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Perspective

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Implementation Strategies for Inpatient Continuous Glucose Monitoring-based Diabetes Management: A Systematic Review

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Abstract

Introduction: Continuous glucose monitoring (CGM) provides real-time glucose data that has revolutionized outpatient diabetes care; however, its impact on inpatient care remains limited, likely due to the lack of standardized CGM-based insulin titration protocols, implementation strategies, and proper familiarity with the technology, among others.

Methods: A systematic literature search was conducted on October 15, 2024, using PubMed and Embase, without a restriction on publication date. The search focused on CGM-based insulin titration protocols and related implementation strategies in non-intensive care unit (non-ICU) settings. This systematic review was registered with PROSPERO (RD42024596819).

Results: A total of 7625 references were screened. Nine protocols for inpatient CGM-based insulin titration and related implementation strategies were identified. Six protocols recommended a weight-based basal-bolus insulin regimen. Insulin titration on basal and bolus insulin was mostly done daily based on either clinical discretion or clearly defined insulin titration protocols. All protocols employed a hybrid approach, utilizing both CGM and finger prick glucose testing to guide glucose management. Diabetes-trained staff oversaw CGM-based insulin titration and glucose management in 5 protocols. CGM alarm settings varied widely, with hyperglycemic alarm thresholds between >13.9 and >22.2 mmol/L and hypoglycemia alarm thresholds between <3.9 and <5.0 mmol/L.

Conclusion: We observed considerable variation in the detail and clarity provided by the reviewed protocols. This highlights the need for standardized operational protocols for CGM-based insulin titration and related implementation strategies to implement CGM effectively in non-ICU settings.

Key Words: diabetes, in-hospital, inpatient, dose, continuous glucose monitoring, insulin titration

Diabetes affects up to 20% of hospitalized patients, and glucose management in these patients presents significant challenges due to altered glucose metabolism during hospitalization (1). Managing in-hospital hyperglycemia relies heavily on insulin therapy; however, developing effective and individualized insulin regimens for inpatients can be difficult, as people with diabetes will be spread over wards where expertise in diabetes care is mostly limited. This, in turn, increases the risk of both hypo- and hyperglycemia as well as high glycemic variability, which are linked to morbidity, longer hospital stays, and mortality (2-4).

Standard-of-care hospital glucose monitoring relies on finger prick glucose testing, typically 3 to 5 times daily in non-intensive care unit (non-ICU) settings. However, finger prick glucose testing leaves significant data gaps, especially at night, complicating insulin titration and increasing the risk of

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dysglycemia and related complications (5). Continuous glucose monitoring (CGM), which measures glucose levels automatically every 5 minutes, provides a more comprehensive glycemic profile. While CGM has significantly improved outpatient diabetes management, its impact on glycemic and clinical outcomes for inpatients has been limited (6, 7).

The limited effectiveness of CGM so far in hospital settings may be attributed to several factors. These include a shortage of diabetes-trained staff to direct CGM-based insulin titration, the absence of operational protocols for CGM-based insulin titration, and unclear implementation strategies defining how diabetes management is organized and who holds specific responsibilities (8-14). Although international guidelines advocate for protocolized CGM-based insulin titration in an inpatient setting, no consensus protocols or overviews of different protocols exist (13, 15, 16). Lack of such protocols can lead to clinical inertia, where healthcare providers, despite having access to real-time CGM data, may hesitate to make active adjustments in insulin therapy. Moreover, a well-designed titration protocol can be rendered ineffective without effective implementation strategies, which likely limits CGM's potential to improve inpatient glycemic control (17).

This systematic review aimed to assess existing protocols for CGM-based insulin titration and related implementation strategies in non-ICU settings. By examining these protocols and strategies, this review seeks to identify key factors for effective inpatient CGM-management, with the potential of informing the development of standardized approaches to CGM implementation in hospitals. These insights could help optimize insulin titration practices and reduce the risks of hypo- and hyperglycemia, ultimately improving glycemic control and patient outcomes in hospital settings.

Methods and Materials

We performed a systematic literature search on October 15, 2024, without a restriction on publication date. We searched the databases PubMed and Embase in addition to performing a free-text literature search and reference checking in the included literature until January 14, 2025. An information specialist assisted the reviewers in defining the search strings [Supplementary Materials (18)]. Important search words included: "continuous glucose monitoring" OR "CGM" AND "inpatient" OR "hospitalized." Titles and abstracts from the search were imported to Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia), and duplicates were removed. The titles and abstracts were screened for eligibility by reviewer 1 (M.T.O.) and reviewer 2 (A.L.L.) in Covidence. Full-text articles were examined by predefined eligibility criteria by reviewer 1 and reviewer 2. Disagreements were resolved by discussion. If an agreement could not be met, the decision of whether to include an article was resolved by reviewer 3 (J.M.). The corresponding author of the included articles was contacted for additional information in case of missing information. This systematic review is registered with PROSPERO (RD42024596819) and follows the PRISMA 2020 guidelines (19).

Eligibility Criteria

Inclusion criteria were prospective studies or study protocols and a description of CGM-based insulin titration or CGM-based glucose management implementation strategies and non-ICU setting and adult populations. Exclusion criteria were sensor-augmented pump therapy or automated insulin delivery systems.

Results

We identified 9 protocols for inpatient CGM-based insulin titration and implementation strategies (Table 1). A PRISMA flow diagram summarizes reference selection [Supplementary Fig. S1 (18)]. Supplementary Fig. S2 (18) illustrates the relationship between the level of detail and clarity provided in CGM-based insulin titration protocols, the diabetes training levels of the staff implementing these protocols, and the obtained glycemic outcomes in the trials. Supplementary Fig. S2 (18) indicates that effective implementation of CGM in hospitals benefits from having diabetes-trained staff implement a protocol with a medium to high level of guidance on how to titrate insulin based on CGM.

Orders at Admission and Glycemic Targets

Four protocols discontinued oral antidiabetic agents and GLP-1 receptor agonists upon admission, instead managing patients with a weight-based basal-bolus insulin regimen (20). Glycemic targets of 3.9 to 10.0 mmol/L were set in 5 protocols; 1 protocol aimed for 5.6 to 10.0 mmol/L and 1 for 4.4 to 7.2 mmol/L, while 2 protocols aimed to prevent hypoglycemic events.

CGM-based Insulin Titration Protocols

There is a high variation in the detail and clarity provided by the reviewed protocols for managing CGM-based insulin titration published between 2018 and 2025. The protocols offered generic guidance on CGM-based insulin titration not tailored to a specific device. In all protocols, a hybrid approach was employed, consisting of periodic finger prick glucose testing as a supplement to CGM due to accuracy considerations of inpatient CGM (21). None of the protocols took CGM trend arrows into account for insulin titration or glucose management. Six protocols included hypoglycemic and/or hyperglycemic alarms, with thresholds between <3.9 and <5.0 mmol/L and >13.9 and >22.2, respectively. Basal insulin was titrated in 5 of the protocols by increasing/decreasing doses in steps of 10%, 20%, or 30%; 3 protocols based titration on the discretion of investigators/staff, while 1 protocol offered no information. Prandial insulin doses were titrated based on postprandial/preprandial glucose levels in 4 protocols and at the discretion of investigators/staff in 3 protocols, while 2 protocols offered no information. Correctional insulin was titrated according to insulin sensitivity in 5 protocols and at the discretion of investigators/staff in 2 protocols, while 2 protocols offered no information. Only 1 protocol (17) provided guidance on titrating insulin if CGM glucose levels during the same period of titration, eg, during nighttime for basal insulin titration, were at once both below, within, and above the target range.

Implementing CGM-based Insulin Titration Protocols and Diabetes Management

In 8 protocols, the Glucose Telemetry System (22), or modified versions, enabled real-time telemetry of glucose data from the patient to stationary tablets in nursing stations and cloud-based servers, providing the basis for retrospective and real-time insulin titration and glucose management. A

Table 1. CGM-based insulin titration protocols and related implementation strategies for diabetes management in nonintensive care unit settings

Trial characteristics									
Author, year, (trial name), NCT	Hirsch et al, 2025 (23) (TIGHT Study) NCT05135676	Olsen et al, 2025 (17, 24) (DIATEC trial) NCT05803473	Thabit et al 2024 (25)	Spanakis et al, 2022 (14) NCT03877068	Dillmann et al 2022 (28)	Klarskov et al, 2021 (26) (CGM-ISO trial) NCT04430608	Fortmann et al, 2020 (27) NCT03068273	Singh et al, 2020 (22) and piloted in (39) NCT03508934	Spanakis et al 2018 (29)
Participant baseline characteristics	n = 110, RCT HbA1c (SD): 74.0 (25.1) mmol/mol Type 2 diabetes, n (%) = 110 (100%) Male, n: 75 (68%) Insulin treatment prior to admission, yes, n: 79 (72%)	n = 166, RCT HbA1c (SD): 53.6 (13.9) mmol/mol Type 2 diabetes, n (%) = 166 (100%) Male, n: 106 (64%) Insulin treatment prior to admission, yes, n: 34 (21%)	n = 64, RCT HbA1c (SD): 86.0 (21.3) mmol/mol Type 2 diabetes, n: 25 (100%) Male, n: 20 (80%) Insulin treatment prior to admission, yes, n: 25 (100%)	n = 162, RCT HbA1c (SD): 80.3 (27.4) mmol/mol Type 2 diabetes, n: 145 (90%) Male, n: 98 (60%) Insulin treatment prior to admission, yes, n: 129 (80%)	n = 53, single-arm pilot study HbA1c (SD): 72.8 (2.2) mmol/mol Type 2 diabetes, n: 25 (47%) Male, n: 41 (77%) Insulin treatment prior to admission, yes, n: 48 (90%)	n = 64, RCT HbA1c (SD): 61.6 (24.8) mmol/mol Type 2 diabetes, n: 44 (69%) Male, n: 39 (61%) Insulin treatment prior to admission, yes, n: 16 (25%)	n = 110, RCT HbA1c (SD): 80.0 (9.6) mmol/mol Type 2 diabetes, n: 110 (100%) Male, n: 50 (45%) Insulin treatment prior to admission, yes, n: no information	n = 72, RCT HbA1c (SD): 68.4 (19.7) mmol/mol Type 2 diabetes, n: 72 (100%) Male, n: 67 (93.1%) Insulin treatment prior to admission, yes, n: 72 (100%)	n = 5, single-arm pilot study HbA1c (SD): 63.9 (9.8) mmol/mol Type 2 diabetes, n: 5 (100%) Male, n: 4 (80%) Insulin treatment prior to admission, yes, n: 5 (100%)
CGM-based insulin titration protocols									
Hybrid protocol	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing	CGM was supplemented with finger prick glucose testing
Insulin orders	No information	Basal-bolus regimen	Continuing outpatient regimen with correctional insulin	Basal-bolus regimen	Basal-bolus regimen	Correctional insulin only	Basal-bolus regimen	Basal-bolus regimen	Basal-bolus regimen
Basal insulin orders	No information	Given at lunch to allow same-day insulin titration decisions during the morning to take effect • 0.25 U/kg/day • 0.20 U/kg/day in patients aged >75 years of age and/or with an eGFR ≤60 mL/min/1.73 m^2 and/or BMI ≤ 22.5 • Patients treated with insulin prior to admission continued this dose	Participants maintained their regular insulin and received correction insulin before meals	Given once daily, at the same time of the day • 0.20 IU/kg/day when randomization glucose levels were <11.1 mmol/L • 0.25 U/kg/day when randomization glucose levels were >11.1 mmol/L • Patients treated with insulin prior to admission received half of 80% of regular total daily dose as basal insulin	No information	Patients were not prescribed basal insulin	No information	Given once daily, at the same time of the day • 0.20 IU/kg/day when randomization glucose levels were <11.1 mmol/L • 0.25 U/kg/day when randomization glucose levels were >11.1 mmol/L • Patients treated with insulin prior to admission received half of 80% of regular total daily dose as basal insulin • 0.15 IU/kg/day in patients ≥70 years of age or with an admission serum creatinine of ≥2 mg/dL	Given once daily, at the same time of the day • 0.15 IU/kg/day when randomization glucose levels were ≤ 8.3 mmol/L • 0.20 IU/kg/day when randomization glucose levels were > 8.3 mmol/L

(*continued*)

Table 1. Continued

Basal insulin titration	At the discretion of inpatient diabetes teams without a predefined protocol.	Titrated daily by retrospective glucose level from 00:00 hours until breakfast: • <3.0 mmol/L for ≥5% of glucose levels and/or at least 1 hypoglycemic event < 3.0 mmol/L: decrease dose by 30% • 3.0-3.8 mmol/L for ≥5% of glucose levels and/or at least 1 hypoglycemic event 3.0-3.8 mmol/L: decrease dose by 20% • 3.9-5.5 mmol/L for ≥10% of glucose levels: decrease dose by 10% • 5.6-7.8 mmol/L: no change • 7.9-10.0 mmol/L for ≥10% of glucose levels: increase dose by 10% • 10.1-15.0 mmol/L for ≥10% of glucose levels: increase dose by 20% • >15.0 mmol/L for ≥10% of glucose levels: increase dose by 30%	At the discretion of nondiabetes speciality clinical teams without a predefined protocol	Titrated daily based on fasting and predinner glucose levels by the preceding 24 hours: • <2.2 mmol/L: decrease dose by 30%-40% • <3.9 mmol/L: decreased dose by 20% • 3.9-5.5 mmol/L in the absence of hypoglycemia: decrease dose by 10% • 5.6 –7.8 mmol/L in the absence of hypoglycemia the previous day: no change • 7.9-11.1 mmol/L in the absence of hypoglycemia: increase dose by 10% • 11.2-15.6 mmol/L in the absence of hypoglycemia: increase dose by 20% • >15.6 mmol/L in the absence of hypoglycemia the previous day: Increase dose by 30%	Titrated daily by the preceding 24 hours at the discretion of physicians	No information	Titrated daily based on fasting glucose levels by the preceding 24 hours: • < 4.4 mmol/L: reduce dose by 20% • 4.4-5.6 mmol/L: reduce dose by 10% • 5.7-8.2: no change • 8.3-13.9 mmol/L and no glucose levels < 5.6 mmol/L: increase dose by 10% • > 13.9 mmol/L and no glucose levels were < 5.6 mmol/L: increase dose by 20%	Based on fasting finger prick glucose testing.Morning values (did not take CGM data into account): • < 3.3 mmol/L: decrease dose by 20% • 3.3-4.4 mmol/L: decrease dose by 10% • 4.4-7.7 mmol/L: no change • 7.8-9.9 mmol/L: increase dose by 10% • 10.0-13.8 mmol/L: increase dose by 20% • >13.9 mmol/L: increase dose by 30% In cases when hypoglycemia alerts were triggered, insulin doses were decreased	Based on fasting finger prick glucose testing.Morning values (did not take CGM data into account): • < 3.3 mmol/L: decrease dose by 20% • 3.3-4.4 mmol/L: decrease dose by 10% • 4.4-7.7 mmol/L: no change • 7.8-9.9 mmol/L: increase dose by 10% • 10.0-13.8 mmol/L: increase dose by 20% • >13.9 mmol/L: increase dose by 30%
Prandial insulin orders	No information	Initiated when postprandially glucose levels >10.0 mmol/L were observed for 1-2 days. Total prandial insulin dose followed basal insulin orders and were divided equally between the 3 main meals.	Patients maintained their regular insulin regimen	Ordered at admission for all patients Total prandial insulin dose followed basal insulin orders and were divided equally between the 3 main meals.	No information.	Patients were not prescribed prandial insulin	Postprandial glucose levels ≥ 11.1 mmol/L at ≥2 meals or pre/postmeal rise > 3.3 mmol/L: initiate prandial insulin at next meal No information on starting doses	Ordered at admission for all patients Total prandial insulin dose followed basal insulin orders and were divided equally between the 3 main meals	Ordered at admission for all patients Total prandial insulin dose was given in 3 equally divided doses: • 0.15 IU/kg/day when randomization glucose levels ≤ 8.3 mmol/L • 0.20 IU/kg/day when randomization glucose levels were > 8.3 mmol/L

(*continued*)

Table 1. Continued

Prandial insulin titration	At the discretion of inpatient diabetes teams without a predefined protocol	Titrated daily by the day-before nadirs of the between-meal CGM glucose levels according to the ranges of basal insulin (without accounting for the percentage thresholds). If there was no nadir, the preprandial glucose level guided the decision to titrate prandial insulin.	At the discretion of nondiabetes speciality clinical teams without a predefined protocol	Titrated daily based on fasting and predinner glucose levels: • <2.2 mmol/L: decrease dose by 30%-40% • 2.2-3.9 mmol/L: decreased dose by 20% • 3.9-5.5 mmol/L in the absence of hypoglycemia: decrease dose by 10%No protocol for increasing prandial insulin	Doses adapted daily based on the sensor glucose readings from the preceding 24 hours at the discretion of physicians	No information	Postprandial blood glucose ≥ 11.1 mmol/L at ≥2 meals or pre/postmeal rise > 33 mmol/L: increase prandial coverage to the next level (not further described what "next level" is); if at highest level, increase prandial coverage by 25%	The previous day's premeal finger prick glucose testing guided a clinical decision In cases when hypoglycemia alerts were triggered, insulin doses were decreased	No information
Correctional insulin orders	No information	Given at 03:00 hours, preprandial at breakfast, lunch, and dinner, and before bedtime (22:00 hours) or for patients not eating at 03:00 hours, 08:00 hours, 12:00 hours, 17:00 hours, and 22:00 hours and/or hyperglycemic alarms if >2 hours since a previous correctional dose was given	Given if previous correctional doses were given ≥ 4 hours ago. Fasting patients received supplemental insulin every 6 hours based on the "sensitive" scale	If a patient was not able to eat, correctional insulin was given every 6 hours following	No information	Administered according to body weight in predefined scales following the Capital Region of Denmark sliding scale (40)	Given if preprandial glucose levels are >7.8 mmol/L and no insulin in past 3 hours has been given Correctional insulin given if glucose levels at bedtime or 02:00 hours are >11.1 and no insulin in the past 3 hours has been given. No information on scales used	Given via "standard," "resistant," or "sensitive" scales	Given via "standard," "resistant," or "sensitive" scales
Correctional insulin titration	At the discretion of inpatient diabetes teams without a predefined protocol	Adjusted daily according to "usual," "sensitive," or "resistant" insulin scales	Adjusted daily according to "usual," "sensitive," or "resistant" insulin scales	Adjusted daily according to "usual," "sensitive," or "resistant" insulin scales	Adjusted daily based on the sensor glucose readings from the preceding 24 hours at the discretion of physicians	No information	No information	Adjusted daily according to "usual," "sensitive," or "resistant" insulin scales	Adjusted daily according to "usual," "sensitive," or "resistant" insulin scales
Titration when glucose levels are both below, within, and above the target range during a titration period	No information	Handled by thresholds for decision-making and "rule of the lowest" and "rule of the extremes" [see discussion section or the protocol (17)]	No information	No information	No information	No information	No information	Did not take CGM-data into account for insulin titration	Did not take CGM-data into account for insulin titration

(*continued*)

Table 1. Continued

Implementation strategies for CGM-based insulin titration protocols and diabetes management									
Responsible for insulin titration and diabetes management	Inpatient diabetes teams	Inpatient diabetes teams	Nondiabetes speciality clinical teams	Endocrinologists and the research team	Endocrinologists and diabetes nurses	Regular staff,	Diabetes-educated nurses and hospitalists	Diabetes-educated nurse and hospitalists	Diabetes-educated nurse and hospitalists
Staff education on CGM-based insulin titration and diabetes management	No information	Training in the protocol prior to trial start-up with fictive patient cases	Education of up to 45 minutes on hypo-/hyperglycemia alerts	Education on how and when to remove or replace CGM sensors and transmitters and hypoglycemia prevention	No information	No information	No information	Education on hypoglycemia preventive action when a hypoglycemia alert sounded	Nurses were educated daily about the CGM system
Glucose telemetry system	Glucose levels displayed at stationary tablets in inpatient diabetes team stations	Glucose levels displayed at stationary tablets in nursing stations and transportable mobiles when on ward rounds	Glucose levels displayed on study phones in the patient rooms	Glucose levels displayed at stationary tablets in nursing stations	Glucose levels displayed at stationary tablets in nursing stations and in the patient rooms	Glucose levels displayed at stationary tablets in nursing stations	Glucose levels displayed at stationary tablets in nursing stations	Glucose levels displayed at stationary tablets in nursing stations	Glucose levels displayed at stationary tablets in nursing stations
Hypo- and hyperglycemic alarms	Hypoglycemic alarms were set for glucose levels <4.4 mmol/L. Adjustments to the threshold was permitted. Hyperglycemic alarms were set for glucose levels >13.9 mmol/L. Adjustments to the threshold were permitted	Hypoglycemic alarms were set for glucose levels <3.9 mmol/L. Confirmed by finger prick glucose testing. Hyperglycemic alarms were set for glucose levels >13.9 mmol/L for 2 hours to avoid alarm fatigue	Hypoglycemic alarms were set for glucose levels <4.0 mmol/L Hyperglycemic alarms were set for glucose levels >13.0 mmol/L. Adjustments to the threshold were permitted. Alarms were audible also for the patient.	Hypoglycemic alarms were set for glucose levels < 4.4 mmol/L. Hyperglycemic alarms were set for glucose levels were >13.9 mmol/L for 1 hour	Hypoglycemic alarms were set for glucose levels <3.9 mmol/L. Confirmed by finger prick glucose testing Hyperglycemic alarms were set for glucose levels >13.9 mmol/L for 2 hours. Confirmed by finger prick glucose testing.	Hypo- and hyperglycemic alarms were turned off.	Hypoglycemic alarms were set for glucose levels < 5.0 mmol/L. Confirmed by finger prick glucose testing Hyperglycemic alarms were set for glucose levels >13.9 mmol/L during evening/night. Confirmed by finger prick glucose testing.	Hypoglycemic alarms were set for glucose levels < 4.7 mmol/L. Confirmed by finger prick glucose testing Hyperglycemic alarms were set for glucose levels >22.2 mmol/L	Hypoglycemic alarms were set for glucose levels < 4.7 mmol/L. Confirmed by finger prick glucose testing

Abbreviations: BMI, body mass index; CGM, continuous glucose monitoring; eGFR, estimated glomerular filtration rate; HbA1c, hemoglobin A1c; RCT, randomized clinical trial.

reinnovation of the system, allowing mobile transmission of glucose data to transportable phones during ward rounds, was seen in 1 trial (17). In 5 protocols, diabetes specialists—such as inpatient diabetes teams, advanced diabetes nurses, or endocrinologists—were responsible for CGM-based insulin titration. Five protocols were implemented alongside staff training in CGM-based insulin titration and glucose management.

Glycemic and Clinical Results Obtained by the Insulin Titration Protocols and Implementation Strategies

In the TIGHT trial by Hirsch et al (23), CGM did not show an improvement in glucose levels compared to finger prick glucose testing. In the DIATEC trial by Olsen et al (17, 24), the primary endpoint time in range (TIR) (3.9-10.0 mmol/L) increased by 15% points in the CGM group, primarily due to a reduction in time above range. CGM also resulted in decreased time below range, reduced glycemic variability, fewer prolonged hypoglycemic events, lower insulin usage, and a reduction in a composite of in-hospital complications. In the trial by Thabit et al (25), no significant differences were observed in glycemic outcomes or insulin doses. The trial by Spanakis et al (14) found no difference in the primary endpoint of TIR, but post hoc analyses indicated a reduction in recurrent hypoglycemic events. In the trial by Klarskov et al (26), there were no differences in glycemic outcomes or insulin doses. The trial by Fortmann et al (27) showed no difference in the primary endpoint of TIR, but post hoc analyses revealed an increase in the range of 3.9 to 13.9 mmol/L in CGM-monitored patients, with no changes in insulin doses. In the trial by Singh et al (22), fewer hypoglycemic events (<3.9 mmol/L) per patient were observed in the CGM group, with no differences in insulin dosing. The trials by Dillmann et al (28) and Spanakis et al (29) were single-arm studies.

Discussion

In this systematic review, we assessed published protocols for CGM-based insulin titration and related implementation strategies in non-ICU settings. We found substantial variation in the detail and clarity provided by the reviewed protocols and focus on optimizing related implementation strategies. The absence of standardized CGM-based insulin titration protocols may help explain why most randomized clinical trials with CGM have not demonstrated improvement in glycemic outcomes compared to finger prick glucose testing (6, 7). Our findings suggest the need for standardized operational protocols and related implementation strategies to effectively implement CGM in non-ICU settings.

An advantage of CGM compared to finger prick glucose testing is CGM's ability to capture glucose levels both *below*, *within*, and *above* the target range in a single titration period, such as overnight for basal insulin titration. However, this can also complicate decision-making, as healthcare providers may be unsure whether to *decrease*, *maintain*, or *increase* insulin, respectively, and to what extent. Only the recent study by Olsen et al (the DIATEC protocol) (17) addresses this by setting percentage-based thresholds for time spent within a specific glycemic range before action is taken on titrating insulin. Additionally, the DIATEC protocol introduces 2 rules for prandial and basal insulin titration. The "rule of the lowest prioritizes" low glucose levels when both low and high glucose levels occur during a titration period, directing a reduction in basal and/or prandial insulin. The "rule of the extremes" prioritizes the most "extreme" glucose levels during a period of titration, eg, level 2 (>13.9 mmol/L) over level 1 (10.0-13.9 mmol/L) hyperglycemia, as the first range represents a more significant ("extreme") deviation from the target range (17).

Currently, there is no consensus on CGM-specific glycemic targets for inpatients in clinical settings; existing guidelines apply only in research contexts (13). Only finger prick-based glucose targets are available, aiming for approximately 5 to 10 mmol/L (30). In contrast, glycemic CGM targets for outpatients have been established in both clinical (31) and research settings (32). Reaching a consensus on clinical inpatient glycemic metrics and targets may influence how CGM-based insulin titration protocols are designed and implemented. However, recent studies have questioned the appropriateness of universal inpatient glycemic targets, instead suggesting individualized targets based on admission hemoglobin A1c levels (33-35), thus further complicating CGM-based insulin titration protocols and related implementation strategies.

A lack of standardization is also reflected in the alarm settings of the reviewed protocols. Most protocols aligned with recommendations against setting hyperglycemic CGM alarms at near-normal glucose targets to avoid alarm fatigue (21). Instead, hyperglycemic alarms were often employed as safety measures, typically set at >13.9 mmol/L to prevent severe hyperglycemia (14, 17, 25, 27). A greater discrepancy was observed in hypoglycemic alarm settings at either entry level to hypoglycemia <3.9 mmol/L (17, 25, 28) or more precautious settings in 2 trials with settings of <4.7 mmol/L (22) and <5.0 mmol/ (27). Recently, the Joint British Diabetes Societies for Inpatient Care group has recommended relatively high CGM alarm thresholds for both hypo- and hyperglycemia at 4.0 to 5.0 mmol/L and 15.0 to 18.0 mmol/L, respectively, as its main focus is to avoid hypoglycemia in an inpatient setting (36). In a study by Singh et al (22), which enrolled only patients with type 2 diabetes at high risk of hypoglycemia, hypoglycemic events (<3.9 mmol/L and <3.0 mmol/L) were reduced by setting high hypoglycemic alarm thresholds.

Similarly, in a larger trial by Spanakis et al (14), which included both low- and high-risk patients for hypoglycemia, a comparable protocol was used and resulted in a reduction in recurrent hypoglycemic events . However, this may be at the cost of an increased workload for nursing staff, potentially resulting in alarm fatigue. Thabit et al (25) implemented patient-specific thresholds for hyperglycemic alarms while Hirsch et al (23) did too for both hypo- and hyperglycemic alarms. This may effectively individualize diabetes care for low- and high-risk patients and reduce alarm fatigue.

Effectively managing CGM-based insulin titration in inpatient settings may also necessitate the involvement of specialized diabetes teams (16), as regular staff may lack the required training in inpatient diabetes management to implement CGM effectively. In our review, we observed substantial variation in who was responsible for CGM-based insulin titration and glucose management, with some protocols relying on regular staff without diabetes-specific training, while others relied on diabetes teams skilled in CGM. Our review indicates that effective implementation of CGM programs in hospitals benefits from having diabetes-trained staff implement the CGM-based insulin titration protocols [Supplementary Fig. S2 (18)]. However, this approach may be challenging in smaller or nonacademic hospital settings (16). Efficient strategies for training inpatient staff and sustainable implementation strategies for CGM-based insulin titration and glucose management are warranted (16).

Strengths and Limitations

We conducted a rigorous systematic literature search with a clinically and scientifically relevant focus on CGM-based insulin titration protocols and related implementation strategies. Although direct comparisons between protocols and implementation strategies are challenging, our approach offers a wide-ranging view of CGM applications in non-ICU settings. However, by narrowing the scope to non-ICU settings, this review may miss valuable insights from ICU protocols that could inform broader applications of CGM across diverse inpatient settings.

Conclusion

We observed considerable variation in the detail and clarity provided by the reviewed protocols on CGM-based insulin titration and related implementation strategies. This highlights the need for standardized operational protocols to effectively implement CGM in non-ICU settings. Without this, the full potential of CGM to improve inpatient glucose control and outcomes compared to standard-of-care finger prick glucose testing may go unrealized. Protocols that offered advanced guidance on CGM-based insulin titration, when implemented alongside diabetes-trained staff, tended to yield the most significant improvements in glycemic control. Currently, 1 protocol from Olsen et al (17) provides the most comprehensive guidance, presenting a potential model for future standardization efforts.

Future Perspectives

Validation of CGM-based insulin titration protocols and related implementation strategies is necessary outside of strictly controlled research settings. Over half of the available protocols originate from a few research groups based in the United States (14, 22, 23, 29, 37) and Denmark (17, 26), highlighting the need for broader perspectives and innovation in this area. Incorporating trend arrows into insulin dosing algorithms in outpatient settings has been proposed to improve glycemic outcomes (38). None of the protocols reviewed here took CGM trend arrows into account for insulin titration or glucose management. Further research is necessary to explore the development and application of trend arrows in inpatient settings.

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Author Contributions

M.T.O. conceptualized the study in collaboration with A.L.L. and J.K.M. M.T.O. drafted the first version of the manuscript. All authors contributed significantly to the interpretation of study results and structuring of the manuscript and provided critical review of the content of the manuscript.

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Data Availability

All data are published within the manuscript or in the supplementary materials (18) (https://osf.io/c9t4 seconds/).

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