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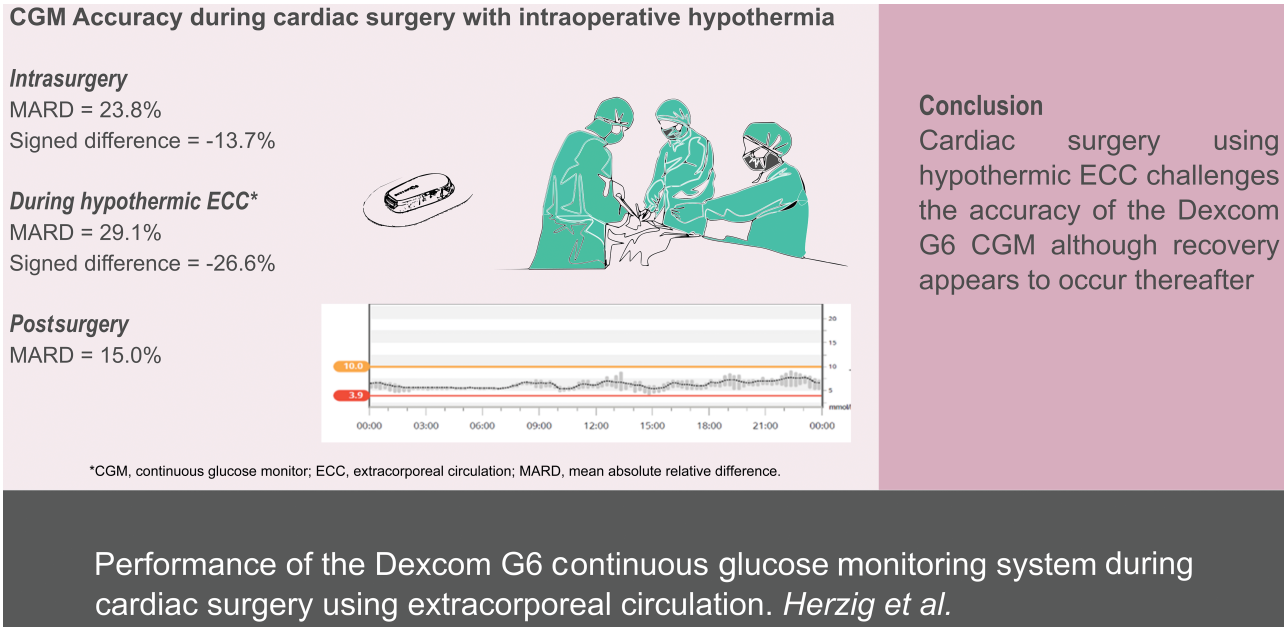

ARTICLE HIGHLIGHTS

- This study tested the accuracy of the Dexcom G6 continuous glucose monitor sensor in patients undergoing cardiac surgery using hypothermic extracorporeal circulatory arrest.
- Our results showed limited performance during surgery and suggest a link to the hypothermia exposure. Of note, most sensors demonstrated adequate accuracy postsurgery.
- Cardiac surgery using hypothermic extracorporeal circulation challenges the accuracy of the Dexcom G6 continuous glucose monitor, although recovery appears to occur thereafter.

Performance of the Dexcom G6 Continuous Glucose Monitoring System During Cardiac Surgery Using Hypothermic Extracorporeal Circulation

David Herzig,[1] Martina Vettoretti,[2] Dominik P. Guensch,[3] Andreas Melmer,[1] Daniel Schürch,[1] Jonathan Roos,[1] Arna M.C. Goerg,[1] Gabija Krutkyte,[1] Luca Cecchini,[1,3] Andrea Facchinetti,[2] Andreas P. Vogt,[3] and Lia Bally[1]

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BRIEF REPORT

OBJECTIVE

Continuous glucose monitoring (CGM) may be challenged by extreme conditions during cardiac surgery using hypothermic extracorporeal circulation (ECC).

RESEARCH DESIGN AND METHODS

We evaluated the Dexcom G6 sensor in 16 subjects undergoing cardiac surgery with hypothermic ECC, of whom 11 received deep hypothermic circulatory arrest (DHCA). Arterial blood glucose, quantified by the Accu-Chek Inform II meter, served as reference.

RESULTS

Intrasurgery mean absolute relative difference (MARD) of 256 paired CGM/reference values was 23.8%. MARD was 29.1% during ECC (154 pairs) and 41.6% immediately after DHCA (10 pairs), with a negative bias (signed relative difference: −13.7%, −26.6%, and −41.6%). During surgery, 86.3% pairs were in Clarke error grid zones A or B and 41.0% of sensor readings fulfilled the International Organization for Standardization (ISO) 15197:2013 norm. Postsurgery, MARD was 15.0%.

CONCLUSIONS

Cardiac surgery using hypothermic ECC challenges the accuracy of the Dexcom G6 CGM although recovery appears to occur thereafter.

There is a growing interest in the use of continuous glucose monitoring (CGM) systems in the hospital setting (1). The benefits are obvious: less labor-intensive finger-stick testing, provision of continuous glucose levels, and customizable alerts.

Modern CGM systems displayed satisfactory performance in noncritically ill patients (2) and patients undergoing elective abdominal surgery (3) (mean absolute relative difference [MARD] <13%). However, because of the physiological effects of severe illness and specific medical interventions, more data related to the accuracy of CGM reading are required in these situations. One example of such a challenging condition is open cardiac surgery. To facilitate the operating environment, cardiac surgery is often combined with cardioplegia-induced cardiac arrest during extracorporeal circulation (ECC) (4). Hypothermia (32–34°C) is often instated for organ protection (5). The most extreme conditions can be found during surgery of the

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ascending aorta and aortic arch, when only the brain is selectively perfused and blood flow to the rest of the body is halted at a core temperature between 15 and 22°C for a short period of time (termed deep hypothermic circulatory arrest [DHCA]) (6).

This study tested the accuracy of the Dexcom G6 CGM (Dexcom, San Diego, CA) sensor in patients undergoing cardiac surgery using hypothermic ECC.

RESEARCH DESIGN AND METHODS

In a prospective observational study, we evaluated the performance of the Dexcom G6 CGM sensor in adults (≥18 years), with or without diabetes, undergoing scheduled cardiac surgery-induced hypothermic ECC. The Ethics Committee Bern approved the study (approval number 2020-01024), and all participants provided written informed consent.

Recruitment was performed at the preoperative anesthesia consultation. Participants were fitted with a Dexcom G6 CGM on the lateral abdominal flank by the study team on the day of hospital admission. The CGM sensor was kept until discharge or end of sensor life (10 days). During hospitalization, reference glucose values were measured using the Accu-Chek Inform II meter (Roche Diagnostics GmbH, Mannheim, Germany). A calibration was performed with arterial blood at the time of anesthesia induction using the Accu-Chek device. During surgery, blood for reference values was sampled every 20 min from the arterial catheter or the heart-lung machine during ECC and immediately after cessation of DHCA, respectively. Postsurgery reference values were measured from capillary blood as part of usual care. Intraoperatively, core body temperature was monitored using a standard urinary catheter with temperature sensor. In addition, esophageal temperature and mean arterial blood pressure were continuously recorded (Philips MX 700, Amsterdam, the Netherlands). Blood gases (P_{O_2}, P_{CO_2}) were measured using a ABL800 blood gas analyser (Radiometer, Brønshøj, Denmark). Patient characteristics and surgical details were obtained from the electronic health record and anesthesia protocol.

CGM measurements were linearly interpolated on a 1-min temporal grid, except for CGM gaps of >10 min, which were not interpolated. Each reference measurement was paired with the closest in time interpolated CGM value and pairs with a time difference >5 min were discarded. MARD was used as the main accuracy metric. Secondary accuracy metrics included signed relative difference (percentage, calculated as $[Glucose_{CGM} - Glucose_{Reference}]/Glucose_{Reference} * 100$), the percentage of pairs in zone A and A+B of the Clark Error Grid (7), the percentage of pairs within ±15 mg/dL or ±15% (15/15%) of references according to International Organization for Standardization (ISO) 15197:2013 standards (8), and the percentage of pairs within 20/20% and 30/30% of the references. Accuracy metrics were calculated during surgery (defined from skin incision to closure) during ECC and immediately after cessation of DHCA as well as during the postsurgery follow-up (from end of surgery until hospital discharge or end of sensor life). In an exploratory analysis, we investigated the correlation of accuracy metrics with core body temperature. CGM accuracy outcomes were calculated using aggregated pairs from all study participants.

Data Resource and Availability

The data sets generated during and/or analyzed in the current study are available from the corresponding author upon reasonable request.

RESULTS

Sixteen patients were included between February 2021 and March 2022. Surgical procedures included four open coronary artery bypass graft (CABG) surgeries and 14 open aortic and 11 valve repair/replacement surgeries. Further patient/surgery characteristics are listed in Supplementary Table 1.

In median, CGM was placed 22.8 h (minimum 11.2, maximum 79.4) prior to surgery. The durations of surgery were 5.4 ± 1.8 h (mean ± SD) including 3.0 ± 1.1 h of ECC. DHCA was performed in 11 patients (mean duration of 20.1 ± 4.0 min). The minimal body temperature ranged between 20.9 and 32.0°C. In all patients, myocardial protection was achieved with a glucose-containing cardioplegic solution, providing between 15.8 and 40.0 g of glucose during the surgery (mean 24.7 ± 7.2 g).

Reference glucose levels ranged between 99.7 ± 29.8 and 289.2 ± 46.2 mg/dL during surgery and between 115.5 ± 15.4 and 172.5 ± 28.8 mg/dL during the postsurgical follow-up period. A total of 400 CGM/reference pairs were obtained (surgery: 256, ECC: 154, DHCA: 10, postsurgery: 144).

Figure 1*A* is an example of the CGM, reference glucose, and temperature trajectory during surgery. MARD for the whole cohort was 23.8% during surgery, 29.1% during ECC, and 41.6% immediately after DHCA, with a negative bias in all three periods (mean signed relative difference was −13.7%, −26.6%, and −41.6%, respectively). During surgery, 86.3% pairs were in Clarke error grid zones A or B (A, 51.6%). All accuracy metrics are reported in the Supplementary Table 2. The sensor accuracy was associated with body temperature (Pearson r = −0.57 and r = 0.63, both $P < 0.001$, for absolute and signed relative differences, respectively) (Fig. 1*C* and *D*). The effect of body temperature on relative differences remained statistically significant ($P < 0.001$) after adjustment for reference glucose, rate of glucose change (ROC), and time since sensor insertion, using linear mixed-effect modeling (Supplementary Table 3). Postoperatively, MARD was 15.0%, with 95.4% pairs in Clarke error grid zones A (73.6%) or B.

Sensor readings were available 90.1% of the time during surgery and 97.6% of the time after surgery. One sensor required replacement in the postoperative period due to sensor failure, while in four patients, dropouts of CGM readings with sensor error alerts were transient and recovered. There were no adverse device effects.

CONCLUSIONS

We investigated the accuracy of the Dexcom G6 CGM during cardiac surgery using hypothermic ECC. Our results showed limited performance during surgery and suggest a link to the hypothermia exposure. Of note, most sensors demonstrated adequate accuracy postsurgery.

Our findings are in line with two recent studies performed by Emory University Investigators (Atlanta, GA) (9,10). In a pilot study performed in 15 patients undergoing CAGB surgery (based on 149 CGM/reference pairs and without information on temperature exposure), the authors report a negative bias in Dexcom G6 glucose values (9). In a second study performed in the intensive care unit setting in patients following cardiac arrest, a negative bias and frequent

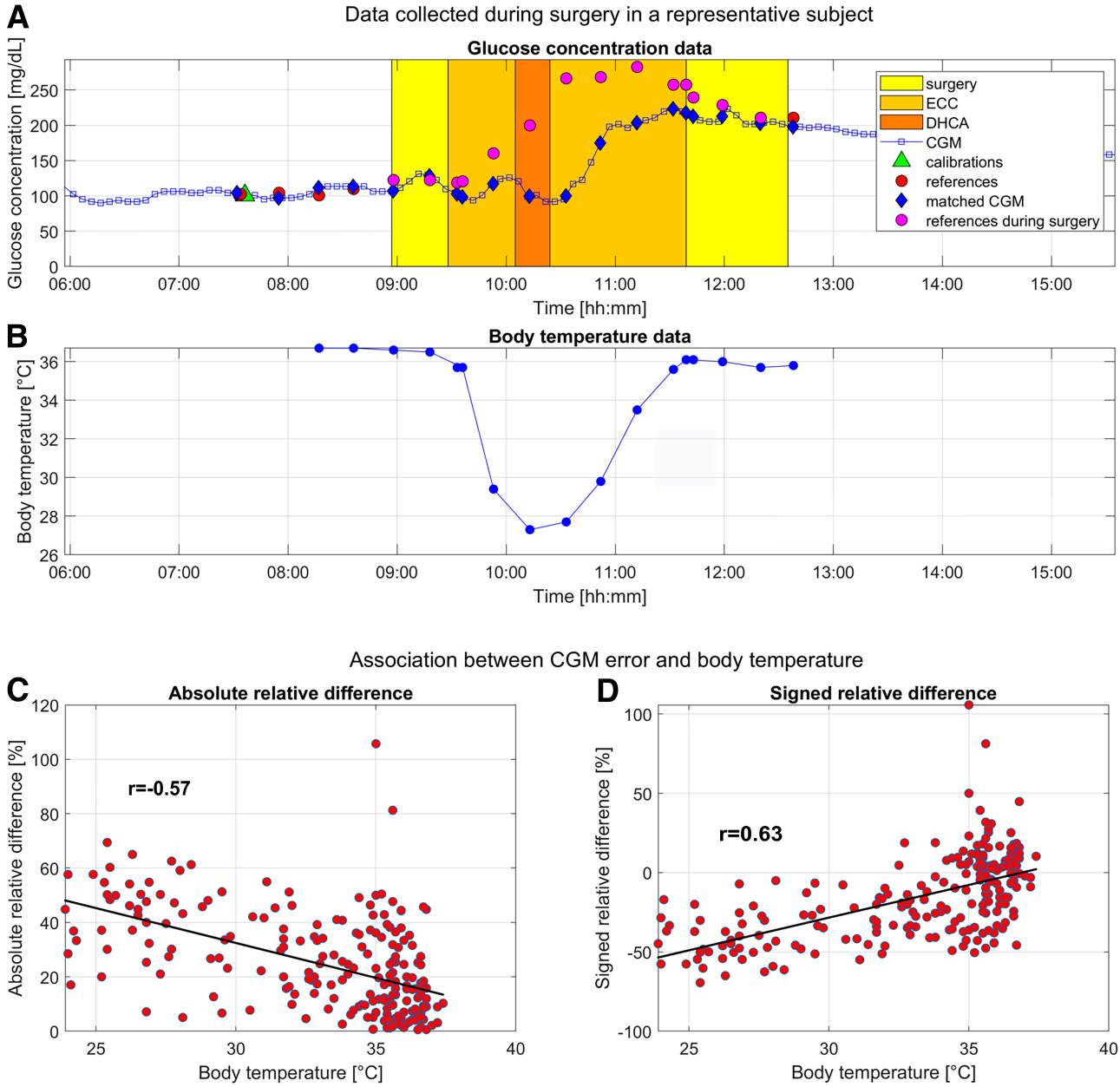

Figure 1—Time course of CGM, with reference glucose levels (*A*) and body temperature (*B*) of a patient during surgery. Scatter plots show the association between the absolute (*C*) and signed relative (*D*) CGM error and body temperature (*r* is the Pearson correlation coefficient, both $P < .001$).

sensor signal losses were observed during hypothermia (10). Similar to our observations, the sensors recovered postsurgery/hypothermia in both studies. We only identified one other study reporting CGM performance data during cardiac surgery. Of note, the study was performed in small children undergoing cardiac bypass surgery and with a different and older generation CGM system (Guardian RT, Medtronic MiniMed). While the authors provide no detailed information regarding the use of hypothermia and cardioplegia, they report a MARD of 16.6% during surgery but state that intraoperative sensor failure was experienced in 50% of the patients (11).

We observed a consistent rise in arterial blood glucose in all participants (mean ± SD 168.5 ± 49.4 mg/dL), which was likely caused to a considerable extent by the glucose-containing cardioplegic solution. Sensor measurement mostly failed to capture the initial rise in glucose (as seen in Fig. 1*A*, upper), resulting in a large discrepancy between sensor and reference glucose. While we cannot rule out that the environmental conditions in the interstitium (such as a reduced Po_2 at the measurement site) may influence the sensing process, other factors more likely explain the observed discrepancy. For example, impaired microcirculation associated with lower temperature on ECC (12,13) is likely to impair the equilibration between the vascular and interstitial compartment, thereby explaining the large discrepancies between arterial and interstitial glucose concentrations. This may be further compounded by rapid glucose dynamics (14), which were induced by the glucose-containing cardioplegic solutions (peak glucose values of 289.2 ± 46.2 mg/dL, maximum ROC of 5.0 ± 3.4 mg/dL/min, minimum

ROC of −3.8 ± 1.7 mg/dL/min). The recovery of the accuracy toward the end of the surgery, when blood glucose levels stabilize again, supports this hypothesis.

We acknowledge limitations of the current study. In particular, the number of patients is small, which results in a limited number of pairs (in particular for DHCA with only 10 CGM/reference pairs). Of note, the time dependence of body temperature and the collinearity with other variables, such as glucose and the rate of glucose change in the current study, do not allow conclusive results on the effects of body temperature on accuracy.

In conclusion, subcutaneous CGM values during cardiac surgery using hypothermic ECC and glucose-containing cardioplegic solutions do not adequately reflect glucose concentration in the vascular space. As diabetes technology continues to evolve in the inpatient perioperative setting, these limitations must be addressed to exploit the full potential of CGM use in the hospital.

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Author Contributions. D.H., A.F., and L.B. contributed to data analysis, including statistical analyses. D.H. and L.B. wrote the report. M.V. analyzed the data and produced the display items. D.P.G., A.M., D.S., J.R., A.M.C.G., G.K., L.C., A.P.V., and L.B. were responsible for screening and enrollment of participants, arranged informed consent from the participants, and provided patient care. A.P.V. and L.B. designed and coordinated the study. All authors contributed to the interpretation of the results, critically reviewed the report, and approved the final manuscript. All authors made the decision to submit for publication. D.H., M.V., and L.B. had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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