Continuous glucose monitors (CGMs) have suddenly become part of routine care in many hospitals. The coronavirus disease 2019 (COVID-19) pandemic has necessitated the use of new technologies and new processes to care for hospitalized patients, including diabetes patients. The use of CGMs to automatically and remotely supplement or replace assisted monitoring of blood glucose by bedside nurses can decrease: the amount of necessary nursing exposure to COVID-19 patients with diabetes; the amount of time required for obtaining blood glucose measurements, and the amount of personal protective equipment necessary for interacting with patients during the blood glucose testing. The United States Food and Drug Administration (FDA) is now exercising enforcement discretion and not objecting to certain factory-calibrated CGMs being used in a hospital setting, both to facilitate patient care and to obtain performance data that can be used for future regulatory submissions. CGMs can be used in the hospital to decrease the frequency of fingerstick point of care capillary blood glucose testing, decrease hyperglycemic episodes, and decrease hypoglycemic episodes. Most of the research on CGMs in the hospital has focused on their accuracy and only recently outcomes data has been reported. A hospital CGM program requires cooperation of physicians, bedside nurses, diabetes educators, and hospital administrators to appropriately select and manage patients. Processes for collecting, reviewing, storing, and responding to CGM data must be established for such a program to be successful. CGM technology is advancing and we expect that CGMs will be increasingly used in the hospital for patients with diabetes.

**Keywords:** Blood glucose; COVID-19; Diabetes mellitus; Glucose; Hospitals; Intensive care units; Technology

**INTRODUCTION**

Recent escalating interest in the use of continuous glucose monitor (CGM) technology for hospitalized patients has been fueled by (1) improvements in the sensing and data management technology; (2) increasing popularity of these devices among outpatients with diabetes as well as others from the athlete community and the quantified self movement; (3) a recent surge of articles in leading diabetes journals describing both good accuracy and improved clinical outcomes in hospitalized patients using these devices; (4) a recent decision by the United States Food and Drug Administration (FDA) related to the coronavirus disease 2019 (COVID-19) pandemic to exercise enforcement discretion and not block hospitals from providing devices and technical support to hospitals wishing to use these systems; and (5) dissemination of guidelines and review articles describing policies for using CGMs in a hospital setting.
DEFINITION OF A CONTINUOUS GLUCOSE MONITOR

A CGM is a device that measures the glucose concentration automatically around the clock [1]. The device must be attached to the body in some way and it can be either a wearable device or an implanted device. A CGM sensor can be situated in the subcutaneous space to measure the glucose concentration in interstitial fluid (ISF) or in a blood vessel and measure the glucose concentration in blood. Intravascular sensors are rarely used and confer a risk of bleeding and thrombosis and will not be covered in this article. Subcutaneous glucose sensors can require calibration anywhere from not at all up to four times daily [2]. One of the advantages of automatic glucose measurements is the time saved for the nurses who do not have to check blood glucose as often, but a disadvantage is that compared to blood glucose monitors, these sensors track ISF glucose rather than reference blood glucose concentrations (which are used for registration studies) less closely. Therefore, if a particular CGM requires regular calibration with blood glucose testing and provides less accurate reading as well, then there will be little interest in using such a product for hospitalized patients.

A CGM sensor with two attractive features: (1) factory calibration and (2) accuracy close to that of most blood glucose monitors (which many clinicians and mathematicians consider to be a mean absolute relative difference (MARD) from reference of below 10%) [3] would be well received in a hospital setting, providing there are no special accuracy concerns about physiological states altering ISF composition in critically ill patients. Two currently available types of sensors, the FreeStyle Libre series (FreeStyle Libre 14 day and FreeStyle Libre 2) from Abbott Diabetes Care (Alameda, CA, USA) [4,5], and the Dexcom G6 from Dexcom (San Diego, CA, USA) [6] provide these two features for most patients. The FreeStyle Libre 3 has a Conformité Européenne (CE) mark, but is not cleared by the FDA. However, none of these products are cleared by the FDA for use by critically ill hospitalized patients. Table 1 presents a list of currently available (in the United States) factory-calibrated subcutaneous CGMs that have product labels available and their known interferences from chemical substances [7-14].

For a given glucose concentration, CGMs from different manufacturers might report different percentages of time spent below range and above range, and might generate different individual times spent below or above range that could lead to different therapy recommendations [15]. Some hospitalized patients are volume depleted or they can experience peripheral vasconstriction from pressors, and it has not been clearly established whether CGMs that are currently intended for outpatient use can deliver adequately accurate results for these people [16]. More data will be needed about the analytical accuracy of CGMs in hospitalized patients before these devices will receive regulatory clearance for use in this setting.

With the recent COVID-19 pandemic straining hospital resources in 2020, the FDA notified Abbott Diabetes Care and Dexcom that they would exercise enforcement discretion and not object if these companies provided devices and technical support to hospitals who used CGMs for off-label use [17-19]. This plan has allowed many hospitals to assign nurses to use these devices for remote monitoring of glucose concentrations in COVID-19 patients with diabetes without needing to spend time performing fingerstick testing, having as much contact with contagious patients, and using up as much (in some cases limited) personal protective equipment (PPE) during fingerstick testing. Furthermore these programs have benefitted both these two manufacturers and the FDA by facilitating collection of real world data on large numbers of patients, whereas in clinical trials of these products in a hospital setting testing protocols would have been expensive and time consuming.

ESTABLISHING A CGM PROGRAM

The implementation of a CGM program in the hospital demands the interaction of multiple stakeholders including hospital leadership, physicians (many times including endocrinologists), nursing leadership, information technologists, quality implementation officers, laboratories representatives, pharmacists, and risk management officers. Ideally, information technology services can facilitate the documentation of CGM in the electronic health records (EHRs) to facilitate the comparison of point of care (POC) tests with CGM values and confirm periodically that CGM readings used for patient care are within an acceptable range [20]. Steps for a successful implementation in the hospital were recently described by Galindo et al. [21].

Current platforms for CGM implementation with factory-calibrated devices (that do not need a confirmatory test for decisions in the outpatient setting) include apps for the patient, apps for remote followers of glucose values, and platforms for population-based management. The Dexcom G6 device from Dexcom can transmit glucose data via Bluetooth to a receiver or smartphone (Android or iOS) within 20 feet. If using a compatible smartphone, then information can then be shared via the “Follow” app to up to 10 selected people, such as clinicians at a...
nursing station (who can use a dedicated tablet), the primary care team, bedside nurses, pharmacists, and/or endocrinologists that follow remotely. The data can also be transferred to online platforms, such as Dexcom CLARITY, that generates CGM-based glucose reports and summarizes data on a daily basis or over any specified period of time [14]. With the FreeStyle Libre 14 day and FreeStyle Libre 2 systems, a similar approach can allow the use of this technology in the hospital. With the FreeStyle Libre 14 day system the information can be transferred to a receiver or a smartphone via the FreeStyle LibreLink app, which then sends data to FreeStyle LibreView. Data on FreeStyle LibreView can be viewed by the patient and clinicians. Data can be viewed by patients via the LibreLink app, then to followers via the LibreLinkUp app, and then to Libreview.com to monitor multiple patients [9,22]. It should be noted that the both of the FreeStyle Libre systems measure glucose every minute; real-time glucose data including the trend and retrospective information is available by scanning the sensor, which holds 8 hours of data. The FreeStyle Libre 2 system has real-time optional alarms, which alert the user to high and low glucose levels without scanning.

Even though CGMs often appear to be reliable in the hospital, we believe regular routine POC blood glucose testing is still needed plus additional confirmatory POC tests are needed when: (1) glucose values are <85 mg/dL or >300 mg/dL; (2) hypoglycemic symptoms occur; (3) glucose readings and/or glucose trend arrows are not present on the monitor; (4) a blood drop symbol appears on the monitor; (5) hemodynamic instability occurs; and (6) a patient is in the immediate postoperative period.

**WHO IS A CANDIDATE FOR USING A CGM IN THE INTENSIVE CARE UNIT**

Reports are emerging on the use of wearable CGMs in the intensive care unit (ICU) setting during the COVID-19 pandemic. CGMs may be practical in the ICU for patients that require continuous intravenous insulin infusion, where hourly POC blood glucose testing is not practical. CGMs can be attractive alternatives to hourly POC capillary blood glucose testing because of the exposure risk of healthcare workers performing assisted monitoring of blood glucose [23], the amount of time needed to don and doff PPE in order to perform a POC capillary blood glucose test, and the depletion of scarce PPE used up just to perform a single POC capillary blood glucose test. Also, at some hospitals there can be a shortage of POC blood glucose monitors. Careful monitoring of POC blood glucose along with CGM readings are required to identify potential mechanical interference [24], such as pressure induced sensor attenuation [25]. Table 2 presents a review of the literature of clinical trials of CGM use in ICU settings for adult patients [26-68]. Table 3 presents a review of the literature of clinical trials of CGM use
### Table 2. Clinical Trials of CGM Use in ICU Settings for Adult Patients

| Study                        | Year | First author | Population          | CGM type       | CGM manufacturer | Performance measurement | Comparator                                                   |
|------------------------------|------|--------------|---------------------|----------------|------------------|-------------------------|--------------------------------------------------------------|
| Goldberg et al. [30]         | 2004 | USA          | ICU (n=22)          | CGMs           | Medtronic MiniMed | Accuracy                | Capillary by POC                                             |
| Vriesendorp et al. [31]      | 2005 | Netherlands  | OR, SICU (n=8)      | CGMs and GlucoDay | Medtronic MiniMed and A. Menarini Diagnostics (A. Menarini Diagnostics Ltd., Florence, Italy) | Accuracy and feasibility | Arterial by blood gas analyzer |
| Corstjens et al. [32]        | 2006 | Netherlands  | MICU (n=45)         | System Gold    | Medtronic MiniMed | Accuracy                | Arterial by blood gas analyzer, YSI (YSI 2300 STAT Plus glucose and lactate analyzer, YSI Life Science, Yellow Springs, OH, USA) and POC |
| De Block et al. [33]         | 2006 | Belgium      | MICU (n=50)         | Glucoday       | A. Menarini Diagnostics | Reliability             | Arterial                                                    |
| Price et al. [34]            | 2008 | UK           | Mixed ICU (n=17)    | Guardian       | Medtronic MiniMed | Accuracy                | Arterial by blood gas analyzer and POC                       |
| Logtenberg et al. [35]       | 2009 | Netherlands  | Cardiac surgery ICU (n=30) | Paradigm        | Medtronic MiniMed | Accuracy and glycemic control | Capillary, arterial, and venous by POC |
| Yamashita et al. [36]        | 2009 | Japan        | ICU (n=50)          | STG 22         | Nikkiso Co. Ltd. (Tokyo, Japan) | Accuracy                | Arterial by blood gas analyzer                              |
| Rabiee et al. [37]           | 2009 | USA          | SICU/Burn (n=19)    | Dexcom STS     | Dexcom           | Accuracy and reliability | Capillary by POC and serum by lab                           |
| Holzinger et al. [38]        | 2009 | Austria      | MICU (n=50)         | System Gold    | Medtronic MiniMed | Accuracy and reliability | Arterial by blood gas analyzer                              |
| Holzinger et al. [39]        | 2010 | Austria      | ICU, mechanical ventilation (n=24) | Guardian       | Medtronic MiniMed | Glycemic control (% time at glucose <110 mg/dL), LOS, mortality | Arterial by blood gas analyzer and blinded Medtronic MiniMed System Gold CGM |
| Jacobs et al. [40]           | 2010 | USA          | ICU (n=29)          | Guardian RT    | Medtronic MiniMed | Accuracy and feasibility | Capillary by POC                                             |
| Brunner et al. [41]          | 2011 | Austria      | MICU (n=174)        | Guardian & System Gold | Medtronic MiniMed | Accuracy and reliability | Arterial by blood gas analyzer                              |
| Kalmovich et al. [42]        | 2012 | Israel       | Perioperative cardiac surgery (n=32) | System Gold Blinded | Medtronic MiniMed | Accuracy and feasibility | Venous by blood gas analyzer                               |
| Lorenco et al. [43]          | 2012 | Spain        | ICU (n=41)          | Guardian       | Medtronic MiniMed | Accuracy                | Arterial by blood gas analyzer                              |
| Kopecky et al. [44]          | 2013 | Czech Republic | Cardiac ICU (n=24) | Guardian RT    | Medtronic MiniMed | Accuracy and glycemic control | Arterial by blood gas analyzer and computer (enhanced model predictive control) algorithm alone |

(Continued to the next page)
Table 2. Continued

| Study                                      | Year | First author country | Population | CGM type                  | CGM manufacturer | Performance measurement | Comparator                                                                 |
|--------------------------------------------|------|----------------------|------------|---------------------------|------------------|-------------------------|---------------------------------------------------------------------------|
| Leelarathna et al. [45]                    | 2013 | UK                   | Neurosurgical ICU ($n=24$) | FreeStyle Navigator | Abbott Diabetes Care | Glycemic control          | Arterial by blood gas analyzer                                            |
| Rodriguez-Quintanilla et al. [46]          | 2013 | Mexico               | ICU ($n=16$) | Guardian RT               | Medtronic MiniMed | Time to normoglycemia    | Venous and capillary by POC                                              |
| Schuster et al. [47]                       | 2014 | USA                  | SICU ($n=24$) | Guardian                  | Medtronic MiniMed | Accuracy                | Capillary by POC                                                          |
| Kosiborod et al. [48]                      | 2014 | USA                  | Cardiac ICU ($n=21$) | Sentrino                  | Medtronic MiniMed | Accuracy and reliability | Central venous by POC or lab                                              |
| Boom et al. [49]                           | 2014 | Netherlands          | MICU/SICU ($n=156$) | FreeStyle Navigator       | Abbott Diabetes Care | Accuracy and glycemic control | Arterial by blood gas analyzer, and POC                                  |
| Umbrello et al. [50]                       | 2014 | Italy                | MICU ($n=6$) | OptiScanner 5000          | OptiScan Biomedical | Glycemic control         | Central venous by blood gas analyzer or lab (reported elsewhere)         |
| van Hooijdonk et al. [51]                 | 2015 | Netherlands          | ICU ($n=50$) | Sentrino                  | Medtronic MiniMed | Accuracy and reliability | Arterial by blood gas analyzer                                            |
| Sechterberger et al. [52]                 | 2015 | Netherlands          | Cardiac ICU ($n=8$) | FreeStyle Navigator       | Abbott Diabetes Care | Accuracy                | Arterial by blood gas analyzer                                            |
| Punke et al. [53]                          | 2015 | Germany              | SICU ($n=14$) | Sentrino                  | Medtronic MiniMed | Accuracy                | Arterial by blood gas analyzer                                            |
| Ballesteros et al. [54]                    | 2015 | Spain                | MICU ($n=18$) | Soft Sensor               | Medtronic MiniMed | Accuracy                | Capillary by POC                                                          |
| De Block et al. [55]                       | 2015 | Belgium              | MICU ($n=35$) | GlucoDay S                | A. Menarini Diagnostics | Accuracy and glycemic control | Arterial by blood gas analyzer and blinded microdialysis-based CGM        |
| Gottschalk et al. [56]                     | 2016 | Germany              | Extracorporeal cardiac life support ($n=25$) | Sentrino                  | Medtronic MiniMed | Accuracy                | Arterial by blood gas analyzer                                            |
| Nohra et al. [57]                          | 2016 | USA                  | SICU ($n=23$) | Optiscanner 5000          | Optiscan Biomedical | Accuracy                | Central venous by YSI                                                    |
| Righy Shinotsuka et al. [58]               | 2016 | Belgium              | ICU ($n=88$) | OptiScanner 5000          | Optiscan Biomedical | Accuracy                | Arterial by YSI                                                           |
| Wollersheim et al. [59]                    | 2016 | Germany              | MICU ($n=20$) | Sentrino                  | Medtronic MiniMed | Accuracy and feasibility | Arterial, central venous, or venous by blood gas analyzer                |
| Schierenbeck et al. [60]                   | 2017 | Sweden               | Cardiac ICU ($n=26$) | FreeStyle Libre Subcutaneous CGM vs. Eirus Intravascular | Abbott Diabetes Care and Maquet Getinge Group | Accuracy | Arterial by blood gas analyzer and capillary by POC                        |
| Song et al. [61]                           | 2017 | Republic of Korea    | OR, ICU ($n=22$) | Guardian | Medtronic MiniMed | Accuracy and reliability | Arterial by blood gas analyzer                                            |
| Ancona et al. [62]                         | 2017 | Australia            | ICU ($n=8$) | FreeStyle Libre CGM       | Abbott Diabetes Care | Accuracy and feasibility | Arterial by blood gas analyzer or capillary by POC                        |

(Continued to the next page)
in ICU settings for pediatric patients [68-74]. Every table in this article presenting studies of CGM trials in hospital settings refers to protocols where these devices are intended to determine insulin doses administered manually rather than by way of automated delivery. In these intended settings, patients are already being closely monitored and there is no convincing data currently that CGM technology will be useful in this setting. Furthermore, patients in an intensive care setting frequently require pressors, which can cause peripheral vasoconstriction. It is possible that in such patients the circulation to the skin where CGMs are placed might be decreased and the CGM readings might or might not be accurate. Recently, Perez-Guzman et al. [26] performed a prospective study with the Dexcom G6 in the ICU, for 15 patients with stress hyperglycemia treated with continuous insulin infusion and vasopressors. The reported accuracy was a MARD of 12.9%. Agarwal et al. [27] conducted a retrospective analysis of 11 diabetes patients who were using Dexcom G6 CGMs. Their series included patients who had anasarca and/or were receiving renal replacement therapy, vasopressors, mechanical ventilation support, or high-dose glucocorticoids.

Table 2. Continued

| Study                   | Year | First author country | Population | CGM type                  | CGM manufacturer | Performance measurement | Comparator                                      |
|-------------------------|------|----------------------|------------|---------------------------|------------------|--------------------------|-------------------------------------------------|
| Bochicchio et al. [63]  | 2017 | USA                  | ICU (n=243) | OptiScanner 5000          | OptiScan Biomedical | Accuracy                | Arterial, central venous, or venous by YSI       |
| Rijkenberg et al. [64]  | 2018 | Netherlands          | Mixed ICU (n=155) | FreeStyle Navigator      | Abbott Diabetes Care | Accuracy and reliability | Arterial by blood gas analyzer                   |
| Nukui et al. [65]       | 2019 | Japan                | Acute stroke (n=39) | FreeStyle Pro CGM        | Abbott Diabetes Care | Accuracy and efficacy   | Capillary by POC                                 |
| Furushima et al. [66]   | 2020 | Japan                | ICU (n=40)  | FreeStyle Libre CGM       | Abbott Diabetes Care | Determine the mean amplitude of glycemic excursions | Arterial by blood gas analyzer                   |
| Chow et al. [67]        | 2020 | USA                  | ICU (n=1)   | Dexcom G6                 | Dexcom            | Accuracy                | Capillary by POC                                 |
| Sadhu et al. [29]       | 2020 | USA                  | ICU (n=11)  | Guardian Connect Dexcom G6| Medtronic MiniMed | Accuracy and feasibility | Capillary, venous, and arterial by POC           |
| Garelli et al. [68]     | 2020 | Argentina            | ICU patients with COVID-19 (n=3) (2 other pediatric patients were also studied) | Dexcom G6 for the ICU patients | Dexcom | Glycemic control using a new multisensor platform | None                                            |
| Agarwal et al. [27]     | 2020 | USA                  | ICU (n=47)  | Dexcom G6                 | Dexcom            | Accuracy                | Capillary by POC                                 |
| Chow et al. [28]        | 2020 | USA                  | ICU patients with COVID-19 (n=30) | Dexcom G6          | Dexcom            | Clinical utility and accuracy | Arterial by POC                                 |
| Perez-Guzman et al. [26]| 2021 | USA                  | OR and cardiac ICU patients without diabetes undergoing scheduled or urgent coronary artery bypass surgery | Dexcom G6          | Dexcom            | Accuracy                | Capillary by POC                                 |

CGM, continuous glucose monitor; ICU, intensive care unit; POC, point of care; OR, operating room; SICU, surgical ICU; MICU, medical ICU; COVID-19, coronavirus disease 2019.
The MARD of these CGMs was 12.58% [27]. In a different cohort of 30 critically ill patients, Chow et al. [28] found a decrease in mean glucose in 77% of the patients after Dexcom G6 monitoring was started. For the full cohort, there was a 14% decrease (235.7 to 202.7 mg/dL, \(P=0.0003\)) in mean sensor glucose. Sadhu et al. [29] reported similar accuracy between the Medtronic Guardian Connect (Medtronic Minimed, Northridge, CA, USA) and Dexcom G6 devices in a cohort of 11 ICU patients. This ICU data is promising for eventual routine use of CGMs in an ICU setting. However, these studies have limitations, including small sample sizes, inconsistent reference matrices (either capillary or arterial blood), and little information on glycemic or clinical outcomes.

As the information about CGMs in the ICU is evolving, we currently recommend using CGM in the ICU for selected candidates, such as patients with COVID-19, who (1) are treated with continuous intravenous insulin infusion; (2) develop steroid-induced hyperglycemia; or (3) have medical nutrition therapy-induced hyperglycemia or high glycemic variability. We also recommend using a hybrid approach (combining CGM with periodical POC blood glucose testing) in the ICU to ensure consistent accuracy. CGM is currently not widely used for non-COVID patients outside of research settings.

### WHO IS A CANDIDATE FOR USING A CGM IN THE WARDS

An emerging use for CGM in the hospital will be detection and prevention of hypoglycemia on the wards among insulin-treated patients. This is a new application of CGM and the early evidence from trials to detect this complication of hospitalizations are promising. Table 4 presents a review of the literature of clinical trials of CGM use in non-ICU settings for adult patients [75-89]. Ward patients sometimes need to have their ongoing

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**Table 3. Clinical Trials of CGM Use in ICU Settings for Pediatric Patients**

| Study                | Year | First author country | Population | Type of CGM | CGM manufacturer | Performance measurement | Comparator |
|----------------------|------|----------------------|------------|-------------|------------------|-------------------------|------------|
| Bridges et al. [69]  | 2010 | USA                  | ICU (n=47) | Guardian    | Medtronic MiniMed | Accuracy                | Arterial, venous, and capillary by iSTAT POC and lab |
| Steil et al. [70]    | 2011 | USA                  | Cardiac ICU (n=311) | Guardian | Medtronic MiniMed | Accuracy and hypoglycemia prevention | Arterial by POC and lab |
| Prabhudesai et al. [71] | 2015 | UK                  | ICU (n=19) | Guardian | Medtronic MiniMed | Accuracy                | Arterial by lab |
| Kotzapanagiotou et al. [72] | 2020 | Greece              | ICU (n=16) | FreeStyle Libre | Abbott Diabetes Care | Accuracy                | Arterial by blood gas analyzer capillary by POC, biochemical serum by lab |
| Sopfe et al. [73]    | 2020 | USA                  | Stem cell transplantation (n=29) | FreeStyle Libre Pro | Abbott Diabetes Care | Accuracy                | Central venous by lab |
| Garelli et al. [68]  | 2020 | Argentina            | ICU patients with COVID-19 (n=2) (3 other adult patients were also studied) | Dexcom G6 for the ICU patients | Dexcom | Glycemic control using a new multisensor platform | None |
| Chesser et al. [74]  | 2021 | USA                  | Children with postprandial hypoglycemia due to late dumping syndrome following gastric surgeries (n=3) | Dexcom G4 Dexcom G5 Dexcom G6 | Dexcom | Diagnose hypoglycemia due to late dumping syndrome. Also to determine best treatment strategies and feeding regimens. | None |

AID, automated insulin delivery; CGM, continuous glucose monitoring; ICU, intensive care unit; POC, point of care; COVID-19, coronavirus disease 2019.
| Study                | Year | First author country | Patient population                                                                 | CGM type                  | CGM manufacturer | Performance measurement | Comparator       |
|---------------------|------|----------------------|-------------------------------------------------------------------------------------|---------------------------|---------------------|--------------------------|-----------------|
| Dungan et al. [77]  | 2012 | USA                  | T1DM and T2DM (n=58), on intravenous or subcutaneous insulin                        | iPro system               | Medtronic MiniMed  | Accuracy                 | Capillary by POC |
| Burt et al. [78]    | 2013 | Australia            | T1DM and T2DM, on basal bolus insulin (n=26)                                        | System Gold               | Medtronic MiniMed  | Accuracy and glycemic control | Capillary by POC |
| Gomez et al. [79]   | 2015 | Colombia             | T2DM, on basal bolus insulin (n=38)                                                | iPro2 system              | Medtronic MiniMed  | Glycemic control and hypoglycemia detection | Capillary by POC |
| Schaupp et al. [80] | 2015 | Austria              | T2DM, on basal bolus insulin (n=84)                                                | iPro2 system              | Medtronic MiniMed  | Accuracy                 | Capillary by POC |
| Spanakis et al. [81] | 2018 | USA                  | T2DM, on insulin therapy (n=5)                                                      | Dexcom G4 CGM with Share2 application | Dexcom              | Glucose telemetry system feasibility | None            |
| Migdal et al. [82]  | 2020 | USA                  | Adult medicine and surgery patients with T1DM and T2DM (n=49)                      | Dexcom (CGM type unspecified) | Dexcom              | Precision and accuracy   | Capillary by POC |
| Shehav-Zaltzman et al. [83] | 2020 | Israel               | T1DM on CSII (n=1) and T2DM on basal bolus (n=3), COVID-19 wards (n=5)             | Guardian                  | Medtronic MiniMed  | Feasibility              | None            |
| Singh et al. [84]   | 2020 | USA                  | T2DM, on basal-bolus insulin (n=13)                                                | Dexcom G4 Platinum CGM   | Dexcom              | Feasibility and prevention of hypoglycemia | Blinded CGM |
| Tripyla et al. [75] | 2020 | Switzerland          | Prediabetes patients undergoing elective abdominal surgery (n=20)                  | Dexcom G6                 | Dexcom              | Accuracy                 | Capillary by POC |
| Reutrakul et al. [85] | 2020 | USA                  | Diabetes (unspecified type) on subcutaneous insulin injection with COVID-19 (n=1) | Dexcom G6                 | Dexcom              | Feasibility              | Capillary by POC |
| Galindo et al. [86] | 2020 | USA                  | T2DM, on basal-bolus insulin (n=97)                                                | FreeStyle Libre Pro CGM   | Abbott Diabetes Care | Accuracy and hypoglycemia detection | Capillary by POC |
| Nair et al. [76]    | 2020 | USA                  | Surgical ward (n=10)                                                               | Dexcom G6 Blinded         | Dexcom              | Accuracy                 | Capillary by POC |
| Singh et al. [87]   | 2020 | USA                  | T2DM, on basal-bolus insulin (n=72)                                                | Dexcom G6                 | Dexcom              | Prevention of hypoglycemia | Blinded CGM |
| Fortmann et al. [88] | 2020 | USA                  | T2DM on subcutaneous insulin (n=110)                                               | Dexcom G6                 | Dexcom              | Effectiveness            | Capillary by POC |
| Ushigome et al. [89] | 2021 | Japan                | Diabetes (unspecified type) with COVID-19 (n=1)                                    | Dexcom G4 Platinum       | Dexcom              | Safety and effectiveness | Lab             |

CGM, continuous glucose monitor; ICU, intensive care unit; T1DM, type 1 diabetes mellitus; T2DM, type 2 diabetes mellitus; POC, point of care; CSII, continuous subcutaneous insulin infusion; COVID-19, coronavirus disease 2019.

The insulin dose significantly decreased suddenly if they miss a meal or if they are receiving a regimen of corticosteroids or parenteral nutrition, which is suddenly curtailed or discontinued, and the communication between the physicians, nurses, and pharmacists is not optimal. Hypoglycemia detection is particularly useful in a setting where ward nurses are not always with...
the patient and where a patient might have hypoglycemia unawareness or might fail to complain of hypoglycemic symptoms and then slowly become confused or even unconscious. Table 5 presents a review of the literature of clinical trials of CGM use to detect hypoglycemia in hospitalized patients [70,74,79,84,86,87]. It is likely that CGM technology will be used frequently for this purpose in the future.

Based on our experience and the results of recent studies of currently available CGM systems, we believe that selected types of patients could benefit from wearing a CGM in a medical or surgical ward. These include patients with (1) a high risk of hypoglycemia (e.g., with a fragile habitus, end stage renal disease, advanced age, or poor nutrition); (2) type 1 diabetes; (3) a requirement for multiple daily insulin injections; (4) high glycemic variability; (5) steroid-induced hyperglycemia; and (6) enteral or parenteral feeding-induced hyperglycemia.

### WHO IS A CANDIDATE FOR USING A CGM IN SURGERY

The opportunity to see a full glycemic profile during the operative time will be ideal for an anesthesiologist (who will receive

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**Table 5. Clinical Trials of CGM Use to Detect Hypoglycemia in Hospitalized Patients**

| Study         | Year | First author country | Patient population | CGM type | CGM manufacturer | Definition of hypoglycemia | Outcome                                                                 |
|---------------|------|----------------------|--------------------|----------|-----------------|---------------------------|-------------------------------------------------------------------------|
| Steil et al.  | 2011 | USA                  | Cardiac ICU (n = 311) | Guardian | Medtronic MiniMed | Blood glucose <60 mg/dL (3.3 mmol/L) | No reduction if CGM alarm was set at 60 mg/dL. 18 out of 40 episodes of hypoglycemia detected when the alarm threshold set to 70 mg/dL. One to two false hypoglycemia alarms in each patient. |
| Gomez et al.  | 2015 | Colombia             | T2DM, on basal bolus insulin (n = 38) | iPro2 system | Medtronic MiniMed | Hypoglycemia was defined as blood glucose <70 mg/dL (3.9 mmol/L) or <60 mg/dL (3.3 mmol/L). | CGM is more effective than POC testing for detecting hypoglycemic episodes and asymptomatic hypoglycemia using either definition of hypoglycemia. |
| Singh et al.  | 2020 | USA                  | T2DM, on basal-bolus insulin (n = 13) | Dexcom G4 Platinum CGM | Dexcom | Blood glucose <70 mg/dL (3.9 mmol/L) | A hypoglycemia prevention protocol using a specific Glucose Telemetry System can reduce incidence of inpatient hypoglycemia. |
| Galindo et al.| 2020 | USA                  | T2DM, on basal-bolus insulin (n = 97) | FreeStyle Libre Pro CGM | Abbott Diabetes Care | Hypoglycemia was defined as <70 mg/dL (3.9 mmol/L) or <54 mg/dL (3.0 mmol/L). | Hypoglycemic events were detected more often by CGM use than POC testing. |
| Singh et al.  | 2020 | USA                  | T2DM, on basal-bolus insulin (n = 72) | Dexcom G6 | Dexcom | Hypoglycemia was defined as blood glucose <70 mg/dL (3.9 mmol/L) for over 15 minutes. Clinically significant hypoglycemia was defined as blood glucose <54 mg/dL (3.0 mmol/L). | In patients with type 2 diabetes who have been treated with insulin, hypoglycemia can be decreased by a combination of RT-CGM use with a protocol for hypoglycemia prevention. |
| Chesser et al.| 2021 | USA                  | Children with postprandial hypoglycemia due to late dumping syndrome following gastric surgeries (n = 3) | Dexcom G4 | Dexcom G5 Dexcom G6 | Hypoglycemia was not explicitly defined, but one patient whose glucose level was up to 65 mg/dL was considered hypoglycemic. | CGM can be used for early diagnosis of dumping syndrome by revealing glycemic dysregulation. It can also be used to evaluate the effectiveness of treatments and feeding regimens for postprandial hypoglycemia due to late dumping syndrome. |

CGM, continuous glucose monitor; ICU, intensive care unit; T2DM, type 2 diabetes mellitus; POC, point of care; RT-CGM, real-time continuous glucose monitor.
Continuous glucose monitors and automated insulin dosing systems; and (5) data management logistics and hands-on care of hospitalized patients using CGMs.

In September 2020, Diabetes Technology Society published the ‘Continuous glucose monitors and automated insulin dosing systems in the hospital consensus guideline’ to address how and when to best use both subcutaneous CGMs and automated insulin delivery (AID) systems, as well as to promote clinical research utilizing these devices [21]. The consensus panel of 24 international experts in the use of CGM developed recommendations for physicians (which the guideline referred to as healthcare professionals), nurses, and hospitals, as well as for industry. The panel covered five topics: (1) continuation of home CGMs after hospitalization; (2) initiation of CGMs in the hospital; (3) continuation of automated insulin dosing systems in the hospital; (4) logistics and hands-on care of hospitalized patients using CGMs and automated insulin dosing systems; and (5) data management of CGMs. The panelists voted on 78 proposed recommendations and 77 recommendations were endorsed and classified as either strong (80% to 100% agreement) or mild (60% to 79% agreement). One recommendation failed to reach consensus.

**IMPLICATIONS OF CGM USE FOR BEDSIDE NURSES**

As inpatient CGM use increases in people with both type 1 and type 2 diabetes, the bedside nurse needs to become familiar with this technology and its advantages and limitations. Understanding that ISF glucose lags behind capillary glucose is important when recognizing and treating hypoglycemia. For example, a patient may feel fine after receiving an appropriate hypoglycemia treatment, and the fingerstick value may be above the recommended threshold of 80 to 100 mg/dL, but the sensor glucose may still reflect a value under 70 mg/dL. Any discrepancies between patients’ symptoms and sensor numbers require a confirmatory finger stick POC capillary blood glucose measurement.

Most medical centers still require finger stick values for dosing insulin as a safety precaution, as if the devices are intended for adjunctive use, even though for outpatients the FDA-cleared factory-calibrated CGMs are approved for non-adjunctive use. Hospitals need a written policy and/or care guideline to provide medical and nursing staff with a system for charting decisions based on CGM data because these devices are not cleared for hospital use and it may be difficult to enter sensor values into the EHR.

Another care concern is documentation of the sensor placement location and inspection of the site any time from every shift to daily. For all radiologic studies, the sensor will need to be removed from the skin and the transmitter and/or receiver should be safely stored. As most medical centers do not carry sensor supplies, patients being admitted should be advised to bring additional sensor supplies.

**HOSPITAL CGM DATA**

CGM data for a hospitalized patient cannot be confirmed through a test using a reference method because it is almost impossible to assay ISF. Many hospital clinical chemists consider CGM data analogous to vital sign information, which is being monitored frequently but which cannot be individually confirmed for accuracy. A CGM can be calibrated in the factory for outpatient use, but it is not known whether this type of calibration will be adequate for a hospitalized patient.

CGM data is currently not compatible with the vast majority of EHRs. A screen shot of a tracing cannot be searched and
therefore, this type of record will have only limited value after the day it is collected. The selection of which types of CGM data to store will likely be various 24-hour or 14-day metrics, such as time in range, glycemic variability, or percentage of time spent in a slightly low, extremely low, slightly high, and extremely high range [90], because the amount of storage space needed to save every data point (up to 288 glucose readings per day or more) could overwhelm many hospital EHRs. Hospitals, CGM manufacturers, and EHR vendors must work together to integrate the most useful CGM data into the EHR. This data acquisition process must be compliant with regulatory privacy rules and sound cybersecurity policies. Successful integration of real-time CGM data into the EHR has been reported in a limited number of cases, so there is hope for the future [91,92]. If CGM data of a hospitalized patient must reside on the website of a CGM manufacturer or a software integrator of data from multiple CGM manufacturers, then the hospital might have concerns about how the data is protected from cyber breaches and who is liable if such data from a hospitalization is lost.

FUTURE TECHNOLOGY

It is likely that future CGM sensors will be more accurate with continued improvements in sensor sensitivity and algorithm fidelity for converting a signal to a glucose concentration. These sensors will likely have a smaller form factor, a longer life, and louder alarms for out of range glucose concentrations. With longer-duration sensors, it will be necessary to develop better adhesives that are less likely to cause a rash [93]. In order to prolong viable implantation time, it will be necessary to develop better coatings that will minimize the foreign body response that limits integration of the sensor into the subcutaneous space [94]. Future CGM data will become interconnected with multiple other data streams to provide a more nuanced pattern of how behavior affects glycemia and to better predict glucose patterns [95]. Data fusion technology will be combined with decision support and behavioral modification software for real-time management and in the hospital this management will be in the form of warnings and treatment recommendations for the hospital staff [96].

Just as in the past, many did not expect that a subcutaneous glucose sensor would ever provide accurate glucose readings comparable to blood glucose testing, many now believe that a wearable optical noninvasive glucose monitor [97] or a monitor that is based on noninvasive collection and measurement of a body fluid (such as sweat, saliva, or tears) [98] cannot be developed to measure glucose almost as accurately as an invasive blood test. These doubters of optical noninvasive technology might prove to be just as wrong as the doubters of subcutaneous minimally invasive technology were 20 years ago. Whether these new technologies can become established will depend significantly on whether human physiology will allow for body compartments other than blood or skin to be measured without significant lag during periods of dynamic fluctuations—not on the expected accuracy of future sensors to measure these matrices. Eventually it will become clear which individual or composite metrics for CGMs (if any) and which definitions of a hypoglycemic episode will best correlate with specific hospital outcomes [99].

CONCLUSIONS

CGMs are gradually migrating from the outpatient setting into the inpatient setting because these devices are becoming more compatible with the needs of the healthcare team that cares for these inpatients. The trend accelerated because of the COVID-19 pandemic, which necessitated collecting data remotely from patients when possible. It is too soon to know whether the accuracy and clinical benefits of CGMs will result in widespread adoption or regulatory clearance of this technology for hospital use. CGMs work extremely well on outpatients and there is reason to believe that they could prove to be effective to achieve well-defined endpoints for hospitalized patients.

CONFLICTS OF INTEREST

M. Citlalli Perez-Guzman, Trisha Shang, and Jennifer Y. Zhang have nothing to disclose. Donna Jornsay was a speaker for Abbott Diabetes Care and BD, and holds Medtronic stock. David C. Klonoff is a consultant for EOFlow, Fraeyt, Lifecare, Novo, Roche, Samsung, and Thirdwayv.

ACKNOWLEDGMENTS

We thank Francisco Pasquel, MD for his helpful advice. We also thank Annamarie Sucher-Jones for her expert editorial assistance.

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