemic control improved with Auto Mode use when measured by percent TIR, mean sensor glucose and HbA1c during 6 months of observation. Increased time spent using auto mode was associated with lower HbA1c. This improvement in HbA1c is particularly remarkable as 37% of participants were 14–17 years of age, the age range when HbA1c tends to be the highest.^{3,7} Notably, the participants with the highest baseline HbA1c experienced the greatest decline in HbA1c after 6 months of Auto Mode use. This suggests that youth struggling with glycemic control may benefit substantially from HCL therapy. Importantly, youth in the high baseline HbA1c group still showed average HbA1c

well above the recommended target of <7.5% after 6 months, but they also experienced significant improvement in glycemic control.

Use of Auto Mode steadily declined from 66% in the first month to 51% after 6 months, and a significant portion of participants discontinued Auto Mode use in the 6 months after starting 670G. Likewise, most of those who discontinued Auto mode also stopped using CGM and CGM use decreased significantly during the same 6 months for those who continued using Auto Mode. These results are similar to Lal et al, who also observed a decline in auto mode use and high rate of discontinuation in a mixed sample of 84 youth and adults (ages 9–61 years) with T1D using 670G for 12 months. Lal and colleagues observed a decline in auto mode use from a mean of 74% in the first week of use to 50% use by month 6 and 35% use by month 12. In this sample, 46% had discontinued HCL by 12 months and the most common reason cited for discontinuing HCL was sensor issues.²⁸ The most common reasons for HCL discontinuation in our sample was difficulty with sensor calibration and perceived high workload required to maintain HCL. Analysis of reasons for HCL discontinuation in our sample of youth is published in a separate manuscript by Messer et al (in press).²⁹ These data suggest that the benefits in glycemic control with use of the HCL system may be hindered by difficulties maintaining use of CGM and sustaining time in Auto Mode. Youth may require substantial clinical support to overcome barriers in using CGM to ensure success in sustaining HCL use. Body image concerns, financial barriers, skin irritation, alarm fatigue, technical problems, and perceived lack of trust in the CGM glucose values are commonly cited barriers to CGM use in youth and young adults.³⁰ It is important that health care providers and educators assess individual barriers to CGM use and provide psychosocial and educational support to assist youth in overcoming these barriers.

There are many possible reasons that CGM and Auto Mode use decreased across time. In a prior study of 72 youth with type 1 diabetes completing a 670G HCL training program at our clinical center, 32% reported difficulty with the number of blood glucose checks required when using Auto Mode, 30% reported challenges in completing sensor calibrations successfully, and 20% reported there were too many system alerts.¹⁷ Grando and colleagues published a pilot user experience survey among 21 adults using the 670G in Auto Mode, which similarly highlighted difficulties using the system.³¹ Although the participants in this study were satisfied with improvements in glucose control using Auto Mode, they also reported frustrations with the frequency of user inputs required to operate Auto Mode (ie, checking and entering a BG into the pump), and alert frequency.²⁹ The youth in this real-world study experienced nearly one Auto Mode exit per day, calibrated their sensor 2–3 times per day, and checked blood glucose levels 5–6 times per day. This is consistent with Faulds and colleagues' study, which reported that adults using 670G in the first 3 months calibrated their sensor 3.2 times/day and checked BG an average of 6.5 times/day.³⁰ In an era when many individuals with type 1 diabetes are using factory calibrated CGM systems,³³ requiring BG checks and sensor calibrations may be too high a burden for sustained use of HCL.

In this real-world sample, perception of diabetes distress did not change with HCL use, as indicated by no change in PAID scores for either parents or youth after 6 months of Auto Mode use. Although there was no net change in burden, it is unknown whether this means

that burden was truly unchanged or if there was a potential counterbalance between adding new technology burdens and reducing burden related to suboptimal glycemic control. Regardless, it is important to note that perceived burden did not increase. Worry about hypoglycemia also did not change for youth or their caregivers after 6 months of HCL use. This could be due to the low prevalence of hypoglycemia in this sample or the fact that HCL use declined across time, thus reducing confidence in hypoglycemia prevention expected from using HCL. It might also indicate that HCL technology does not have impact on long-standing worry.

Stone and colleagues collected retrospective data from the first 3 months of 670G upload data from 3141 individuals ages 7 to 75 years, and reported significantly increased TIR during Auto Mode compared to baseline standard sensor-augmented pump therapy in all age groups.³² Notably, the 3 months median Auto Mode use was 80.8% with 73.3% TIR, both significantly higher than our findings in this present study. Several key differences in study design could account for these differences in study findings. First, Stone and colleagues analyzed data from the first 3141 people to start the 670G system worldwide. Therefore, there may have been a selection bias towards highly engaged early adopters who were more motivated to succeed with technology than the average individual with type 1 diabetes. Additionally, Stone and colleagues analyzed data from a convenience sample of individuals who uploaded their 670G devices into personal CareLink accounts at home, potentially creating further selection bias, as this data may not reflect usage patterns from individuals who do not upload their devices to CareLink outside of clinic visits. Second, more time in Auto Mode and greater time in range have been reported for adults compared to youth and young adults. It is possible the majority of the data in the Stone et al study represent an adult sample, given the system was initially approved for those 14 years and older, however, the authors did not report the age distribution of the sample, so it is unclear. Finally, the Stone et al study only included median Auto Mode use and TIR over a 3-month period and did not analyze any changes in Auto Mode use or TIR across time. The current study includes data during 6 months, at two time points, therefore describing changes in Auto Mode use and TIR over time.

A second retrospective observational clinical study analyzed data from 34 adults with type 1 diabetes who had used Auto Mode on the 670G system for 3 months and showed a non-significant improvement in TIR at 2 weeks and 3 months, but a significant improvement in HbA1c at 3 months.³² The study may have been underpowered due to the small sample size to detect a significant change in TIR, however, these results are similar to our study which showed both an improvement in HbA1c and TIR at 3 months and 6 months. Further, Faulds and colleagues observed a decrease in Auto Mode use from 79.2% at 2 weeks to 72.3% at 3 months in their retrospective analysis, however, they did not report any data on discontinuation of Auto Mode. Although our study shows lower Auto Mode use overall compared to Faulds et al, both reports indicate a decrease in Auto Mode use across time, suggesting a challenge in sustaining HCL use for both adults and youth using 670G Auto Mode.

This study has several notable strengths. The data presented in this study represent the first report of clinical HCL implementation during a 6-month follow-up period in a pediatric

clinical population. The observational nature of this study is central to its implications for HCL effectiveness in the real-world compared to efficacy data gathered from structured clinical trials. This is also the first study to move beyond glycemic measures by also examining the impact of HCL technology on psychosocial measures in a real-world population. The sample included participants across a wide range of pediatric ages. However, the results should also be considered in the context of its limitations. All data were gathered at a single clinical center. Many of the clinical staff had years of experience with the 670G system in clinical trials prior to commercial release, potentially limiting generalizability of these findings. The data presented were obtained with the original Guardian Sensor 3 transmitter, and fewer alerts and exits may be seen with the upgraded transmitter that was released late in 2018. Additionally, HCL discontinuation was high, and the reasons for HCL discontinuation were not collected as part of this study. Analysis of reasons for HCL discontinuation in a sub-set of youth in this study who discontinued HCL is published in a separate manuscript by Messer et al (in press).²⁹ A treatment satisfaction questionnaire may have provided more insight into understanding reasons for discontinuation. We plan to include a treatment satisfaction scale into future work examining the impact of HCL systems in the real-world.

In summary, we observed improved glycemic control and no change in hypoglycemia worries or perceived care burden for youth who used HCL therapy for approximately 6 months. The decrease in Auto Mode use throughout 6 months and high discontinuation rate suggest sustained use of HCL therapy may be a challenge for some individuals in its current state. As HCL therapies continue to evolve, it is important to reduce system burdens and exits from HCL to ensure sustainability of HCL therapy long term. Further analysis is ongoing to determine factors associated with discontinuation of HCL and to investigate strategies to sustain use of HCL technology for all youth with type 1 diabetes.

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FIGURE 1.
Flowchart of participant recruitment

FIGURE 2.
Mean change in HbA1c across time by baseline HbA1c group

FIGURE 3.
HbA1c by Auto Mode (AM) use

TABLE 1

Baseline characteristics for 92 youth starting HCL therapy for their type 1 diabetes care

Characteristic	Baseline value
Baseline HbA1c	8.8% $\pm$ 1.8%
Type 1 diabetes duration, (yrs.)	7.0 $\pm$ 4.1
Age, (yrs.)	15.7 $\pm$ 3.6
Male	46 (50%)
Age group	
<14 years	31 (33%)
14–17 years	34 (37%)
18 years	27 (30%)
HbA1c group	
Low Baseline HbA1c (<7.5%)	17 (22%)
Middle Baseline HbA1c (7.5–8.9%)	33 (43%)
High Baseline HbA1c (≥9.0%)	27 (35%)
Ethnicity	
Hispanic or Latino	8(9%)
Not Hispanic or Latino	79 (86%)
Unknown	5(5%)
Race	
American Indian/Alaska Native	1 (1%)
Pacific Islander	1 (1%)
White	76 (83%)
More than 1 race	5(5%)
Unknown	9 (10%)
Insurance type	
Public insurance	14 (15%)
Private insurance	72 (79%)
Other	5(6%)
History of insulin pump use	
month	1 (1%)
1–6 months	3 (3%)
6 months–1 year	11 (12%)
1–3 years	11 (12%)
3–5 years	21 (23%)
years	45 (49%)
History of CGM use	
month	18 (20%)
1–6 months	4 (4%)
6 months–1 year	14 (15%)
1–3 years	32 (35%)
3–5 years	13 (14%)

Characteristic	Baseline value
years	11 (12%)

Note: Statistics are reported as either mean ± SD or counts (% of sample).

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Mixed models summary: change in use of HCL system, sensor glucose time in range and psychosocial outcomes for 92 youth using 670G HCL system for 6 months

TABLE 2

	Baseline	Month 1	Month 3	P value	Month 6	P value
Median (25th, 75th %tile) # days since HCL start (Auto Mode)	-11 (7,14)	+30 (28, 32)	+95 (71, 112)	N/A	+189 (169, 210)	N/A
Use of HCL system (Auto Mode)						
% time HCL (Auto Mode)	80.2 ± 2.6	65.5 ± 3.0	56.2 ± 3.2	.008	51.2 ± 3.4	<.001
% time using CGM			72.4 ± 3.0	.03	68.1 ± 3.1	.001
# of system exits from HCL mode (Auto Mode) to standard pump mode (Manual Mode) per day		0.9 ± 0.05	0.8 ± 0.1	.91	0.8 ± 0.1	.68
% system exits related to hyperglycemia		38.3 ± 2.6	34.8 ± 2.9	.48	38.0 ± 3.1	.91
% system exits related to hypoglycemia		4.4 ± 1.0	3.4 ± 1.1	.52	3.3 ± 1.2	.42
% system exits due to user manually exiting Auto Mode (%)		6.7 ± 1.4	6.6 ± 1.4	.95	3.4 ± 1.5	.12
% system exits due to other reasons (ie, no calibration, BG entry required, unknown)		51.3 ± 2.5	55.5 ± 2.8	.40	55.5 ± 3.0	.29
# of BG checks per day	7.4 ± 0.3		5.3 ± 0.4	<.001	5.9 ± 0.4	.004
# sensor calibrations per day	2.7 ± 0.1		2.7 ± 0.1	.95	2.3 ± 0.1	.01
Total daily insulin dose (TDD), units	51.4 ± 2.7		52.7 ± 2.8	.51	55.4 ± 2.8	.01
% TDD delivered as basal insulin	44.2 ± 1.1		48.3 ± 1.3	.008	48.3 ± 1.3	.01
% TDD delivered as bolus insulin	55.8 ± 1.1		51.6 ± 1.3	.008	51.7 ± 1.3	.01
Sensor glucose data						
Mean sensor glucose (mg/dL)	185.7 ± 3.2		175.7 ± 3.7	.002	177.5 ± 3.7	.01
% sensor glucose values <55 mg/dL	1.4 ± 1.0		1.4 ± 1.0	.91	1.5 ± 1.0	.30
% sensor glucose values <70 mg/dL	2.9 ± 0.1		2.9 ± 1.0	.91	3.0 ± 1.0	.72
% sensor glucose values 70–180 mg/dL	50.7 ± 1.8		58.7 ± 2.0	<.001	56.9 ± 2.1	.01
% sensor glucose values >180 mg/dL	47.4 ± 1.8		39.1 ± 2.0	<.001	40.8 ± 2.1	.007
% sensor glucose values >250 mg/dL	18.8 ± 1.4		15.8 ± 1.5	.03	16.2 ± 1.5	.08
Psychosocial outcomes (PAID & HFS; worry)						
Median # days since HCL start	N/A		75 (51, 98)	N/A	167 (148, 185)	N/A
HFS worry Z score (youth)	0.05 ± 0.1		-0.31 ± 0.1	.71	-0.20 ± 0.2	.14
HFS worry Z score (caregivers)	0.08 ± 0.1		-0.04 ± 0.1	.52	-0.13 ± 0.1	.25
PAID (youth)	35.8 ± 2.4		36.4 ± 3.0	.91	34.5 ± 3.2	.72
PAID (caregivers)	44.2 ± 2.0		46.2 ± 2.3	.52	46.9 ± 2.6	.33

Note: Results presented as mean ± SE. P value at 3 months represents change from either baseline or month 1 to month 3; P value at 6 months represents change from either baseline or month 1 to month 6.