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ORIGINAL ARTICLE

Evaluation of a Blood Glucose Monitoring System with Automatic High- and Low-Pattern Recognition Software in Insulin-Using Patients: Pattern Detection and Patient-Reported Insights

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Abstract

Background:

This study aimed to evaluate the performance of a glucose pattern recognition tool incorporated in a blood glucose monitoring system (BGMS) and its association with clinical measures, and to assess user perception and understanding of the pattern messages they receive.

Methods:

Participants had type 1 or type 2 diabetes mellitus and were self-adjusting insulin doses for ≥1 year. During a 4-week home testing period, participants performed ≥6 daily self-tests, adjusted their insulin regimen based on BGMS results, and recorded pattern messages in the logbook. Participants reflected on usability of the pattern tool in a questionnaire.

Results:

Study participants (n = 101) received a mean ± standard deviation of 4.5 ± 1.9 pattern messages per week (3.6 ± 1.8 high glucose patterns and 0.9 ± 1.3 low glucose patterns). Most received ≥1 high (96.5%) and/or ≥1 low (46.0%) pattern message per week. The average number of high- and low-pattern messages per week was associated with higher and lower, respectively, baseline hemoglobin A1c ($p < .01$) and fasting plasma glucose ($p < .05$). Participants found high- and low-pattern messages clear and easy to understand (84.2% and 83.2%, respectively) and considered the frequency of low (82.0%) and high (63.4%) pattern messages about right. Overall, 71.3% of participants indicated they preferred to use a meter with pattern messages.

Conclusions:

The on-device Pattern tool identified meaningful blood glucose patterns, highlighting potential opportunities for improving glycemic control in patients who self-adjust their insulin.

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Abbreviations: (BGMS) blood glucose monitoring system, (FPG) fasting plasma glucose, (HbA1c) hemoglobin A1c, (HCP) health care professional, (SMBG) self-monitoring of blood glucose

Keywords: blood glucose monitoring system, diabetes, pattern analysis, self-monitoring of blood glucose

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Introduction

For patients with type 1 diabetes mellitus, flexible, intensive insulin management to enable dietary freedom has been shown to improve glycemic control and quality of life without increasing the risk of severe hypoglycemia or cardiovascular disease.[1,2] For patients with non-insulin-treated type 2 diabetes mellitus, structured self-monitoring of blood glucose (SMBG) is reported to improve hemoglobin A1c (HbA1c) levels and facilitate more timely/aggressive treatment changes without decreasing general well-being.[3,4]

A key to effective SMBG use is pattern management, a systematic approach to recognizing glycemic patterns within SMBG data to enable appropriate action to be taken based on those results.[5–7] By using data gathered during a specified period, health care professionals (HCPs) and patients can identify consistent patterns of glycemic excursions and make necessary adjustments to better control glucose levels, minimize glycemic excursions, and limit hypoglycemia.[8,9] Benefits of pattern management include reduction in HbA1c levels and prediction of severe hypoglycemia.[8]

Data collection and management tools can facilitate the pattern recognition process by enabling more robust and efficient use of SMBG data by patients and HCPs.[6,10] Most currently available blood glucose monitoring systems (BGMSs) require connection to (Web-based) pattern management software, but experience has shown that patients often do not consistently download data. A BGMS with an onscreen (real-time) pattern analysis tool could, therefore, be a valuable asset to patients by providing immediate feedback on blood glucose values, which could have an impact on an individual's behavior and self-management.

The OneTouch® Verio®Pro and VerioIQ BGMSs (LifeScan Inc., Milpitas, CA) incorporate proprietary High/Low PatternAlert™ technology (hereafter referred to as the Pattern tool). The Pattern tool informs users and HCPs of trends that require closer attention by providing real-time, onscreen messages when high patterns (before meal) or low patterns (any time) are detected. The tool prompts the user to review the specific results that triggered the pattern message (**Figure 1**). The high- and low-pattern alerts enable individuals to consider making timely changes in diabetes medication (under the direction of a HCP) or behavior. However, there are a lack of data on how users perceive these pattern alerts, and patients are sometimes reluctant to follow advice from automated systems.[9] Knowledge of individual patient preference is essential for determining which pattern management tools are most effective.[7]

This study was conducted to evaluate the performance of the Pattern tool and its association with clinical measures, to assess user perception of the pattern messages, and to assess if users understood the reasons for the pattern messages they received.

Methods

Study Design

This multicenter, open, single-arm, nonrandomized clinical study was conducted at three National Health Service clinics in the United Kingdom (LifeScan Scotland Clinic, Highland Diabetes Institute; Diabetes Outpatient Department, Royal Infirmary of Edinburgh; and Diabetes Centre, Birmingham Heartlands Hospital). The study was approved by the relevant internal ethics committees, and all participants provided written informed consent prior to initiation of the study.

The study included participants aged ≥16 years with type 1 or type 2 diabetes mellitus who were managing their diabetes with multiple daily insulin injections or insulin pump therapy and had been self-adjusting their insulin doses based on SMBG values for ≥1 year. Subjects who were currently working for, had previously worked for, or had an immediate family member working for a company that manufactures or markets blood glucose monitoring products and those who were pregnant were excluded.

Measures of Pattern tool performance included average number of high- and low-pattern messages per participant per week; association of low-pattern messages (threshold <70 mg/dl) with subsequent severe hypoglycemia (<50 mg/dl) in the 24 h period following a low-pattern message; association between frequency of pattern messages and number of insulin-dosing adjustments; change in fasting, before-meal, after-meal, and overall average blood glucose values from week 1 to week 4; change in number of low blood glucose values (<70 mg/dl), hypoglycemic values (<50 mg/dl), and hyperglycemic values (>180 mg/dl) from week 1 to week 4; and change in frequency of before-meal high-pattern messages, before-meal SMBG results >130 mg/dl, all before-meal tagged SMBG results, after-meal tagged SMBG results >180 mg/dl, and all after-meal tagged SMBG results from week 1 to week 4. User experience was assessed by a user acceptance questionnaire.

The study procedure included two site visits, a 4-week structured home-testing period, and two telephone calls with a HCP. Site visit 1 included assessment of participants' medical history, instruction on study procedures and requirements, structured self-training on meter (VerioPro) use, and instruction on using the home-testing logbook for recording structured SMBG test results, bolus insulin doses, and any high- and/or low-pattern messages that appeared during home testing.

Participants were instructed to perform and tag ≥6 daily self-tests (four structured tests [one fasting, two before meal, and one at bedtime] and two discretionary tests) during the 4-week home testing period; to adjust their insulin regimen based on BGMS results; to record low-pattern, fasting high-pattern, and before-meal high-pattern messages in the logbook, including reasons for messages using either predefined codes or free text; and to participate in two telephone interviews with a National Health Service registered research nurse to verify compliance with the protocol and address any questions relating to home testing.

During site visit 2, participants were debriefed, the logbook was collected and reviewed, and participants completed a user acceptance questionnaire.

Meters were preset to detect patterns and provide pattern alerts: low patterns were defined as two readings of ≤70 mg/dl over a 5-day period within a 3 h time bracket and high patterns were defined as three (tagged before-meal or fasting) readings ≥130 mg/dl over a 5-day period within a 3 h time bracket (**Figure 1**).

Statistical Analyses

Pattern tool performance data were reported as mean, standard deviation (SD), median, minimum, and maximum statistics for each of the pattern message types per week and across all 4 weeks. For associations between number of pattern messages and HbA1c or fasting plasma glucose (FPG), the pooled average number of messages per week was plotted against the baseline HbA1c or FPG level, respectively. Separate linear regression analyses were performed for low-pattern and high-pattern messages to test the hypothesis that the slope was not equal to 0. Changes in clinical parameters from week 1 to week 4 were evaluated using the paired *t* test with a 95% level of significance.

Results

Participants

Baseline characteristics of the 101 participants who completed the study and the user acceptance questionnaire are shown in **Table 1**. At study initiation, 75.2% of the study participants indicated that they used SMBG results to monitor their blood glucose, and 36.6% made bolus insulin adjustments based on blood glucose readings.

Performance of the Pattern Tool

In total, 1809 pattern messages (low and high) were received across all 101 participants during the 4-week period (**Table 2**; **Figure 2A**). Overall, study participants received a mean ± SD of 4.5 ± 1.9 pattern messages per week, including 3.6 ± 1.8 high-pattern messages and 0.9 ± 1.3 low-pattern messages (**Table 2**).

Most participants (96.5%) received ≥1 high-pattern message per week and almost half (46.0%) received ≥1 low-pattern message per week. High-pattern messages were generated and localized to specific times over a 24 h period (fasting or around meals), whereas low-pattern messages occurred throughout the period (**Figure 2B**).

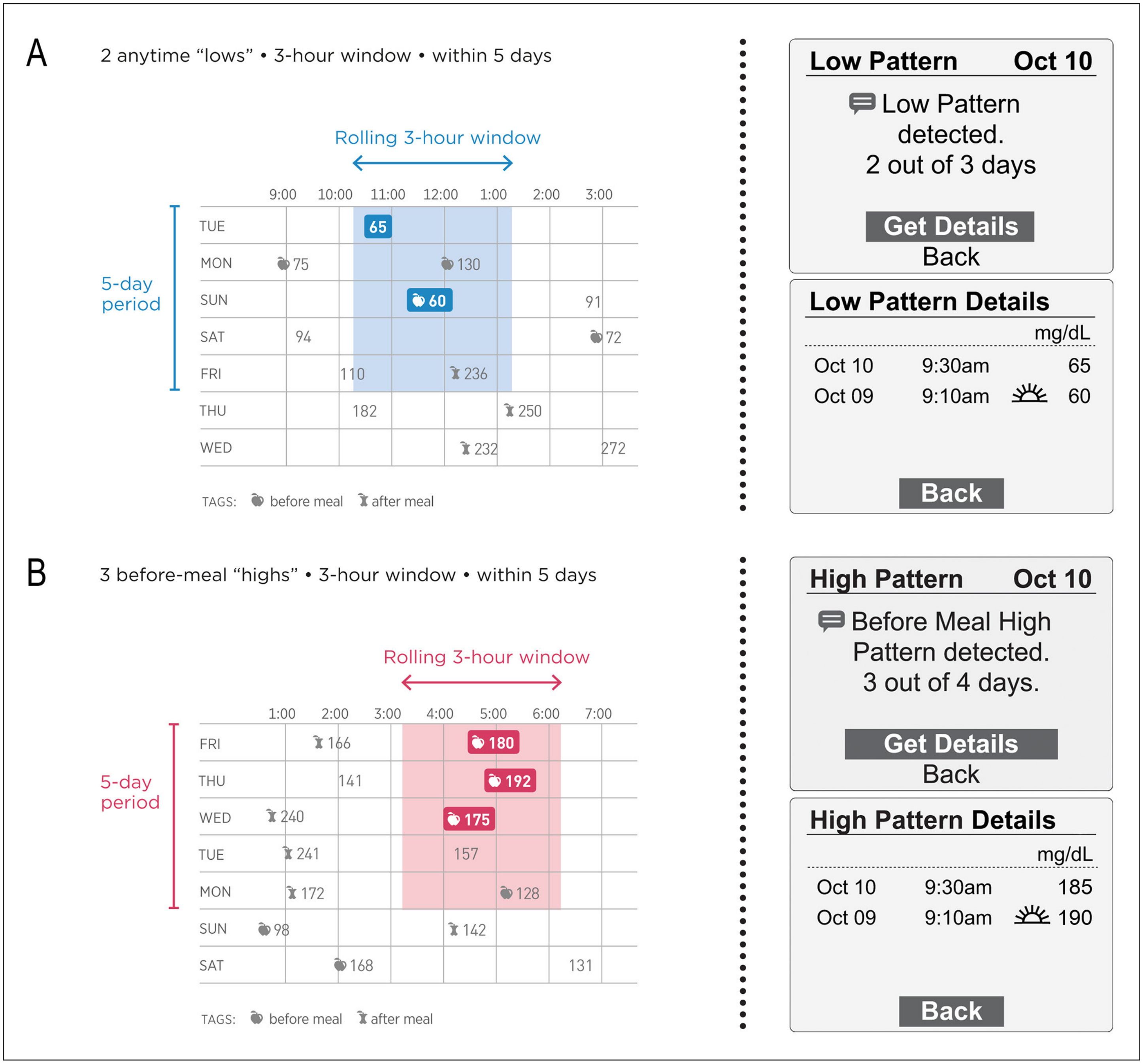

Figure 1. Examples of the Pattern tool rolling window and alert messages for recognition of (A) low and (B) high blood glucose patterns.

Association between Pattern Messages and Clinical Measures

The average number of high-pattern messages per week was associated with higher baseline HbA1c levels (p = .0062), and the average number of low-pattern messages per week was associated with lower baseline HbA1c levels (p = .0008).[11] Likewise, the average number of high-pattern messages per week was associated with higher FPG levels ($p < .0001$), and the average number of low-pattern messages per week was associated with lower baseline FPG levels (p = .0145).

There was no association between the number of low-pattern messages (n = 357) and the occurrence of severe hypoglycemia (<50 mg/dl) in the following 24 h period (n = 28; p = .653). The association between frequency of pattern messages and number of insulin-dosing adjustments could not be performed due to lack of insulin-dosing adjustment data.

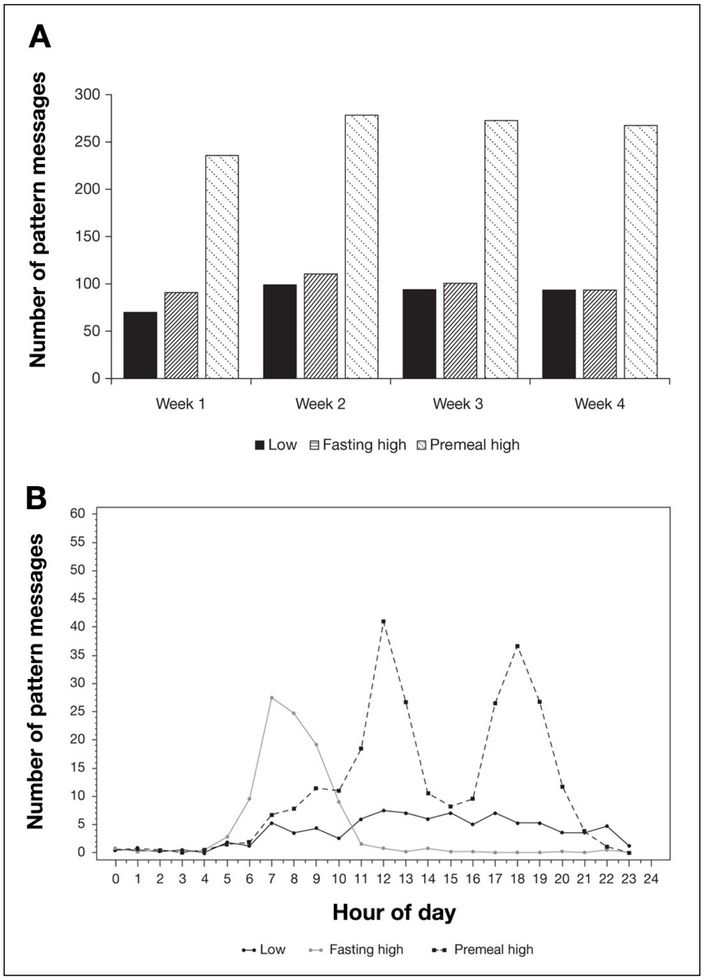

Figure 2. Distribution of low- and high-pattern messages **(A)** by week and **(B)** by hour for one representative day.

There were no significant changes from week 1 to week 4 in fasting (-1.5 ± 45.4 mg/dl; p = .747), before-meal (2.9 ± 37.7 mg/dl; p = .44), after-meal (6.5 ± 49.2 mg/dl; p = .20), or overall (2.2 ± 29.6 mg/dl; p = .457) blood glucose values. There was little or no change from week 1 to week 4 in the number of low (<70 mg/dl; +0.03%), hypoglycemic (<50 mg/dl; +0.02%), high (>130 mg/dl; -0.03%), or hyperglycemic (>180 mg/dl; -0.03%) values. There was no significant change from week 1 to week 4 in the frequency of before-meal high-pattern messages (59.3% versus 58.1%, respectively; p = .94); however, the frequency of before-meal tagged SMBG results >130 mg/dl was significantly lower in week 4 (61.4%) than in week 1 (66.5%; p = .005).

User Perception of the Pattern Tool

Responses to the user questionnaire showed that most participants found high (84.2%) and low (83.2%) pattern alert messages clear and easy to understand. Of those

Table 1.
Baseline Patient Characteristics and Medical History

Characteristic	Participants (n = 101)
Male gender, n (%)	44 (43.6)
Mean age, years (range)	44.1 (16.1–76.3)
Type 1 diabetes mellitus, n (%)	91 (90.1)
Years since diagnosis, mean (range)	22.5 (1.3–63.7)
Years on basal/bolus insulin regimen, mean (range)[a]	15.7 (0.5–58.2)
Years altering (adjusting) own insulin dosage, mean (range)	14.7 (0.7–51.7)
Insulin(s) taken, n (%)	
Rapid-acting insulin	
Humalog (lispro)	30 (29.7)
Novo Rapid (aspart)	57 (56.4)
Long-acting insulin	
Lantus (glargine)	55 (54.5)
Levemir (detemir)	32 (31.7)
None	11 (10.9)
Method of insulin administration, n (%)	
Self-inject	88 (87.1)
Insulin pump	13 (12.9)
Frequency of administering fast-acting insulin (or a bolus), n (%)	
<3 times/day	2 (2.0)
3 times/day	69 (68.3)
4 times/day	20 (19.8)
5 times/day	5 (5.0)
>5 times/day	5 (5.0)
Years of SMBG, mean (range)[b]	18.6 (1.3–53.8)
Frequency of self-monitoring (per day), n (%)	
3–4	53 (52.5)
5–6	33 (32.7)
>6	15 (14.9)
HbA1c (%), mean (range)	8.5 (6.6–11.1)

[a] n = 97.
[b] n = 93.

Table 2.
Pattern Messages across All Participants during the 4-Week Period

Pattern message	Total number of messages[a]	Number of messages per day per participant	
		Mean ± SD	Median (range)
All	1809	4.5 ± 1.85	5 (0–11)
Low	357	0.888 ± 1.27	0 (0–8)
High	1452	3.612 ± 1.80	4 (0–9)
Fasting high	397	0.988 ± 0.86	1 (0–3)
Before-meal high	1055	2.624 ± 1.45	3 (0–7)

[a] Number of messages over the 4-week period.

participants who clicked on the pattern message every time (74.3%) or occasionally (21.8%) to see the extra details describing the pattern, 89.3% found the extra details about the pattern useful. Most participants considered the frequency of low (82.0%) and high (63.4%) pattern messages about right.

A total of 987 coded and 199 free-text reasons for messages were recorded in the home diary. When using predefined reason codes, study participants perceived that 37.2% of before-meal high-pattern messages resulted from snacking and that 46.4% of fasting high-pattern alerts resulted from insufficient basal insulin (**Figure 3A**). Similarly, participants who provided free-text reasons reported that 21.1% of before-meal high-pattern alerts resulted from food or snacking, and that fasting high-pattern alerts resulted from insufficient basal insulin or wrong insulin-to-carbohydrate ratio (21.4%) or food or snack at bedtime (21.4%; **Figure 3B**). Perceptions of low-pattern messages were more varied. Participants who used predefined reason codes considered that 41.2% of low-pattern alerts resulted from activity of some kind (**Figure 3A**), whereas those who provided free-text reasons attributed them to insufficient food (29.2%; **Figure 3B**).

In all, 71.3% of participants indicated they preferred to use a meter that provides high- and low-pattern messages, whereas only 9.9% preferred to use a meter without this option. However, 92.1% of the participants indicated that they would prefer to set the high and low blood glucose thresholds themselves, or have them set by their HCP, rather than using the default thresholds.

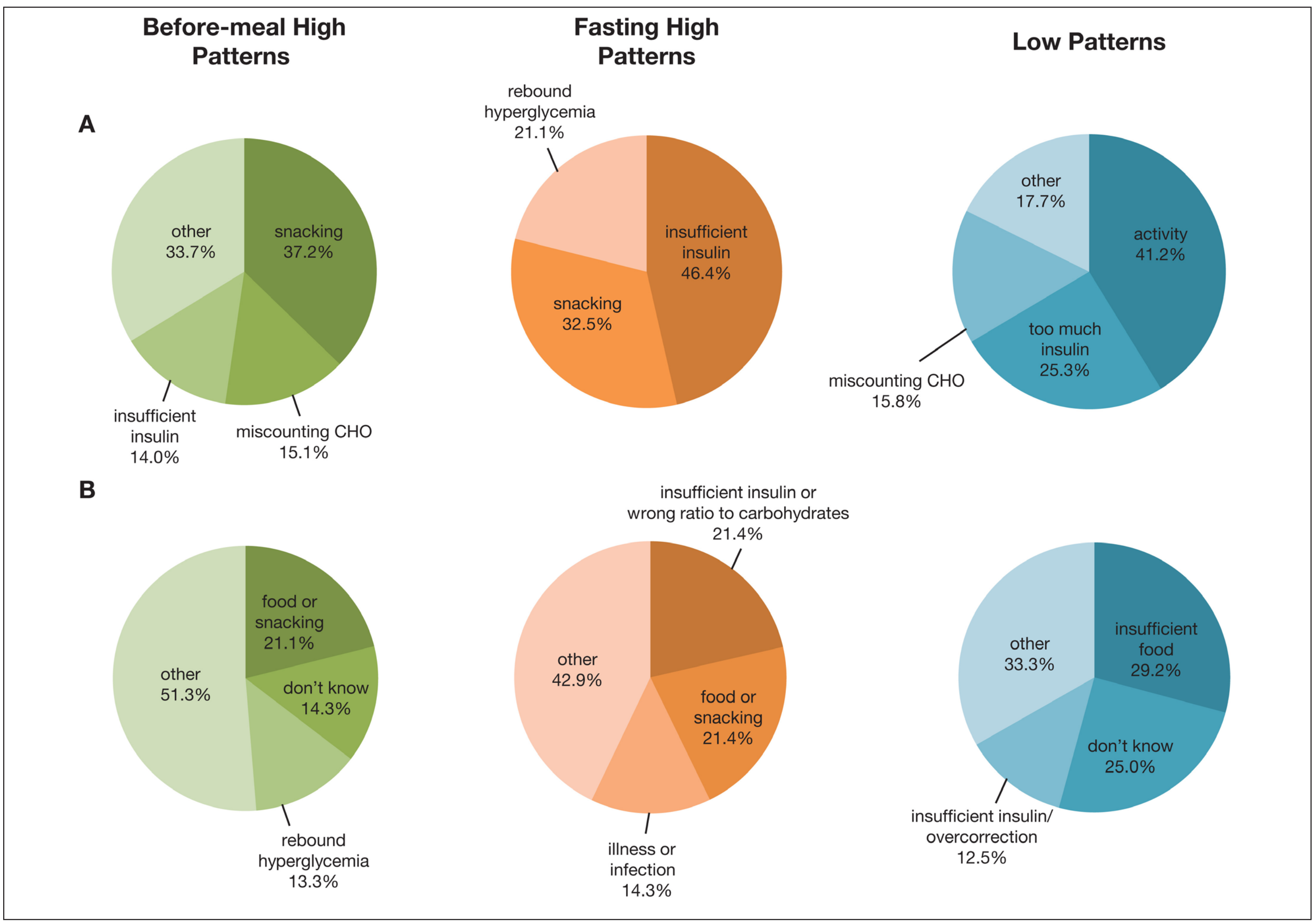

Figure 3. Understanding of pattern messages by participants. **(A)** Coded reasons given by study participants when before-meal high-pattern alerts, fasting high-pattern alerts, and low-pattern alerts were received. **(B)** Free-text reasons given by study participants when before-meal high-pattern alerts, fasting high-pattern alerts, and low-pattern alerts were received. CHO, carbohydrates.

Safety

No unanticipated device-related adverse effects were reported. The three serious adverse events reported were considered to be unrelated to the study device.

Discussion

This study showed a significant correlation between the frequency of low or high patterns detected by the Pattern tool and baseline glycemic control (HbA1c or FPG) of study participants. In addition, the study provided important insights into how participants interpreted reasons for their low- or high-pattern messages.

The novel on-device Pattern tool evaluated in this study was well received by study participants, with 71.3% indicating they preferred using a meter with pattern tools compared with one without such tools. The number of pattern messages generated was well accepted.

Participants received a sufficient number of pattern messages during the 4-week period to become familiar with the onscreen messages and to start considering the timing and nature of these pattern messages in terms of their lifestyle and diabetes management. Before-meal high messages (n = 1055) predominantly occurred at lunch and dinner times, and fasting high messages (n = 397) were predominantly received around breakfast time. As the vast majority of patients test in the morning and around meals to make decisions on basal or bolus insulin injections, it is to be anticipated that, in real-world extended use of the system, the patterns as observed in this study would be similarly clustered at these times of the day. In this study, the low-pattern messages (n = 357) were experienced consistently throughout the day, which highlights the challenge patients and HCPs face in discovering low patterns in particular.

In a retrospective study, Lee-Davey and coauthors[12] showed that clinical patterns of low blood glucose identified by this specific Pattern tool may predict increased risk of severe hypoglycemia in the following 24 h period. However, in the current study, low-pattern alerts were not associated with an increased risk of severe hypoglycemia in the next 24 h, possibly due to the limited number of participants (101 versus ≥200) and the shorter duration of the study (4 weeks versus ≥4 months). Alternatively, it is possible that, because participants acted correctly on the low-pattern alerts, actual hypoglycemia was mitigated; however, due to the one-armed design of the study, it is not possible to assess this. In addition, there was little change in glycemic end points, possibly also due to the short duration of the study. It is anticipated that, over time, glycemic improvements may become more clinically meaningful.

The data indicate that individuals with poorer glycemic control would be expected to be running high more often and to traverse the 130 mg/dl glucose threshold for either fasting or before meal more often than individuals with tighter glycemic control (low HbA1c and/or FPG), thereby triggering more high-pattern messages. Conversely, individuals with tighter glycemic control (low HbA1c and/or FPG) would be expected to trigger low-pattern messages more frequently, as observed in this study. This is consistent with a previous study that reported that HbA1c could be used to estimate the percentage of SMBG measurements expected to be within, above, and below the target range.[13] Therefore, HCPs could estimate or predict the frequency of patterns that would be triggered by patients (based on their current glycemic control) whom they may consider providing with a meter incorporating such a pattern recognition tool.

The need for personalized glucose targets was highlighted by the observation that the majority (92.1%) of participants would have preferred to set glycemic thresholds for triggering high- and low-pattern messages by themselves (or with a HCP). In practice, HCPs would be encouraged to customize alerts (over time) so that patients receive the appropriate number and type of messages to facilitate improved glycemic control.

Results from this study provide important insights about how onscreen low- or high-pattern messages were interpreted by patients. When the study participants were asked at baseline how they manage bolus insulin adjustments, 36.6% stated that they review blood glucose results every few days and make bolus adjustments based on any high or low blood glucose readings. It is unclear how representative this level of self-reflection on blood glucose data is for the wider population, but it points to a cohort of users who could derive value from automatic low- or high-pattern alerts.

In addition, 75.2% of the participants stated that testing their blood glucose enabled them to check if they were running high or low. In comparison, 63.4% indicated that they used blood glucose results to "work out how much insulin to inject or what to set on the insulin pump."

The patient-driven insights as observed in this study shed light on what patients believe are the reasons for low or high patterns and the actions insulin-using patients might consider after a pattern has been revealed. The consistency of responses by the participants regarding the reasons for high-pattern alerts indicates that most participants have a good understanding of the factors that affect hyperglycemia. However, the variability in responses for low-pattern messages may emphasize a need for participants to better understand the reasons for individual hypoglycemic events. This is an important issue to address, because hypoglycemia can lead to a cycle of recurrent hypoglycemic episodes, which increases the risk for severe hypoglycemia.[12,14] Although studies have clearly demonstrated that pattern analysis is an important element in predicting and preventing severe hypoglycemia,[8,12,15] low-pattern alerts can only be effective if patients also understand what action is required in response to the alert.

Insights into user perception of blood glucose patterns may be useful in facilitating and guiding conversations between patients and HCPs and may enable HCPs to identify patterns in both a more time-efficient manner and more accurately. In one study, Katz and coauthors[16] demonstrated that using a meter with a pattern alert technology (i.e., VerioIQ) was associated with faster and more accurate pattern reviews by HCPs compared with handwritten logbooks.

Although the participants in the current study had been on insulin therapy for an average of 15.7 years and had been self-adjusting insulin for on average 14.7 years, the mean HbA1c was 8.4%, demonstrating the challenges of maintaining good glycemic control, even in a group of experienced insulin self-adjusters. A pattern tool, such as the one described here, could help patients with day-to-day disease management by providing information to make informed decisions about insulin dose adjustment.

This study was limited by the use of preset thresholds for high- and low-pattern alerts, the absence of after-meal high-pattern alerts, and the short duration of the study. Although the VerioPro and VerioIQ BGMSs both allow patients (and/or HCPs) to personalize glucose thresholds to enable more specific and appropriate pattern messages to be identified and presented to the patient, this feature was not implemented in the study. This could have impacted patient acceptance; however, even with the preset thresholds, the acceptance and understanding of the Pattern tool was high (71.3% and ≥83.2%, respectively). The Pattern tool was specifically designed to not implement after-meal high-pattern messages, as these could result in an alert frequency that may be perceived as too high. Postprandial testing was only optional, but including this as required testing could have further impacted improvement in BG values. The short duration of the study could have further impacted the benefits (in terms of glycemic outcomes) and insights (of participants) into the pattern messages.

Conclusions

The proprietary Pattern tool on the VerioPro and VerioIQ meters identified meaningful blood glucose patterns, highlighting potential opportunities for improving glycemic control in individuals with diabetes who self-adjust their insulin doses (multiple daily insulin injections or insulin pump therapy). The results from this study validate the use of this Pattern tool and suggest that it offers clinical value to potential users.

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Disclosures:

Mike Grady, Denise Campbell, and Kirsty MacLeod are employees of LifeScan Scotland Ltd. Aparna Srinivasan is an employee of LifeScan, Inc.

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