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# Implementation of Continuous Glucose Monitoring in Critical Care: A Scoping Review

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## Abstract

**Purpose of Review** The aim of this review is to identify the implementation approaches, strategies, and outcomes for continuous glucose monitoring (CGM) in the intensive care unit (ICU). Medline and Web of Science databases were searched to report relevant literature published between September 12, 2016 and September 12, 2021. Implementation outcomes and strategies, defined by the Expert Recommendations for Implementing Change (ERIC) project, were extracted.

**Recent Findings** Of the 324 titles reviewed, 16 articles were included in the review. While no studies were identified as implementation research, 14 of 16 identified implementation strategies that aligned with ERIC definitions. Included studies described a multi-disciplinary approach. Clinical outcomes included Mean Absolute Relative Difference (MARD), ranging from 7.5 to 15.3%, and 33–71% reduction in frequency of point-of-care (POC) blood glucose monitoring (BGM) using hybrid protocols.

**Summary** This scoping review provides valuable insight into the process of CGM implementation in the ICU. Continued research should include implementation outcomes to inform widespread utilization.

**Keywords** Continuous glucose monitoring · Inpatient · Hospitalized · Intensive care unit · Implementation science · Glucose monitoring

Continuous glucose monitoring (GCM) has been a mainstay of diabetes care with consistently positive outcomes across diabetes populations managed in ambulatory and home settings. While CGM has been studied in the inpatient setting, it is not approved by the Food and Drug Administration (FDA) for use within the hospital setting. The potential benefit of these systems within the hospital setting, and more specifically in the critical care environment has long been recognized. [1, 2•] Much of the previous inpatient CGM research has been focused primarily on device accuracy rather than people with diabetes (PWD) or clinical use outcomes.

During the COVID-19 pandemic, CGM emerged as an important and innovative approach to manage hyperglycemia while reducing healthcare worker exposure to the virus. In April 2020, the FDA provided emergency use authorization for CGM to be used in hospitals during the pandemic. [3] Since then, there have been increasing reports in the research literature of successful use of CGM for critically ill patients, with demonstrated safety and efficacy primarily among COVID-19 patients. [4•, 5•, 6•, 7–10] The rapid clinical deployment of CGM in the hospital during the COVID-19 pandemic provided a unique opportunity to study integration of these systems into practice. While studies demonstrate a reduction in point of care (POC) glucose monitoring, reasonable accuracy, and consistent safety, few studies specifically reported on the process of implementing CGM into current workflow.

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Use of an implementation science approach allows for investigation into factors that facilitate or inhibit routine uptake of research findings into practice settings. Previous reviews on the use of CGM in the hospital and critical care environment have focused primarily on clinical outcomes. [1, 11] While an understanding of clinical outcomes is essential for future inpatient CGM use, information on implementation specific strategies and outcomes are equally important to advance potential use of CGM for hospitalized patients outside of the urgency of a pandemic.

The field of implementation science provides a taxonomy of implementation strategies and outcomes to continue to advance knowledge about effective approaches for increasing uptake of new treatments or services in practice settings. [12, 13] Implementation strategies are the specific actions taken to increase routine use of a new practice. These strategies have been categorized and defined by the Expert Recommendations for Implementing Change (ERIC) project and include 73 distinct activities that have been extensively studied for their effectiveness of uptake of new practices among end users. [12] Similarly, implementation outcomes reflect measures that evaluate frequency and degree of uptake and routine use of new treatments or services within practice settings. These outcome measures include acceptability, adoption, appropriateness, cost, feasibility, fidelity, penetration, and sustainability [13].

Information on implementation factors must accompany current data on clinical effectiveness of CGM in critical care units. This information is particularly relevant, given that CGM devices currently available are designed for personal use in the ambulatory setting, and not necessarily for inpatient hospital use. Potential considerations when seeking to evaluate use of CGM for hospitalized patients include training of personnel, device set-up, data transmission and sharing, documentation of glucose measures, clinical protocols, and frequency and feasibility of routine use. While some research has evaluated CGM use for non-critically ill patients, little work has evaluated factors impacting routine use in critical care settings due to rapidly changing clinical factors that can cause unpredictable glucose fluctuations and potentially affect the accuracy and safety of interstitial glucose measurements. Additional concerns exist about interfering substances, medications, and devices that could impede CGM accuracy in the inpatient setting. [5•] Moreover, ICU patients are less likely to be able to communicate symptoms of hypoglycemia. In light of the preliminary research that has established clinical efficacy and effectiveness of CGM in critical care settings, additional data are needed to inform actual approaches to routine implementation. Therefore, the purpose of this scoping review was to identify the implementation approaches, strategies, and outcomes for CGM use in critical care hospital settings.

## Methods

A scoping review was conducted to understand the implementation factors associated with CGM use in the critical care environment. A protocol to guide this scoping review was created a priori and components aligned with the Preferred Reporting and Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR).

### Search Strategy

A structured librarian-assisted literature search of peer reviewed articles was performed using electronic databases including Medline and Web of Science. Reference lists of eligible articles and related systematic reviews were reviewed to identify additional articles. The search strategy was based on the following keywords: (Continuous Glucose Monitoring OR CGM) AND (ICU OR Intensive Care Unit OR Critical Care). Filters were used to limit results to reports of primary studies, in the English language, published between September 12, 2016 and September 12, 2021. Covidence systematic review software (www.covidence.org) was used for all stages of the review.

### Inclusion and Exclusion Criteria

Articles were included if they were published between 9/12/2016 and 9/12/2021, were available in English language, and reported findings from original research, implementation science, and/or quality improvement designs published in a peer reviewed journal. Articles also had to report implementation approaches, strategies, and/or outcomes for CGM in pediatric and/or adult critical care settings. Publications were excluded if they were commentaries or editorials, literature reviews, published abstracts/conference proceedings, and if the setting for CGM use was not critical care.

### Data Extraction

Two reviewers (ERF, MM) independently reviewed titles and abstracts of search results to determine initial eligibility based on inclusion and exclusion criteria. The same two reviewers then reviewed the full text articles to verify final inclusion in the review. At each stage of the review process, any discrepancies were resolved through consensus with a third reviewer (KMD).

Extracted data elements were established a-priori in the review protocol. Two reviewers (ERF, MM) independently extracted data from included articles using standardized extraction forms. Extracted data elements included the following elements: title/author, year of publication, aims, country, setting (type of unit), project design, theory/model/framework guiding the project, implementation strategies as outlined by the ERIC group, [12] and implementation outcomes as outlined by Proctor. [13] Specific components of the implementation process were also extracted, which included type of training/education for CGM use, team members involved in use/implementation, protocol identified/used, and CGM data transmission strategy. Lastly, clinical outcomes were extracted and included mean absolute relative difference (MARD) ([absolute value of the reference glucose – CGM glucose]/reference glucose), time in range (70-180 mg/dl), and Clark Error Grid of glucose values. MARD is a commonly used measurement that is easy to calculate and interpret which matches CGM values to a comparison glucose measurement for all patients in a sample.

## Results

The initial search retrieved 443 manuscripts with 324 titles and abstracts reviewed after duplicates were removed (Fig. 1). Of these, 290 were excluded for not meeting initial inclusion criteria resulting in 34 articles that underwent full text review. Articles were eliminated for the follow reasons: no approaches, strategies, and/or outcomes of CGM implementation or sustainability efforts were reported ($n = 12$); because the research in fact did not occur in the critical care

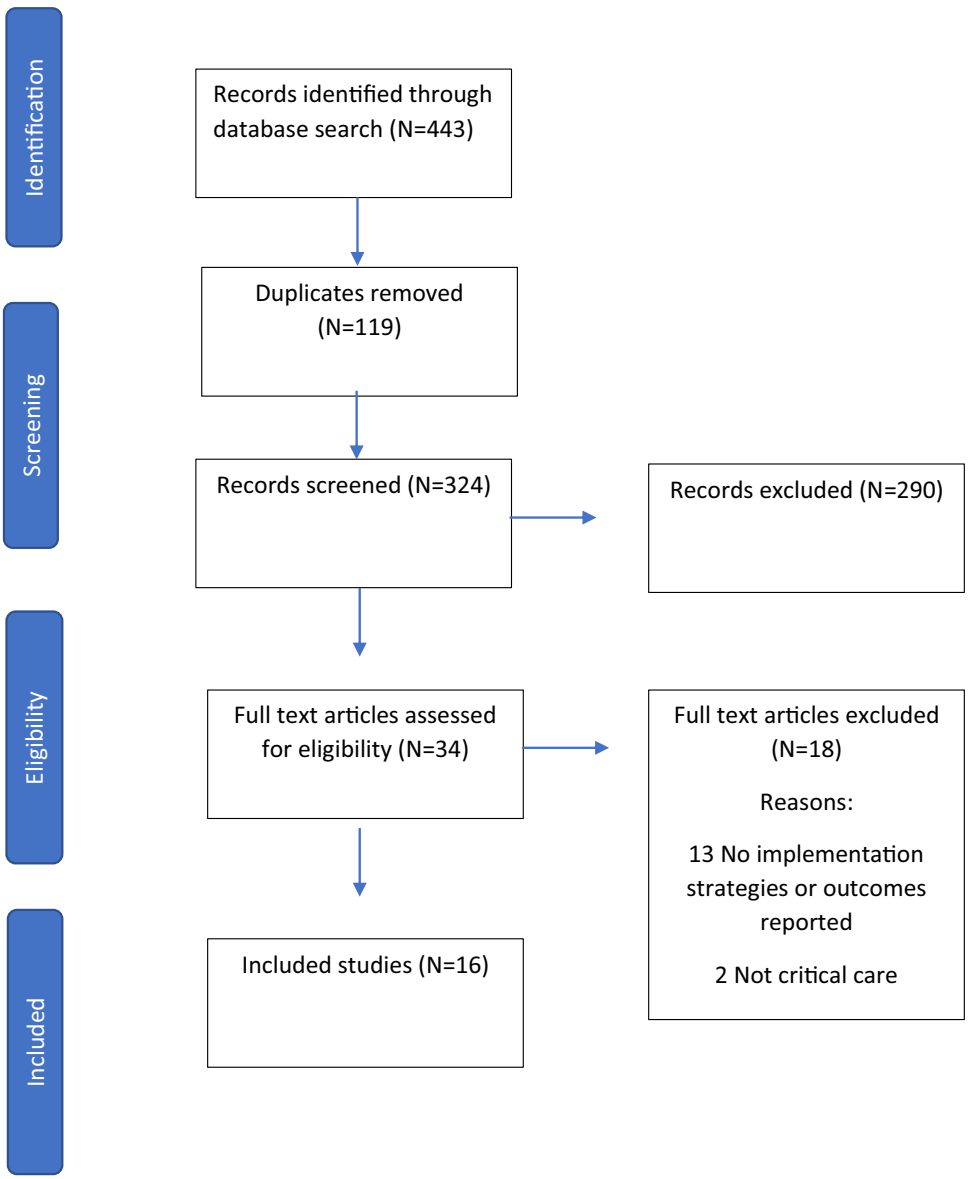


**Fig. 1** PRISMA diagram

setting ($n=2$); studies were not original research, implementation science, and/or QI designs ($n=2$); the study used blinded CGM ($n=1$); and because no outcomes were reported ($n=1$). Sixteen articles were identified to meet inclusion criteria and were included in the review.

## Characteristics of Included Studies

All 16 articles included in the review were original research studies. Included studies represented a wide variety of methodological approaches including: randomized controlled trial ($n=4$) [14, 15, 16, 17], retrospective cohort studies ($n=7$) [4•, 5•, 6•, 8, 10, 18, 19•, 20], prospective cohort studies ($n=3$) [9, 21, 22], quasi-experimental ($n=1$) [23], and qualitative ($n=1$) designs [24]. Eight studies included implementation and clinical data collected during the COVID-19 pandemic [4•, 5•, 6•, 7, 8, 9, 10, 24]. Studies were from 2016 to 2021 and incorporated a total of 1,290 critical care patients. Most studies were conducted in medical intensive care units (MICU) ($n=11$) [4•, 5•, 8, 9, 10, 14, 19•, 21, 24, 25], with other studies conducted in mixed intensive care unit (ICU) environments ($n=2$) [18, 26], in the pediatric ICU (PICU) [27], and in a cardiac ICU ($n=1$) [28]. Half of the studies were conducted in the USA ($n=8$) [4•, 5•, 6•, 7, 8, 10, 15, 20, 24], while others were conducted in Europe ($n=5$) [14, 17, 21, 22, 29], China ($n=1$) [16], Korea ($n=1$)[28], and Columbia ($n=1$). [9] A number of different types of CGM devices were used (Table 1), with the Dexcom G6 CGM system used most frequently. [4•, 5•, 6•, 7, 8, 10, 20] Several studies featured CGM systems that are not commercially available [14–18, 21, 22, 28].

## Implementation Approaches and Strategies

There was wide heterogeneity in implementation approaches across the included studies (Table 2). The majority of studies ($n=10$) reported at least intermittent non-adjunctive CGM use, meaning a confirmatory POC measure was not always required. [4•, 5•, 8, 10, 18, 19•, 24, 25, 26, 28] In 9 studies, the CGM value could be used to titrate insulin. [4•, 5•, 7, 9, 10, 17, 20, 24, 25, 29] Interestingly non-adjunctive use and use for insulin titration were not mutually exclusive. For example, Song 2017 reported that the CGM could be used non-adjunctively but when CGM glucose values met a threshold for insulin adjustment or dosing, then POC glucose was obtained for insulin administration. [28] Not surprisingly, the majority of articles reporting non-adjunctive use and CGM use for insulin dosing were observational studies conducted during the COVID-19 pandemic [4•, 5•, 8, 9, 10, 19•, 20, 24].

In studies describing CGM device set up and sensor insertion most indicated members of the research team performed these tasks. [14, 16–18, 21, 28] However, during the COVID-19 pandemic, device set-up was performed by members of the endocrinology/diabetes team [4•, 10, 24] while sensor insertion and pairing of the CGM was completed by either the endocrinology/diabetes team [6•, 10, 19•] or by members of the nursing team. [4•, 5•, 8, 9, 20, 24] Several studies described CGM glucose monitoring as performed by nurses, [5•, 20, 24]while in others, the endocrinology team[8] or research team[14] primarily performed monitoring activities. Individuals involved in CGM activities and team composition varied across included studies. Nurses were mentioned most often [5 •, 6 •, 8, 9, 10, 15, 16, 17, 18, 19•, 21, 22, 24] with only 2 studies not mentioning their involvement. [14, 28] Not surprisingly, the pre-COVID era studies all mentioned the role of research staff members, [14, 15, 16, 17, 18, 21, 28] whereas 7 of the 8-pandemic era retrospective studies reported endocrinology/diabetes (DM) team involvement [5•, 6•, 8, 9, 10, 19•, 24].

How glucose was visualized or transmitted was described in 10 studies. [5•, 6•, 8, 10, 16, 18, 19•, 24, 28, 30] Glucose was most often transmitted via Bluetooth to receivers or phones, [5•, 6•, 8, 10, 18, 19•, 20, 24] often kept outside the patient room. [5•, 6•, 8, 10, 19•, 20, 24] Davis et. al., created a glucose telemetry system in which CGM glucose data was transmitted to the Dexcom G6 app on phones kept just outside the person's room. The Dexcom Follow app was then used to transmit glucose to the nurses' station where values could be visualized and alarms could be heard in real-time. [5•] Several studies mentioned the use of download visualization software (i.e., Dexcom Clarity, LibreView, CoPilot Health Management System) [5 •, 6•, 9, 18, 24] with a handful specifically mentioning use by the endocrinology/DM teams [5•, 20, 24].

While none of the studies were identified specifically as implementation research, 14 of the 16 identified inpatient implementation strategies that aligned with ERIC definitions (Table 2). Only two studies did not report on any implementation strategies. [14, 28] Across the remaining studies, the frequency of specific implementation strategies used are displayed in Fig. 2. Seventeen different ERIC strategies were described and included in descending order: facilitate relay of clinical data, [4•, 5•, 6•, 8, 9, 10, 16, 17, 19•, 24, 27] educational meetings, [4•, 18, 22, 24] change in physical structure, [6•, 8, 10, 24, 25] distribute materials, [8, 9, 25] identify facilitators and barriers, [21, 24] develop educational materials, [8, 24, 25] assess for readiness,[21, 24] provide clinical supervision, [8, 24] centralize technical assistance, [15, 24] create new clinical teams, [24] conduct ongoing training, [4•] identify and prepare champions, [24] change record systems, [5•] data experts, [5•] data warehousing techniques, [5•] build a coalition, [24] and bedside reference materials [8].

**Table 1** Description of included studies

| Study ID | Country | Primary Aim | Study design | Population description | | Total number of participants | Critical Care Setting |
|---|---|---|---|---|---|---|---|
| DeBlock 2016 | Belgium | Assess clinical performance of two insulin infusion protocols by means of CGM | RCT Pooled Analysis | Adult critical care patients | | 57 | MICU |
| Leopold 2016 | Netherlands | Compare CGM readings with frequently measured arterial blood glucose values | Prospective cohort | | | 12 | Mixed ICU |
| Wollersheim 2016 | Germany | Evaluate reliability, feasibility, nurse acceptance and accuracy of CGM system | Prospective cohort | Adult critical care patients | | 20 | MICU |
| Agus 2017 | United States | Compare effects of tight vs moderate glycemic management in critically ill children on ICU free days | RCT | Pediatric critical care patients | 698 | | PICU |
| Song 2017 | | Determine safety, accuracy, feasibility of CGM | Quasi-experimental | Adult hospitalized patients scheduled for elective cardiac surgery and ICU admission | 24 | | |
| Lu 2018 | China | | RCT | Adult critical care patients | 144 | | MICU |
| Preiser 2018 | Belgium | Compare a strategy of glycemic management guided by CGM with the current standard of care based on intermittent BG readings | RCT | Adults critical care patients | N = 77 | | Mixed ICU |
| Rijkenberg 2018 | Amsterdam | Assess accuracy and reliability of the CGM and patient related factors influencing accuracy and reliability | Retrospective cohort | Adult critical care patients | 155 | | Mixed ICU |

**Table 1** (continued)

| Study ID | Country | Primary Aim | Study design | Population description | Total number of participants | Critical Care Setting |
|---|---|---|---|---|---|---|
| Sadhu 2020 | United States | Evaluate feasibility of using CGM for real-time sensor glucose trends, intermittent point-of-care blood glucose testing to guide insulin therapy | Retrospective cohort | Adult critical care patients with COVID-19 11 | | MICU |
| Agarwal 2021 | United States | Determine performance and accuracy of CGM in critically ill patients during pandemic | Retrospective cohort | Adult critical care patients 11 | | MICU |
| Chow 2021 | United States | Assess clinical utility and accuracy of real time CGM | Retrospective cohort | Adult critical care patients with COVID-19 30 | | MICU |
| Davis 2021 | United States | Report on proof-of-concept experience using hybrid CGM and POC glucose testing protocol linked to computerized decision support system for continuous insulin infusion | Retrospective cohort | Adult critical care patients with COVID-19 9 | | MICU |
| Faulds 2021 | United States | Describe experience implementing a CGM guideline to support IV insulin administration and reduce the need for fingerstick POC glucose monitoring in ICU patients with COVID-19 | Qualitative | MICU nurses, MICU nurse leaders (ie, CNS, nurse manager), NPs who managed consult 9 | | MICU |
| Faulds 2021 | United States | Assess changes in frequency of POC glucose measurement and glycemic outcomes with CGM | Retrospective cohort | Adult critical care patients with COVID-19 19 | | MICU |

**Table 1** (continued)

| Study ID | Country | Primary Aim | Study design | Population description | Total number of participants | Critical Care Setting |
|---|---|---|---|---|---|---|
| Gomez 2021 | Columbia | Examine glycemic outcomes metrics using flash glucose monitoring including time in range [TIR], time above [TAR] and below [TBR] range | Prospective cohort | Adult hospitalized patients with COVID 19 | 66 (n = 13 ICU) | Medical unit, MICU |
| Longo 2021 | United States | Investigate use and accuracy of CGM in the inpatient setting | Retrospective cohort | Adult hospitalized patients with COVID-19 | 28 (n = 10 ICU) | Medical unit, MICU |

*RCT* randomized control trial; *MICU* medical intensive care unit; *PICU* pediatric intensive care unit; *BG* blood glucose; *CNS* clinical nurse specialist; *NP* nurse practitioner

## Clinical and Implementation Outcomes

Several different clinical and implementation outcomes were reported across the various studies, which were not consistent or mutually exclusive. (Table 3). Most studies reported both clinical and implementation outcomes (10/16, 63%), [4•, 5•, 6•, 8, 15, 16, 20, 21, 22, 26, 28] while one study reported only implementation outcomes (1/16, 6%), [24] and some reported only clinical outcomes (5/16, 31%). [7, 9, 10, 14, 18] Clinical outcomes are synthesized in Fig. 2. MARD was reported in 7 studies and ranged from 7.5 to 15.3%. [4•, 8, 10, 19•, 21, 22, 29] MARD source varied between studies including arterial,[29] a combination of capillary, venous, or arterial[4•, 8, 10, 21, 22] or not specified. [19•] Seven studies reported Clark Error Grid analysis with results showing > 75% of values in zone A (within 20% of reference glucose value). [5•, 6•, 10, 19•, 21, 22, 28] Time in range (70–180 mg/dl), was reported in 5 studies and fell within a wide range of 46.1% and 75.7%. [4•, 5•, 17, 19•, 30] In one study, time in range was reported as 144-180 mg/dl to better align with American Diabetes Association in hospital recommendations for critical care [31] and found significantly higher time between 144 and 180 mg/dl for participants on CGM vs. standard POC blood glucose monitoring (BGM) ((51.5% vs 29.0%). [16] One study reported similar accuracy (60.1% vs. 57%, in zone A of the Clark Error Grid, respectively) between CGM placement sites (thigh vs. abdomen). [28] Frequency of POC BGM was reported most often in COVID-19 related studies that used a hybrid protocol combining reduced frequency POC BGM and intermittent non-adjunctive CGM. Reduction in POC was dependent on hybrid protocol design, for which studies reported a 33–71% reduction in POCBGM [4•, 5•, 6•, 8, 10, 19•, 20].

Implementation outcomes included various measures of components outlined by Proctor in the field of implementation science (acceptability, adoption, appropriateness, cost, feasibility, fidelity, penetration, sustainability). [13] Across the studies included in this review, feasibility was reported most often (6), along with fidelity (2), acceptability (2), and appropriateness (1). Feasibility was defined as the ability to successfully implement CGM (e.g., training program development, sustained use, successful data capture), while fidelity was the degree to which CGM was implemented as prescribed (e.g., protocol adherence, consistent application) [13].

Acceptability was defined as the perception among end users that CGM was satisfactory for routine use, and appropriateness referred to the perceived fit or relevance of CGM for the population and setting among end users. [13] Using these established definitions, two studies reported non-adherence to the protocol in which nurses continued to check POC glucose after CGM had been validated for intermittent non-adjunctive use. [4•, 8] Interestingly, both

**Table 2** Continuous glucose monitoring implementation

| Study ID | CGM Device | Protocol | Team/Actor | Initiation/Use | Training | Implementation Strategies |
|---|---|---|---|---|---|---|
| DeBlock 2016 | Microdialysis based CGM (GlucoDay) | CGM used only as prompt to collect additional POC sample if rate of change was > 25 mg/dl in 30 min. Leuven or Yale protocol used for insulin titration; Adjunctive use of CGM and CGM not used for insulin titration | Research staff | Study team members for prior RCTs performed all CGM related procedures and management | Not described | Not described |
| Leopold 2016 | Microdialysis based CGM (EIRUS) | Protocol evaluating point and trend accuracy/reliability of microdialysis-based CGM device; Adjunctive use of CGM and CGM not used for insulin titration | Nurses | ICU nurses followed protocol, measured CGM and POC BG, adjusted insulin dosage | Multiple group trainings with nurses; just-in-time training with nurse on patient inclusion in study | Educational meetings |
| Wollersheim 2016 | Medtronic Sentrino | Protocol included 2 calibrations after sensor insertion. Target BG 80-149 mg/dl. Nurses took arterial catheter or peripheral venous catheter samples q2-4 h and adjusted IV insulin per local protocol; Adjunctive use of CGM and CGM not used for insulin titration | Study team, nurses | Study team set up devices and inserted sensor into upper leg; ICU nurses monitored and performed BG measurements; Sensors required initial calibration followed by two further calibrations at 1 and 2 h and ongoing calibrations Q8 hr; calibrations performed by study staff | Nurses instructed on glucose trends and insulin titration per protocol | Assess for readiness and identify barriers and facilitators, facilitate relay of clinical data to providers |
| Agus 2017 | Dexcom G4 | CGM and computer-guided insulin adjustment used to minimize hypoglycemia and determine timing of BG measurements, insulin dosing. Adjunctive use of CGM and CGM not used for insulin titration | Study staff; ICU nurses performed insulin dosing titrations | Evaluated two ranges of glycemic control per computerized protocols | Not described | Centralize technical assistance, facilitate relay of clinical data to providers |
| Song 2017 | Medtronic Guardian (commercially available) | Not fully described; after calibrations performed, all sensor values compared with arterial values; Non-adjunctive use of CGM but CGM was not used for insulin titration | Study staff, anesthesia personnel | Two sensors inserted in OR after anesthesia induction, one in abdomen, one in thigh; after 5 min calibration period sensor connected to transmitters; after 2 h initialization period, arterial BG value entered for calibration; | Not described | Not described |
| Lu 2018 | DGMS San MediTech | Protocol followed to keep BG 144-180 mg/dl; CGM group compared to control group; Non-adjunctive use of CGM and CGM used for insulin titration in experimental group | Study team; ICU nurses | Nurses inserted sensor into right chest wall, connected to monitor, and calibrated during a 3-h initiation period; CGM readings evaluated q2hrs to adjust insulin. Target alarms set, frequency of measurement could increase to q15min for out of range values until back within target ranges | Nurses trained prior to study initiation on how to connect, setup, and calibrate CGM system;; study team reviewed insulin titration to ensure protocol compliance and asked nurses reasons for protocol deviations | Develop educational materials, distribute educational materials, facilitate relay of clinical data to providers, change physical structure and equipment |

**Table 2** (continued)

| Study ID | CGM Device | Protocol | Team/Actor | Initiation/Use | Training | Implementation Strategies |
|---|---|---|---|---|---|---|
| Preiser 2018 | Edwards Lifesciences Gluco-Clear | Glucose management protocol followed with target range 90–150, rate adjusted on repeated BG values via blood gas analyzer 4–6 times daily. CGM values manually entered into bedside computer q30-60 min to adjust insulin rates. Additional reference blood samples taken if significant decrease in 2 consecutive measurements, alarm triggers sound, any doubt of CGM value. If difference between CGM and reference > 20 mg/dl, then reference BG used for insulin titration; Non-adjunctive use of CGM and CGM used for insulin titration | Study team, ICU nurses | Peripheral venous catheter inserted in a forearm vein for up to 3 days;<br>Unblinded CGM had major alarms at 40 mg/dl and 220 mg/dL and minor alarms at 70 mg/dl and 180 mg/dL. The blinded CGM only had alarms triggered by technical issues, such as open door, inability to measure BG, near-expired cartridge, flushing problem | training sessions delivered to staff nurses | Facilitate relay of clinical data to providers |
| Rijkenberg 2018 | Abbott FreeStyle Navigator | Glycemic management performed with computerized algorithm. Data display every minute via transmitter and receiver. Non-adjunctive use of CGM and CGM was used for insulin titration | Study team, ICU nurses | Trained bedside nurse or research assistant inserted CGM sensor into the abdomen or upper arm and calibrated the device with arterial blood samples; Calibrations performed 5 times (at 1, 2, 8–10, 24–32 and 72–80 h); CGM alarmed for scheduled or additional calibration; CGM glucose transmitted to remote receiver; data downloaded to dedicated computer using CoPilot Health Management System | ICU nurses trained in the study procedures and insertion of CGM; research assistant available to respond to questions; study user manuals on procedures and CGM device were available at the bedside and ICU intranet; Study procedures and instructions integrated in clinical information system | Facilitate relay of clinical data to providers, conduct educational meetings |
| Sadhu 2020 | Dexcom G6, Medtronic Gardian (both commercially available) | Insulin infusion protocol followed. For first 24 h, CGM documented but not used for clinical management. POC obtained per usual practice. Target BG range 100-200 mg/dL with POC BG testing q2hrs. Testing changed to q4hrs if within range; Non-adjunctive use of CGM but CGM was not used for insulin titration | Endocrinology/ Diabetes team, ICU nurses | Individual patient accounts were created; ICU nurse inserted sensor in upper arm or abdomen with endocrinology monitoring at bedside; CGM data transmitted to either iPad or iPhone outside the patient room; Log sheet provided to document hourly CGM or POC BG | nurse trained by manufacturer's instructions; nurses trained on application features, alarms/alerts, calibrations; reference materials at bedside | Facilitate relay of clinical data to providers, develop educational materials, distribute educational materials, bedside reference materials, provide clinical supervision, change physical structure and equipment |

**Table 2** (continued)

| Study ID | CGM Device | Protocol | Team/Actor | Initiation/Use | Training | Implementation Strategies |
|---|---|---|---|---|---|---|
| Agarwal 2021 | Dexcom G6 (commercially available) | Protocol included 20% of POC hybrid, daily POC testing for validation, alarm triggers, parameters for confirmatory POC testing. Non-adjunctive use of CGM and CGM used for insulin titration | Endocrinology/ DM team including DM NP/CNS; staff nurses | DM team identified candidates and performed surveilled for validation; NP or CNS placed sensors in patient abdomen or upper arm. CGM receivers placed outside door. POC testing by nurses; Establish early feasibility and accuracy of CGM in MICU during COVID-19 pandemic | Not described | Facilitate relay of clinical data to providers |
| Chow 2021 | Dexcom G6 (commercially available) | CGM blinded for first 24 h then validated within 20% of POC value via arterial line. If within 20% of values, then CGM used to adjust insulin | Diabetes/Endocrinology team; staff nurses | DM team placed sensor and transmitter; Receiver hung outside the patient's room in view of the ICU nurse; nurses recognize/respond to alerts; nurses uploaded CGM receivers to Dexcom Clarity at the end of use; Assessment of clinical utility and accuracy of real time CGM | Nurses trained to recognize and respond to alerts and problematic glycemic patterns. Nurses trained to upload CGM data to Dexcom Clarity after use complete | Change physical structure and equipment, facilitate relay of clinical data to providers |
| Davis 2021 | Dexcom G6 (commercially available) | Hybrid CGM + POC glucose testing protocol used. CGM sensor validation if there was < 20% variance with POC for 2 consecutive hrs. Continued validation q6hrs. POC values used for BG < 100 mg/dL. Non-adjunctive use of CGM and CGM used for insulin titration | Pharmacologists, endocrinologists, ICU nurses | Dexcom G6 App for transmission of sensor data to a smartphone (with internet connectivity) placed outside patient's room. Follow App for remote monitoring and glucose telemetry at nursing station. Clarity Dashboard for population-based data monitoring | Endocrinologist trained critical care staff, Educational materials shared from other health system | Data warehousing techniques, data experts, facilitate relay of clinical data to providers, change record systems |
| Faulds 2021 | Dexcom G6 (commercially available) | Hybrid CGM + POC protocol used; CGM used non-adjunctively and CGM for insulin titration | Multidisciplinary team; Inpatient DM consult service, ICU nurses, critical care medicine, critical care pharmacy | MICU nurse leaders performed device insertion and transmitter pairing. Sensor placed in upper arm. Sensors validated and worn up to 10 days; ICU nurses monitored POC/CGM values and adjusted insulin | Education/training provided by inpatient DM consult service to ICU nurse leaders | Assess for readiness and identify facilitators/barriers, build a coalition, centralize technical assistance, change physical structure and equipment, conduct educational meetings, create new clinical teams, develop educational materials, facilitate relay of clinical data to providers, identify and prepare champions, provide clinical supervision |

**Table 2** (continued)

| Study ID | CGM Device | Protocol | Team/Actor | Initiation/Use | Training | Implementation Strategies |
|---|---|---|---|---|---|---|
| Faulds 2021 | Dexcom G6 (commercially available) | Hybrid POC + BG protocol used. Initial validation done with paired POC readings within 5 min. After 2 consecutive validation pairs of BG < 20% of POC 1 h apart, CGM values used for insulin titration. If BG < 100, POC was used. ICU nurses monitored and measured BG values, adjusted insulin | Multidisciplinary team of inpatient diabetes consult service, ICU nurses | Dummy Dexcom Clarity accounts created, transmitter and sensor serial numbers scanned into G6 App prior to use; used combination of Android phones and receivers; MICU nurse leaders performed CGM insertion and pairing; sensor placed patient's upper lateral arm; Phones/receivers kept just outside patient room, typically 10–15 ft from transmitter and separated by a glass paneled door; DM service could access Clarity to visualize/assess glucose | Team members participated in a 1-h manufacturer training; two educational documents (focused insertion, initiation and protocol) stored at the bedside; DM team members provided single session training with MICU nurse leaders; MICU nurse leaders provided just-in-time training to staff nurse focused on CGM validation and use | Conduct educational meetings, conduct ongoing training, facilitate relay of clinical data to providers |
| Gomez 2021 | Freestyle Libre flash glucose monitoring (commercially available) | Three CGM scans performed daily and institutional protocol followed for target BG. Non-adjunctive use of CGM and CGM was used for insulin titration | ICU nurses | Patient and nurses performed scans; asked perform at least 3 scans/day; CGM data downloaded using the Libreview platform | Education provided to patients and nursing staff | Distribute educational materials, facilitate relay of clinical data to providers |
| Longo 2021 | Dexcom G6 (commercially available) | Reviewed pilot data then derived protocol in concert with nursing; POC glucose testing done for first 24 h, if within range then CGM used for monitoring. Daily lab glucose and evening POC glucose performed. If difference between reference and CGM was > 35, then accuracy reviewed; Non-adjunctive use of CGM and CGM was used for insulin titration | Multidisciplinary team of endocrinology, internal medicine and critical care physicians and advanced practice providers, nurses | Member of endocrinology team assessed patient for eligibility and placed sensor in upper arm; Android phones displayed CGM values outside of patient room | Not discussed | Change physical structure and equipment, facilitate relay of clinical data to providers |

*CGM* continuous glucose monitor; *RCT* randomized control trial; *ICU* intensive care unit; *POC* point-of-care; *BG* blood glucose; *DM* diabetes mellitus; *CNS* clinical nurse specialist; *NP* nurse practitioner; *MICU* medical intensive care unit

**Fig. 2** Synthesis of CGM outcomes

| | Leopold 2016 | Wollersheim 2016 | Song 2017 | Lu 2018 | Preiser 2018 | Rijkenberg 2018 | Sadhu 2020 | Agarwal 2021 | Chow 2021 | Davis 2021 | Faulds 2021 | Gomez 2021 | Longo 2021 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Time in Range >50%** | | | | ✓ | | | | | | ✓ | ✓ | ✓ | |
| **Mean Absolute Relative Difference <15%** | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ |
| **Frequency of POC Testing** | | | | | | | ↓ | ↓ | ↓ | ↓ | ↓ | | |
| **Accuracy: >75% values in zone A** | ✓ | ✓ | ✓ | | | | ✓ | ✓ | ✓ | ✓ | | | |
| **Glucose Variability** | | | | ↓ | | | | | | | | | |
| **Incidence/duration of Hypoglycemia** | | | | ↓ | ↓ | | | | | | | | |

studies reported that nursing adherence improved over time. [4•, 8] Only three studies examined nursing acceptance of CGM systems within the ICU with two studies conducted during the COVID-19 pandemic showing positive sentiment. [6•, 21, 24] In a qualitative focus group, nurses reported perceived accuracy was high and there was a strong sense of nursing ownership over the technology. [24] Interestingly, while nurses felt time spent obtaining glucose information was reduced, they actually reported time monitoring glucose increased because CGM values were continuously available. [24] Chow et. al. reported survey data showing 63% of nurses felt CGM use improved clinical care and 49% indicated CGM reduced use of personal protective equipment (PPE). [6•] In an earlier study by Wollersheim et. al., 79.1% of nurses rated CGM as non-beneficial. [21] It is important to note that the study used older technology that required frequent calibration and additionally, the study reported a high rate of premature removal of sensors (21 out of 31) with 71% of early removals attributed to sensor related issues [21].

## Discussion

This scoping review is the first to synthesize existing literature on factors influencing implementation of CGM in the critical care setting. Examination of factors influencing use of the systems within the critical care infrastructure will help facilitate safe and effective use of CGM. This information is critically important during a pandemic as health systems work to rapidly deploy CGM, but even more importantly, this information will establish a blueprint for successful deployment of CGM into routine critical care settings.

The inclusion of both clinical and implementation outcomes and strategies within research protocols is essential for the evaluation of CGM in the critical care environment. While an examination of clinical outcomes such as sensor accuracy and glycemic management are of undoubted importance, if we are to move toward routine use of CGM in the hospital, an examination of implementation factors such as fidelity to treatment guidelines and feasibility are also critical. We can illustrate this by examining current standard of care POC glucose monitoring in the inpatient setting. The accuracy of inpatient POC meters, particularly those FDA approved for critical care use, is excellent with 97.2% of the Novo StatStrip's values lying in A zone and 2.8% in the B zone of the Clark Error Grid. [32] However, intensive inpatient POC blood glucose monitoring is a time-consuming task, often resulting in insufficient frequency and inadequate timing of BGMing [32].

The communication of implementation approaches and strategies are essential as health systems begin to consider what supports (e.g., training, team) are needed for safe and effective future use of these systems within the hospital. Specifically, clinical outcomes should be evaluated and reported in the context of implementation strategies and approaches. For instance, two observational COVID-19 era studies reported vastly differed in time in range (46.1% vs. 72.5%, respectively) as their clinical outcomes. [7, 30] These outcomes can be heavily influenced by the protocol via which CGM was deployed, but also by team composition, training, and ongoing management and monitoring of values. Reductions in POC BGMare also difficult to evaluate without contextual factors, such as full institutional protocol description, to understand whether this was an expected reduction in frequency of POCBGM [7].

Several studies included in this review did report on approaches to implementation, which included team composition, delineation of roles, and protocols. Overall, team composition and delineation of CGM tasks and responsibilities varied significantly across studies. Previous publications have discussed the importance of hospitalendocrinology and diabetes teams in the future implementation of hospital CGM. [2•, 33] All but one pandemic era study mentioned endocrinology and diabetes team involvement which is an important consideration for health systems and hospitals that do not have dedicated inpatient diabetes teams.

Prior to this review, team member roles and responsibilities had not been synthesized. Given that glucose monitoring with

**Table 3** Summary of CGM outcomes

| Study ID | CGM Device Type | Primary Clinical Outcomes | Implementation Outcomes | Other Outcomes |
|---|---|---|---|---|
| DeBlock 2016 | Microdialysis based CGM (GlucoDay) | CGM only used to evaluate two IV insulin protocols; no CGM specific outcomes reported | NA | NA |
| Leopold 2016 | Microdialysis based CGM (EIRUS) | Point accuracy: 93.6% paired values in zone A (Bland–Altman); 93.6% of values > 75 mg/DL within 20% of reference value; MARD 7.5%. Trend accuracy: 96.4% of paired values in zone A (Clarke error grid) | Feasibility: Start-up time was 58 min [56–67; 48–112.8] (median [IQR; total range]) | Sensor failed to calibrate in 3 patients; 2 patients had CVC malfunction |
| Wollersheim 2016 | Medtronic Sentrino CGM | MARD 15.3%. Accuracy: 76.9% within zone A (Clarke error grid). No reduction in dysglycemic events during CGM. CGM identified more hyperglycemic events when compared to intermittent monitoring | Acceptability: 79.1% of nursing staff rated device as not beneficial | 21/31 sensors removed prematurely |
| Agus 2017 | Dexcom G4 CGM | CGM used in comparing effects of tight vs moderate glycemic management in critically ill children on ICU free days. No CGM specific clinical outcomes reported | Fidelity: High adherence to insulin dosing recommendations based on CGM and computerized protocol in the lower (97.3%) and higher (99.2%) target groups | Trial stopped early due for low benefit/possible harm |
| Song 2017 | Medtronic Guardian REAL time CGMS | Statistically significant differences in thigh vs abdomen measurements in OR setting only. Correlation between thigh/abdomen values vs arterial values was 0.67, 0.60. 60.1% of thigh values and 57% of abdomen values were within zone A (Clark error grid) | Feasibility: Successful measurements higher in ICU (73.2%) vs OR (66.0%) | 3 cases of abdominal sensor loss. Other sensors well tolerated without any occurrence of adverse skin reactions, infections, or bleeding |
| Lu 2018 | DGMS San MediTech CGMS system | TIR (144-180 mg/dl) higher in CGM group vs conventional POC testing group (51.5% vs 29.0%). Glucose variability improved with CGM. Proportion of hypoglycemia similar between groups. Duration of hypoglycemia lower in CGM group (15 vs 28 min) | Fidelity: Adherence similar between groups (85.4% vs 85%) | NA |
| Preiser 2018 | Edwards Lifesciences GlucoClear CGMS | TIR similar between CGM and intermittent monitoring groups. Incidence of hypoglycemia was lower in CGM group (20.5% vs 39.5%). TBR (< 70 mg/dL) lower in CGM group (0.4% vs 1.6%) | Feasibility: Average down time was 6.4% in CGM vs intermittent monitoring group 8.3% | NA |

**Table 3** (continued)

| Study ID | CGM Device Type | Primary Clinical Outcomes | Implementation Outcomes | Other Outcomes |
|---|---|---|---|---|
| Rijkenberg 2018 | Abbott FreeStyle Navigator CGM | MARD between CGM and arterial values was 13.3%. 57.3% of CGM values met ISO system accuracy and 47% of CGM values were within 12.5% of reference values | NA | 5 device failures due to user error. Two device failures due to sensor failures. Median display per sensor 69.7 h, which accounted for 94% of total CGM monitoring time |
| Sadhu 2020 | Dexcom G6 CGM, Medtronic Connect CGM | Both systems feasible and reliable. Dexcom MARD was 11.1% with 98% of readings within zones A and B of Bland–Altman Grid analysis; Medtronic MARD was 13.1% with 100% of readings within zones A and B. Overall 33.11% reduction in POC BG testing | Acceptability: High nurse acceptance rate for both systems. Non-uniformity with nurse compliance for excess POC testing, which decreased by Day 2. Sensor insertion done within 5 min, set up display within 10 min | NA |
| Agarwal 2021 | Dexcom G6 CGM | Frequency of POC decreased by 60% with routine CGM use. Mean number of hours of potential POC testing was 72.1 h, which decreased to 28 h with CGM use. Median number of days on CGM was 9.0. Mean TIR (70-180 mg/dl) was 46.1%. MARD was 12.5%, with 77% of values within zone. 98% of sensors had clinically acceptable correlation | NA | NA |
| Chow 2021 | Dexcom G6 CGM | High concordance of CGM values with arterial reference values (within 20%) in all but 2 patients. CGM enabled reduction in glucose from 440 mg/dL to 200-300 mg/dL within first 12 h and sustained decreases to 100-200 mg/dL within 7 days. Reduction in daily POC testing in 50% of patients | Appropriateness: 56% of nurses reported interactions with CGM, 63% reported use improved clinical care; 49% indicated CGM reduced use of PPE | NA |
| Davis 2021 | Dexcom G6 CGM | 75.7% of CGM values were within 20% of POC reference values. Mean TIR (70-180 mg/dl) was 71.4%. CGM reduced POC tests to $8.24 \pm 3.06$, resulting in 63% reduction | Feasibility: Reported reductions in numbers of bedside nursing encounters and PPE use | NA |

**Table 3** (continued)

| Study ID | CGM Device Type | Primary Clinical Outcomes | Implementation Outcomes | Other Outcomes |
|---|---|---|---|---|
| Faulds 2021 | Dexcom G6 CGM | NA | Feasibility: CGM sensor insertion process was uncomplicated. Nurse perceived device accuracy and utility high. Barriers centered on contextual issues, such as limitations in physical environment, device set up, hospital firewalls, need for training, and CGM documentation. Pairing typically occurred in less than 1 min. Rarely, a transmitter required several attempts to pair. At the time of this publication, all CGM systems initiated were successfully validated; | 4 qualitative themes: accuracy, nursing ownership, workflow, barriers/suggestions |
| Faulds 2021 | Dexcom G6 CGM | On day 1, 41% of all IV insulin titrations were performed non-adjunctively using CGM glucose; by day 2, non-adjunctive titration using CGM had risen to 63%. TIR (70-180 mg/dl) was 64% on day 1 and 72% on days 2–7. Time < 70 mg/dL was 1.5% on day 1 and < 1% on days 2–7. Overall there was a 71% decrease in POC testing with CGM use. MARD was 13.9% | Feasibility: Mean duration of 1st sensor was 191 h (8 days) | Sensor was replaced/removed before 10 days because of accidental dislodgement (n = 1), placement error (n = 1), accuracy concern (n = 1), hospital discharge or patient expiration (n = 3) |
| Gomez 2021 | Intermittent Freestyle Libre flash glucose monitoring | TIR (70-180 mg/dl) using CGM was 72.5%, time above range 18%, time below range 4% During treatment, coefficient of variation was 30% | Average device readings per patientwas 5,7 time per day | NA |
| Longo 2021 | Dexcom G6 CGM | MARD was 13.2%. 93% of values within 15% ISO accuracy standards vs 87.6% of POC pairs | NA | NA |

*MARD* mean absolute relative difference; *TRI* time in range (70–180 mg/dl; *CVC* central venous catheter; *TBR* time below range

traditional POC BGM is currently performed by nurses or by individuals under nursing supervision (e.g., nursing assistants), an understanding of nursing role and responsibilities in the implementation of CGM in the critical care environment is essential. All but two studies mentioned at least some aspect of the nursing role in CGM use. [4•, 5•, 6•, 8, 9, 10, 15, 17, 19•, 20, 21, 22, 24, 25, 29] These pandemic-era studies provided valuable data on how nurses use CGM in clinical practice and nursing scope surrounding the technology. In addition to nursing team members, pandemic-era approaches also involved other individuals within a multi-disciplinary team and roles among members. Teams included members of the diabetes or endocrinology service, [4•, 5•, 6•, 8, 10, 19•, 20, 24] critical care medicine, [10, 24] and pharmacy. [5•, 20, 24] While these studies reported on team composition, less information was supplied on actual role delineation among team members. For example, few studies explored or reported on the fact that the ICU nurse needs to use CGM data in real time to dose insulin and prevent and treat hyperglycemia and hypoglycemia, whereas prescribers on care teams may be more likely to use CGM data retrospectively to make treatment decisions and change insulin orders. Future research is needed to better explore this concept of role delineation in CGM use within critical care settings.

In addition to team composition and roles for CGM use, several studies reported on protocols which inform the overall approach to scale this type of monitoring for use in critical care settings. Hybrid protocols were widely described in COVID-19 pandemic-era studies and offered a means of reducing the frequency of POC measures while still requiring intermittent POC BGMfor confirmation of CGM accuracy or when glucose exceeded certain thresholds or other clinical criteria were met. [4•, 5•, 6•, 8, 10, 19•, 20] All 6 studies using hybrid protocols required more stringent validation measures on sensor insertion [4•, 5•, 6•, 8, 10, 19•, 20] and 3 studies did not use the CGM clinically for the first 24 h. [6•, 8, 10] Previous outpatient CGM research has shown somewhat lower accuracy during the first 12–24 h of CGM use, [34]supporting the rationale for increased POC BGM and validation on initial CGM insertion. Of the 6 studies describing hybrid protocol use, 4 used 20% as a threshold for nonadjunctive use. [4•, 5•, 6•, 7, 20] with one study requiring the difference in values to be < 35 mg/dl [10] Another study allowed intermittent non-adjunctive use if the CGM glucose level fell between 100 and 200 mg/dl. [8] Ongoing POC BGM and validation was most often performed every 6 h, [4•, 5•, 20] while two studies required only daily POC, [10, 19•], and one study fluctuated between Q2 and Q4 hour POC glucose monitoring [8]. The data from this review shows safe and effective intermittent non-adjunctive use of CGM within the constraints of a hybrid protocol. Specifically, investigations into CGM impact on workflow among nurses is of particular interest, given preliminary work demonstrating reduced care burden, coupled with current estimates of an unprecedented nursing shortage [35].

Another consideration when evaluating implementation approaches is the type of CGM sensor. Many of the studies included in this review feature older technologies which are either no longer commercially available, [15, 18, 28] or were previously under development for the inpatient environment but not commercially available. [14, 16, 17, 21, 22] The effect of technology specification on clinical outcomes such as accuracy is well understood and studied, however technology design has a significant impact on implementation. For instance, Wollersheim et. al., reported poor acceptance and use of CGM, which they attributed to application and performance of the CGM system. In the study, 21 out of 31 sensors were removed prematurely, data transmission was poor, and the system under investigation required every 8 h calibrations for routine use. Not surprisingly, nearly 80% of nurses found the system to be unhelpful [21].

When examining implementation strategies, several were reported consistently across the studies included in this review. All studies utilized facilitated relay of clinical data, while 6 studies included use of educational meetings, and 5 reported use of changes to clinical structures. Facilitating relay of clinical data refers to providing real-time data to clinicians about key process/outcomes using various channels of communication to promote use of the targeted innovation. [12] Clearly this component is critical for increasing routine use of CGM as clinical providers need to be able to easily access readings in real time to inform treatment interventions. Relay of this clinical data for CGM was done by a variety of measures, including use of apps and handheld devices, receivers placed just outside the person's room for ease of visualization, and centralized dashboards. Conducting educational meetings was another implementation strategy commonly used. This strategy refers to holding meetings with different stakeholder groups to teach them about the clinical innovation. [12] Education would be a required component for implementation of any new technology; as such, it is an expected strategy to increase initial and ongoing use of CGM in critical care settings. The final common implementation strategy was change in physical structures and equipment, which is defined as evaluating and adapting structures and equipment to accommodate the targeted innovation. [12] Studies, particularly those performed on CGM use during the COVID-19 pandemic, report on changing the physical structure of critical care rooms to accommodate closed door systems with CGM receivers placed in clear view of clinical staff either right outside the room, or in adjacent areas. Other implementation strategies were reported in single studies and included creating new clinical teams, building a coalition, conducting ongoing training, use

of champions, changing record systems, use of data experts, data warehousing, and creating bedside reference materials. As research continues to evaluate use of CGM in critical care settings, integrating this taxonomy of strategies is necessary to generate evidence about frequency and effectiveness of specific implementation strategies. Ultimately, this collective information about strategies can be used to inform future development of toolkits and bundles for sites seeking to integrate CGM as routine care.

The majority (11 out of 16) of the studies in this review reported on some aspect of implementation outcomes. One study used a qualitative design and only reported on implementation outcomes [24]; the remaining (10 out of 11) studies reported on both clinical and implementation outcomes. Across implementation outcomes, feasibility was reported most often. Feasibility refers to the degree that a new treatment or innovation can be successful integrated into a practice setting. [13] Common measurement indices for this outcome are lacking [36]: as such, there was wide heterogeneity in how this outcome was measured and reported across the studies in our review. Indicators of feasibility included measurement of startup time, [22] percentage of successful measurements,[28] average down time, [32] number of nurse encounters, [5•] and degree and duration of CGM insertion. [4•, 24] Fidelity to treatment protocols is an important implementation outcome, yet was only reported in two studies. [15, 25] However, both reported fidelity as the degree of adherence to CGM protocols. Similarly, acceptability, defined as the degree that stakeholders perceive the innovation to be agreeable, [13] was only reported in 2 studies, [8, 21] but both included nurse perceptions of CGM use. Future research evaluating CGM use should aim to incorporate these and other implementation outcomes using established definitions, [13] as well as recommendations for measurement and reporting [36] to continue to generate knowledge on optimal methods for uptake of routine CGM use in critical care settings.

Use of hybrid implementation research designs [37] is one approach to efficiently advance CGM use in critical care settings. Hybrid effectiveness-implementation designs incorporate a dual focus to evaluate both effectiveness of an intervention and factors associated with implementation. In traditional research approaches, implementation research is often not pursued until clinical outcomes are well established in the field, which may take several years. This approach contributes to the persistent research to practice gap, delaying systematic uptake of best practices. However, because hybrid designs combine elements of both effectiveness and implementation research, it is possible to simultaneously generate evidence on whether a therapy or treatment is effective, and what are the best mechanisms to integrate it into routine clinical practices. Use of this approach for CGM use in critical care has potential to enable more rapid adoption of CGM as a standard of care if it continues to demonstrate positive benefit for patients and clinicians. Incorporation of implementation outcomes, and particularly cost, offers additional benefit to inform return on investment and drive decisions at policy and reimbursement levels [38, 39].

This scoping review has several limitations including the fact that many of the inpatient studies used older technologies that are either no longer commercially available or were under development at the time. Given that technology specifications can greatly influence implementation and expected accuracy, findings from a study using one type of technology may not be generalized across similar technologies. Additionally, studies differed according to protocol and research method. It is possible that some studies that include implementation data were missed based on the search strategy, inclusion or exclusion criteria, or the databases searched.

## Conclusion

This scoping review provides valuable consensus on implementation strategies and outcomes employed in existing studies in the critical care environment. The rapid integration of CGM into the hospital setting during the COVID-19 pandemic provided a unique opportunity to assess implementation while generating valuable clinical outcomes data. The use of CGM in the inpatient setting holds tremendous promise to improve glycemic outcomes, and reduce nursing workload and associated healthcare costs; however, the inpatient use of CGM beyond the pandemic presents unique challenges associated with staff training, use in a variety of health systems and team structures, and EHR integration, necessitating future implementation research.

**Author Contribution** ERF, KMD, and MM designed the scoping review protocol. ERF extracted manuscripts from included databases. ERF and MM reviewed titles and abstracts and later full text articles. KMD resolved any discrepancies. ERF and MM extracted data from included studies. ERF, KMD, and MM crafted the manuscript.

**Data Availability** These data were derived from the following resources available in the public domain: Medline and Web of Science.

## Declarations

**Conflict of Interest** Eileen R Faulds received consultation from Dexcom, and speaker fees from Medscape and Dexcom. Molly McNett, Eileen R. Faulds, and Kathleen M. Dungan have received research funding from Dexcom LLC. K.D. has declared research support from Sanofi, Viacyte, Abbott, and Dexcom, consulting activities with Eli Lilly, Boehringer Ingelheim, Elsevier, Dexcom, honoraria from UptoDate, Medscape, Academy for Continued Healthcare Learning, Cardiometabolic Health Congress.

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3. U.S. Food & Drug. Coronavirus (COVID-19) Update FDA allows expanded use of devices to monitor patients vital signs remotely
4.• Faulds, E. R., et al. 2021 Use of Continuous Glucose Monitor in Critically Ill COVID 19 Patients Requiring Insulin Infusion An Observational Study J Clin Endocrinol Metab 106(10):e4007–e4016. **A retrospective analysis of an initial cohort (N=19) of COVID-19 patients using CGM within a hybrid point-of-care + CGM protocol. The authors report a 71% reduction in frequency of POC glucose testing compared with standard hourly POC testing for patients on IV insulin. Glycemic outcomes included TIR (70–180mg/dl), which was 72% after day one, and MARD, which was 13.9%.**
5.• Davis GM, Faulds E, Walker T, et al. 2021 Remote Continuous Glucose Monitoring With a Computerized Insulin Infusion Protocol for Critically Ill Patients in a COVID 19 Medical ICU Proof of Concept Diabetes Care 44 1055 8 **The authors report on experience and outcomes from an initial cohort (N=9) using a hybrid CGM and POC glucose monitoring protocol in the ICU during the COVID-19 pandemic. Mean TIR (70–180mg/dl) was 71.4%. CGM reduced POC tests to 8.24+/-3.06, resulting in 63% reduction and 75.7% of CGM values were within 20% of POC reference values. The authors provide a detailed description of a remote patient monitoring and telemetry system configured within the ICU.**
6.• Chow KW, Kelly DJ, Rieff MC, et al. 2021 Outcomes and Healthcare Provider Perceptions of Real-Time Continuous Glucose Monitoring rtCGM in Patients With Diabetes and COVID-19 Admitted to the ICU J Diabetes Sci Technol 1932296820985263 **The largest retrospective analysis of hospitalized COVID-19 patients (N=30) using CGM. There was a high concordance of CGM values with arterial reference values (within 20%) in all but 2 patients. CGM enabled a reduction in glucose from 440mg/dL to 200–300mg/dL within first 12hrs and sustained decreases to 100–200mg/dL within 7 days. Reduction in daily POC testing in 50% of patients. The publication is one of a handful to include nursing perspectives with a nursing survey showing 63% of nurses (N=66) felt that CGM improved the care their patient received.**
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