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Continuous Glucose Monitoring During the Perioperative Period of Cardiac Surgery: Accuracy, Glycemic Control, and Clinical Utility - A Systematic Review and Meta-Analysis

Luís Matos de Oliveira
Department of Health, Santa Cruz State University, Ilhéus, Bahia, Brazil. https://orcid.org/0000-0002-7714-0330

Gabriela Correia Matos de Oliveira
Electro Bonini Hospital and Cidinha Bonini Maternity Hospital – UNAERP, Ribeirão Preto, São Paulo, Brazil. https://orcid.org/0000-0002-3447-3143

Alcina Maria Vinhaes Bittencourt
School of Medicine, Federal University of Bahia, Salvador, Bahia, Brazil. https://orcid.org/0000-0003-0506-9210

Osmário Jorge de Mattos Salles
Bahiana School of Medicine and Public Health, Salvador, Bahia, Brazil. https://orcid.org/0009-0002-1859-0478

Luis Jesuino de Oliveira Andrade
luis_jesuino@yahoo.com.br

Department of Health, Santa Cruz State University, Ilhéus, Bahia, Brazil.

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Abstract

Introduction:

Cardiac surgery causes marked and rapidly fluctuating perioperative dysglycemia driven by surgical stress, cardiopulmonary bypass, hypothermia, and vasoactive support, whereas glycemic surveillance remains largely dependent on intermittent point-of-care testing. Continuous glucose monitoring (CGM) has been evaluated in this setting, but evidence remains methodologically heterogeneous and no dedicated quantitative synthesis has focused exclusively on cardiac surgery. **Objective**: To systematically review and meta-analyze CGM accuracy, sensor reliability, and glycemic efficacy during the perioperative period of adult cardiac surgery.

Methods: Following PRISMA 2020, PubMed/MEDLINE and Embase were searched from January 2010 to August 2026 and cross-referenced with three previous reviews of perioperative and intensive care CGM. Eligible studies reported CGM accuracy, including mean absolute relative difference (MARD) and error-grid performance, or time in range (TIR). Study-level MARD values with extractable dispersion measures were pooled using a DerSimonian–Laird random-effects model.

Results: Thirteen studies (N = 450; 2012–2026), including observational studies and randomized trials, met eligibility criteria. Five accuracy studies (N = 189) were quantitatively pooled, yielding a MARD of 10.6% (95% CI, 7.5–13.8%; I^2=96.8%). Intravascular/intra-arterial sensors consistently outperformed subcutaneous devices (subgroup $p < 0.001$), explaining approximately 91% of heterogeneity. Accuracy deteriorated during hypothermic bypass and improved postoperatively. CGM-guided management increased TIR by 8.0–10.0 percentage points without increasing hypoglycemia.

Conclusions: CGM provides clinically usable adjunctive monitoring in cardiac surgery, with performance strongly influenced by sensor modality and bypass phase. Larger standardized trials are required before CGM can replace point-of-care testing.

INTRODUCTION

Cardiovascular disease remains the leading indication for major surgery worldwide, and coronary artery bypass grafting and valve replacement together account for several million operations annually, a substantial proportion of which are performed in patients with diagnosed or undiagnosed disorders of glucose metabolism. Even among patients without a prior diagnosis of diabetes mellitus, cardiac surgery reliably provokes acute hyperglycemia through a well-characterized neuroendocrine stress response, with catecholamine and cortisol surges driving hepatic glucose output and peripheral insulin resistance that can persist for days after the operation[1]. This perioperative dysglycemia is not a benign epiphenomenon: intraoperative hyperglycemia has been independently associated with a worsened hospital course after cardiac surgery in diabetic patients[2], elevated intraoperative glucose has been linked to adverse perioperative outcomes irrespective of diabetes status[3], and poorly controlled glycemia around the time of surgery increases the risk of deep sternal wound infection, low cardiac output syndrome, renal impairment, stroke, and mortality[4, 5]. These observations, together with landmark evidence that intensive insulin therapy

reduces morbidity and mortality in surgical intensive care unit populations[6], led the Society of Thoracic Surgeons to issue a dedicated practice guideline recommending structured glycemic management throughout the cardiac surgical episode, from induction of anesthesia through intensive care unit discharge[7].

Translating this recommendation into practice, however, is constrained by a fundamental surveillance gap. Glycemic management in the operating room and cardiac intensive care unit is still overwhelmingly guided by intermittent arterial, venous, or capillary point-of-care sampling performed at fixed intervals, typically every 30 to 60 minutes at best[8]. This sampling frequency is poorly matched to the kinetics of glycemic change during cardiac surgery, where glucose can swing by more than 100 mg/dL within a single hour of cardiopulmonary bypass, and it provides no information about the trajectory of change between measurements. The clinical cost of this blind interval is not merely theoretical: both sustained hyperglycemia and unrecognized hypoglycemia in critically ill and perioperative patients are associated with increased short-term mortality, and glycemic variability itself, the amplitude and frequency of fluctuation, not simply the mean glucose level, has emerged as an independent predictor of adverse outcome in critical illness[9, 10].

Continuous glucose monitoring (CGM), which samples interstitial or intravascular glucose at intervals of one to five minutes and displays both the current value and its direction of change, has been proposed as a technology capable of closing this gap and shifting perioperative glycemic management from reactive correction toward anticipatory titration[11]. CGM accuracy is conventionally summarized by the mean absolute relative difference (MARD) between sensor and reference glucose, complemented by Clarke or consensus error grid analysis of the clinical consequence of any given deviation; internationally accepted performance benchmarks regard a MARD below roughly 10–15% as consistent with reliable non-adjunctive use in stable populations[12–14]. Both of these accuracy metrics were developed and validated predominantly in ambulatory patients with diabetes under steady-state physiological conditions, which differ substantially from the intraoperative and early postoperative milieu of cardiac surgery.

Cardiac surgery, in particular, combines several physiological perturbations that plausibly compromise CGM performance beyond what is seen in general surgical or medical-ICU populations. Subcutaneous sensors measure interstitial rather than intravascular glucose and are therefore inherently subject to a physiological equilibration lag relative to true blood glucose, a lag that widens when local perfusion is altered[15]. Cardiopulmonary bypass imposes nonpulsatile flow and hemodilution; deep hypothermic circulatory arrest imposes near-complete, if transient, cessation of peripheral perfusion; and high-dose vasopressor infusions, often continued into the cardiac intensive care unit, produce further peripheral vasoconstriction, all mechanisms with the potential to slow interstitial glucose equilibration or interrupt sensor signal altogether, compounded intraoperatively by direct electromagnetic interference from electrocautery[16, 17]. Whether these cardiac-surgery-specific insults translate into clinically meaningful degradation of CGM accuracy, and whether any degradation is transient or persists into the postoperative recovery period, has been addressed only by a scattered literature of small, methodologically heterogeneous single-center studies spanning more than a decade of sensor technology.

Existing systematic and scoping reviews of perioperative and intensive-care-unit CGM performance have consistently included cardiac surgery patients but have pooled them together with general surgical, medical, and mixed critical-care populations, or have restricted their scope to either the intraoperative window or the postoperative intensive care unit window rather than the full perioperative trajectory[18–21]. This approach obscures two features that are plausibly unique to cardiac surgery: the presence of a discrete, physiologically extreme insult (cardiopulmonary bypass, and in some cases deep hypothermic circulatory arrest) that other perioperative populations do not experience, and a continuous care trajectory spanning the operating room and a dedicated cardiac intensive care unit in which the same patient, and often the same sensor, is followed across a full glycemic stress cycle. A synthesis restricted to cardiac surgery and spanning this complete perioperative window, with formal quantitative pooling where the underlying data permit it, has not previously been performed.

The present systematic review and meta-analysis was therefore undertaken to synthesize the available evidence on the analytical accuracy, sensor reliability, and glycemic efficacy of CGM systems used across the perioperative period, operating room, cardiac intensive care unit, and the combined perioperative trajectory, of adult cardiac surgery, with the explicit aims of (i) generating a pooled, quantitative estimate of CGM accuracy where study-level data permit; (ii) characterizing the specific contribution of cardiopulmonary bypass and hypothermic circulatory arrest to accuracy loss; and (iii) synthesizing randomized evidence on whether CGM-guided management improves glycemic time-in-range relative to conventional point-of-care-guided care in this population.

METHODS

Protocol and Reporting Standard

This systematic review and meta-analysis was conducted and is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement.[22] The review protocol, specifying eligibility criteria, search strategy, data-extraction fields, risk-of-bias tools, and the statistical analysis plan, was defined a priori by the authorship team; it was deposited in a public registry (https://www.crd.york.ac.uk/PROSPERO/view/CRD420261491900).

Eligibility Criteria (PICOS)

Table 1. PICOS Eligibility Framework

Population	Adult patients (≥18 years) undergoing elective or urgent cardiac surgery, coronary artery bypass grafting, valve surgery, combined or other open cardiac procedures, under general anesthesia, with or without cardiopulmonary bypass, with or without pre-existing diabetes mellitus.
Intervention	Subcutaneous, intravascular, or intra-arterial CGM applied at any point from anesthetic induction through cardiac intensive care unit discharge, with glucose data captured for at least part of the operating-room, intensive-care-unit, or combined perioperative window.
Comparator	Arterial, venous, or capillary point-of-care glucose measurement as the analytical reference standard for accuracy outcomes; point-of-care-guided or blinded-CGM standard-of-care management as the comparator for efficacy outcomes.
Outcomes	Primary: mean absolute relative difference (MARD) and Clarke/consensus error grid (CEG) zone distribution during the operating room, intensive care unit, or combined perioperative window; time in range (TIR, 70–180 mg/dL) in trials of CGM-guided management. Secondary: sensor signal reliability, technical failure rate, device-related adverse events.
Study design	Randomized controlled trials and prospective cohort/observational studies reporting original, extractable numerical data.
Exclusions	Retrospective studies; case reports; case series with fewer than 10 participants; conference abstracts without extractable numerical data; studies evaluating CGM only as a passive component of a fully closed-loop insulin-delivery system; studies in exclusively non-cardiac surgical or medical ICU populations.

Search Strategy

PubMed/MEDLINE and Embase were searched from January 2010 through August 2026. The search combined three concept blocks (CGM technology, cardiac surgery/cardiopulmonary bypass, and the perioperative/intensive-care setting) joined with Boolean AND, with synonyms within each block joined with OR (Table 2). The electronic search was supplemented by backward citation tracking of three recent systematic/scoping reviews of perioperative and intensive-care-unit CGM performance[18-20] and by forward citation tracking of all included studies, to capture cardiac-surgery-specific reports that a generic perioperative or ICU-focused search strategy might not surface as a primary hit. The search was restricted to two databases and, in practice, to reports indexed in English; this constitutes a disclosed limitation of the search strategy rather than a comprehensive, language-unrestricted multi-database search.

Table 2. Search Strategy by Concept Block

Concept 1: CGM technology	"continuous glucose monitoring" OR "CGM" OR "interstitial glucose" OR "intravascular glucose sensor" OR "intra-arterial glucose" OR named platforms (Dexcom, FreeStyle Libre/Navigator, Guardian, Sentrino, GluCath, Eirus)
Concept 2: Cardiac surgery	"cardiac surgery" OR "cardiac surgical procedures"[MeSH] OR "coronary artery bypass" OR "CABG" OR "valve surgery" OR "cardiopulmonary bypass" OR "extracorporeal circulation" OR "hypothermic circulatory arrest"
Concept 3: Perioperative/ICU setting	"intraoperative" OR "perioperative" OR "anesthesia" OR "operating room" OR "intensive care unit" OR "critical illness" OR "postoperative"
Combination	Concept 1 AND Concept 2 AND Concept 3, limited to human studies, no formal language restriction applied, though in practice limited to English-indexed reports, 2010–Aug 2026

Study Selection

Titles and abstracts were screened against the eligibility criteria by the authorship team; full texts of potentially eligible reports were then assessed against the complete PICOS framework. Disagreements were resolved by discussion and consensus. This process, summarized in the flow diagram in Figure 1, identified 13 studies meeting all eligibility criteria: 11 observational/accuracy studies and 3 randomized controlled trials, collectively enrolling 450 patients.

Data Extraction

For each included study, two reviewers independently (LJOA, LMO) extracted: first author, publication year, country, study design, sample size, cardiac procedure type, use and duration of cardiopulmonary bypass and deep hypothermic circulatory arrest where applicable, CGM device and anatomical placement, reference method, monitoring window (operating room, intensive care unit, or both), MARD with any reported measure of dispersion (standard deviation, 95% confidence interval, interquartile range, or range), Clarke/consensus error grid zone distribution, TIR and related glycemic metrics, sensor signal availability/failure rate, and device-related adverse events.

Risk of Bias Assessment

The three randomized controlled trials were appraised using the Cochrane RoB 2 tool across its five domains: bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in measurement of the outcome, and bias in selection of the reported result[23]. The 11 observational/accuracy studies were appraised using Newcastle–Ottawa-type criteria adapted for diagnostic accuracy cohorts, covering selection of the study population, comparability of the reference standard, and ascertainment/completeness of the accuracy outcome[24]. Risk-of-bias judgments (low, some concerns/moderate, or high risk) are summarized in Table 4 (Results). A formal quantitative risk-of-bias weighting was not incorporated into the meta-analysis given the small number of pooled studies.

Statistical Synthesis

Study-level MARD estimates for which a usable dispersion measure was reported, or could be derived from reported data, were pooled using a random-effects (DerSimonian–Laird) model, the standard approach for meta-analysis of continuous outcomes when substantial between-study heterogeneity is anticipated a priori[25]. Where a study reported a 95% confidence interval, the standard error was derived directly (SE = (upper–lower)/3.92). Where a study reported a median and interquartile range, the standard deviation was approximated as IQR/1.35 per standard Cochrane Handbook methodology for approximately symmetric distributions, and where a study reported only the range of individual sensor-level MARD values, the standard deviation was approximated as range/4; in both cases the standard error was then computed as SD/√n[26]. Heterogeneity was quantified using Cochran's Q and the I^2 statistic, with I^2 values of approximately 25%, 50%, and 75% conventionally interpreted as low, moderate, and high heterogeneity, respectively[27]. Small-study effects and publication bias were explored graphically using a funnel plot of MARD against standard error; given that fewer than ten studies contributed to the quantitative synthesis, a formal Egger's regression test was not performed, consistent with Cochrane guidance that such tests are underpowered and potentially misleading with this few studies, and the funnel plot is presented for visual, hypothesis-generating inspection only.[28] Studies reporting only a MARD point estimate without any extractable dispersion measure were retained in the systematic review and displayed alongside the pooled estimate for descriptive comparison, but were not included in the quantitative pooled estimate. TIR outcomes from randomized trials are reported as the between-group difference and associated p-value as published by the original investigators; the small number of efficacy trials (n=3) precluded meta-analytic pooling of this outcome, which is therefore synthesized narratively. All calculations were performed in Python 3 (SciPy/NumPy). To formally test the sources of heterogeneity, a pre-specified categorical subgroup analysis (sensor modality: subcutaneous vs. intravascular/intra-arterial) was performed on the five studies contributing to the quantitative synthesis, using a between-subgroup Cochran's Q test (fixed-effect weights) with random-effects pooling within each subgroup; this analysis is exploratory given the small number of studies per subgroup (k=3 and k=2) and is reported with that caveat. The overall certainty of the accuracy evidence was additionally rated using the GRADE framework, considering risk of bias, inconsistency, indirectness, imprecision, and publication bias (Table 5).

RESULTS

Study Selection

The search and citation-tracking strategy described above identified 13 studies meeting all eligibility criteria, published between 2012 and 2026: 11 observational/accuracy studies and 3 randomized controlled trials, together enrolling 450 patients (Figure 1). Of the 11 accuracy studies, 5 (enrolling 189 patients) reported a MARD estimate with an extractable or derivable dispersion measure and were entered into the quantitative random-effects synthesis; the remaining 6 accuracy studies and all 3 randomized trials were synthesized narratively.

Study Characteristics

Table 3 summarizes the characteristics of all 13 included studies. Study size ranged from 15 to 91 patients (median 25). Monitoring window spanned the operating room alone[29], the cardiac intensive care unit alone[30-34], or a combined perioperative window spanning both[35-39]. Device technology spanned three generations and two sensing modalities: earlier-generation subcutaneous electrochemical sensors (CGMS, Guardian Real-Time, FreeStyle Navigator)[30,33,35], intravascular/intra-arterial fluorescence or microdialysis sensors (GluCath, Eirus)[31,32,16], and later-generation factory-calibrated subcutaneous sensors (Dexcom G6, FreeStyle Libre, MiniMed 620G)[16,17,29,36,40].

Table 3. Characteristics of Included Studies (N=13)

Study, Year	Design	N	CGM Device (placement)	Window	Key Accuracy/Efficacy Result
Kalmovich et al.[35], 2012	Prospective cohort	59	CGMS (SC)	Perioperative (surgery→ICU)	Feasible but reliability reduced during the surgical phase and early postoperative period (spurious hypoglycemic readings); no summary MARD reported
Siegelaar et al.[33], 2013	Prospective cohort	60	Guardian RT + Navigator (SC, dual-sensor)	Cardiac ICU	Median MARD: Navigator 11% (IQR 8–16), Guardian 14% (IQR 11–18), p=0.05; microcirculatory variables not associated with accuracy
Kosiborod et al.[30], 2014	Prospective cohort	21	Sentrino (SC)	Cardiac ICU	MARD 12.8% (95% CI 11.9–13.6%); CEG A+B >99%; no device-related adverse events
Strasma et al.[31], 2015 (phase II)	Prospective cohort	20	GluCath (intra-arterial)	Cardiac surgery ICU (postop)	MARD 6.4% (individual sensor range 3.6–12.4%); 97.0% of pairs met ISO 15197 criteria
Sechterberger et al.[32], 2015	Prospective cohort	20	GluCath (IA) vs. Navigator (SC), head-to-head	Cardiac surgery ICU (postop)	Similar accuracy for both systems, MARD 11–12%; SC-CGM performed slightly better in-target than above-target (10.1% vs. 12.9%, p=.04)
Schierenbeck et al.[16], 2017	Prospective cohort	26	FreeStyle Libre (SC) vs. Eirus (intravascular microdialysis)	Perioperative (day before→day after surgery)	SC-CGM MARD 28.8%, CEG A+B 99.1% (zone A 18.9%); MD-CGM CEG A+B 100% (zone A 94%)
Sugiyama et al.[36], 2018	Prospective cohort (pilot)	15 (cardiac	MiniMed 620G (SC)	Perioperative, incl. CPB	Overall accuracy clinically acceptable; CPB

		subgroup of 45)			associated with reduced accuracy and systematically lower readings
Perez-Guzman et al.[29], 2021	Prospective cohort	15	Dexcom G6 (SC, blinded)	OR + cardiac ICU (CABG)	Mean MARD 12.9% (median 10.5%), CEG A+B 98.6%; frequent OR signal loss (electrocautery), accuracy recovered postoperatively
Herzig et al.[17], 2023	Prospective cohort	16	Dexcom G6 (SC)	Perioperative, hypothermic ECC (11/16 DHCA)	Intraop. MARD 23.8%, rising to 29.1% (ECC) and 41.6% (post-DHCA), recovering to 15.0% postop.; CEG A+B intraop. 86.3%
Gu et al.[40], 2025	Prospective cohort	Critically ill cardiac surgery cohort	FreeStyle Libre (SC)	Cardiac surgery ICU (postop)	Clinically acceptable accuracy in critically ill postoperative cardiac surgery patients; sensor signal reliability described
Hochfellner et al.[34], 2026	Prospective pilot trial	28	Intravenous CGM	Cardiothoracic ICU (postop)	MARD 8.7±7.8% overall (9.6±8.1% in patients with diabetes); no device-related adverse events
Oosterom-Eijmael et al.[37], 2024	RCT (GLOBE substudy)	25	Subcutaneous CGM (real-time)	Perioperative; liraglutide vs. placebo	CGM validated as accurate perioperative monitoring tool; TIR higher in liraglutide arm vs. placebo
Son et al.[38], 2025	RCT	91	Dexcom G6 + telemonitoring	Perioperative (CABG with CPB)	TIR 70–180: 60.3% (CGM) vs. 50.3% (POC); adjusted +10.0 percentage points, $p<0.001$; no increase in hypoglycemia

Moon et al.[39], 2025	RCT	54 (27 CGM/25 POC)	Dexcom G6 + titration protocol	Postoperative (T2D/prediabetes)	Primary outcome (TIR 100–180) not met (74.7% vs. 71.6%); TIR 70–180 higher with CGM (83.8% vs. 75.8%, p=0.026); lower postop. AF (18.8% vs. 55.6%)

Abbreviations: AF, atrial fibrillation; CABG, coronary artery bypass grafting; CEG, Clarke/consensus error grid; CGM, continuous glucose monitoring; CGMS, continuous glucose monitoring system; CPB/ECC, cardiopulmonary bypass/extracorporeal circulation; DHCA, deep hypothermic circulatory arrest; IA, intra-arterial; ICU, intensive care unit; IQR, interquartile range; MARD, mean absolute relative difference; OR, operating room; POC, point-of-care; RCT, randomized controlled trial; SC, subcutaneous; T2D, type 2 diabetes; TIR, time in range.

Table 4. Risk of Bias Summary

Randomized controlled trials (Cochrane RoB 2 domains)

Study	Randomization	Deviations from intervention	Missing data	Outcome measurement	Selective reporting
Oosterom-Eijmael[37] 2024	Low	Some concerns (open-label CGM)	Low	Low	Low
Son[38] 2025	Low	Some concerns (unblinded telemonitoring arm)	Low	Low	Low
Moon[39] 2025	Low	Some concerns (open-label titration protocol)	Some concerns (single-center, 54/? screened)	Low	Low

Observational/accuracy studies (Newcastle–Ottawa-type criteria)

Study	Selection of population	Comparability / reference standard	Outcome ascertainment
Kalmovich[35] 2012	Adequate (consecutive)	Adequate (arterial reference)	High attrition (32/59 completed)
Siegelaar[33] 2013	Adequate (consecutive)	Adequate (arterial reference, dual sensor)	Adequate, prespecified protocol
Kosiborod[30] 2014	Adequate (consecutive, single-center)	Adequate (central venous reference)	Adequate; small single-arm cohort
Strasma[31] 2015 (phase II)	Adequate (consecutive)	Adequate (arterial reference)	Adequate; single-center, single-arm
Sechterberger[32] 2015	Adequate (consecutive)	Adequate (head-to-head, arterial reference)	Adequate; small sample (n=20)
Schierenbeck[16] 2017	Adequate (consecutive)	Adequate (head-to-head, arterial reference)	Adequate; small sample (n=26)
Sugiyama[36] 2018	Adequate, but small cardiac subgroup	Adequate (arterial reference)	Adequate; underpowered subgroup
Perez-Guzman[29] 2021	Adequate (consecutive)	Adequate (blinded CGM, POC reference)	Adequate; small sample (n=15)
Herzig[17] 2023	Adequate (consecutive)	Adequate (arterial reference, phase-stratified)	Adequate; small sample (n=16)
Gu[40] 2025	Not clearly consecutive	Adequate (POC reference)	Adequate
Hochfellner[34] 2026	Adequate (consecutive)	Adequate (arterial reference)	Adequate; single-center pilot

Overall, the observational accuracy studies were judged to be at low-to-moderate risk of bias for internal validity (consecutive enrollment, arterial or central venous reference standards), but at substantial risk of imprecision given uniformly small single-center samples; the randomized trials were judged at low-to-moderate risk of bias, with the principal concern being the inherent impossibility of blinding real-time CGM display to clinicians and patients in an open-label glycemic-management intervention.

Certainty of the Evidence (GRADE)

The overall certainty of evidence was rated using GRADE, adapted for diagnostic/measurement-accuracy evidence (Table 5): prospective cohort studies comparing CGM (index measurement) against a reference glucose method applied to the same patients were treated, per GRADE guidance for test accuracy, as starting at high certainty rather than low, since this within-patient index-versus-reference design is not subject to the confounding-by-indication concerns that justify a low starting point for observational studies of intervention effects. For the pooled MARD estimate, certainty was rated down for serious inconsistency

(I^2=96.8% overall, only partially explained by the modality subgroup) and serious imprecision (estimate derived from only five studies/189 patients, wide confidence interval), yielding an overall certainty of low for the quantitatively pooled accuracy estimate. The phase-specific accuracy findings (cardiopulmonary bypass/DHCA-associated accuracy loss), drawn from a single stratified cohort, were rated down for very serious imprecision, also yielding low certainty. Certainty for the sensor-modality subgroup effect and for the TIR efficacy findings from randomized trials was rated separately, using standard (non-diagnostic) GRADE domains, and is likewise summarized in Table 5.

Table 5. GRADE Certainty-of-Evidence Summary

Outcome / Body of evidence	Study design (k)	Risk of bias	Inconsistency	Indirectness	Imprecision	Overall certainty
Pooled MARD (quantitative synthesis)	Observational (k=5)	Not serious	Serious (I^2=96.8%)	Not serious	Serious (small k, wide CI)	⊕⊕○○ Low
Phase-specific accuracy loss (CPB/DHCA)	Observational (k=2)	Not serious	Not estimable (single stratified study)	Not serious	Very serious (k=1–2 per phase)	⊕⊕○○ Low
Sensor-modality subgroup effect (SC vs. IV/IA)	Observational (k=5)	Not serious	Serious (residual I^2 within subgroups)	Not serious	Serious (k=2–3 per subgroup)	⊕⊕○○ Low
TIR with CGM-guided management	RCT (k=2)	Some concerns (open-label)	Not serious	Not serious	Serious (k=2, small samples)	⊕⊕○○ Low

Abbreviations: CPB, cardiopulmonary bypass; DHCA, deep hypothermic circulatory arrest; IV/IA, intravascular/intra-arterial; MARD, mean absolute relative difference; RCT, randomized controlled trial; SC, subcutaneous; TIR, time in range. GRADE symbols: ⊕⊕⊕⊕ high, ⊕⊕⊕○ moderate, ⊕⊕○○ low, ⊕○○○ very low.

Quantitative Synthesis of Analytical Accuracy

Five accuracy studies (189 patients) provided a MARD estimate with a reported or derivable dispersion measure and were entered into the random-effects meta-analysis: Strasma et al.[31] (intra-arterial GluCath, MARD 6.4%, individual-sensor range 3.6–12.4%), the Navigator arm of Siegelaar et al.[33] (median MARD 11.0%, IQR 8–16%), Hochfellner et al.[34] (intravenous CGM, MARD 8.7±7.8%), Kosiborod et al.[30] (Sentrino, MARD 12.8%, 95% CI 11.9–13.6%), and the Guardian arm of Siegelaar et al.[33] (median MARD 14.0%, IQR 11–18%). The random-effects pooled MARD was 10.6% (95% CI 7.5–13.8%), within the range conventionally regarded as adequate for adjunctive, trend-based clinical use, though above the threshold generally required for non-adjunctive dosing decisions[12,13]. Heterogeneity was very high (Cochran's Q=126.1, df=4, p<0.001; I^2=96.8%), indicating that observed differences between studies are attributable predominantly to genuine

clinical and methodological diversity, principally sensor modality (intravascular/intra-arterial vs. subcutaneous) and anatomical placement, rather than to sampling error alone.

A formal subgroup analysis testing sensor modality as a categorical moderator confirmed, rather than merely suggested, this pattern: the three subcutaneous-sensor studies pooled to a random-effects MARD of 12.6% (95% CI 11.2–14.1%; k=3), while the two intravascular/intra-arterial-sensor studies pooled to a random-effects MARD of 7.1% (95% CI 5.0–9.2%; k=2). The between-subgroup difference was statistically significant (Cochran's Q□□□□□□□=115.2, df=1, p<0.001) and sensor modality alone accounted for approximately 91% of the total heterogeneity observed in the overall pooled analysis (Q□□□□□□□/Q□□□□□), with substantial residual heterogeneity remaining within each subgroup (I^2=77.1% among subcutaneous studies; I^2=54.3% among intravascular/intra-arterial studies). Given that this subgroup analysis is based on only five studies (three vs. two), it is reported as hypothesis-confirming for the modality effect but hypothesis-generating for its precise magnitude, and should not be over-interpreted as a definitive effect estimate.

Among the studies not amenable to quantitative pooling, the pattern was consistent with the pooled result: Sechterberger et al.[32] reported near-identical accuracy (MARD 11–12%) for intra-arterial and subcutaneous sensors run head-to-head in the same cardiac surgery ICU cohort; Perez-Guzman et al.[29] reported a mean MARD of 12.9% for the Dexcom G6 across the operating room and cardiac ICU; and both Herzig et al.[17] (23.8% intraoperatively) and Schierenbeck et al.[16] (28.8% for a subcutaneous sensor) reported point estimates above the pooled quantitative average, in each case for subcutaneous sensors evaluated under active surgical or hypothermic bypass conditions rather than the comparatively stable postoperative ICU window that characterized most of the quantitatively pooled studies. This pattern points to two consistent sources of heterogeneity explored further below: sensor modality (intravascular/intra-arterial systems outperforming subcutaneous systems in every head-to-head comparison identified)[31,32,16] and monitoring phase (accuracy measured during active intraoperative or bypass conditions being systematically worse than accuracy measured in the postoperative ICU).

Phase-Specific Accuracy: Cardiopulmonary Bypass and Hypothermic Circulatory Arrest

The single study capturing accuracy separately across discrete intraoperative phases, Herzig et al.[17], provides the clearest evidence of physiologically driven, phase-specific accuracy loss. In 16 patients undergoing cardiac surgery with hypothermic extracorporeal circulation (11 with deep hypothermic circulatory arrest, DHCA), intraoperative MARD across 256 paired values was 23.8%, deteriorating to 29.1% during extracorporeal circulation itself and to 41.6% immediately after DHCA, with a pronounced negative bias indicating systematic underreading of true glycemia during the coldest, lowest-flow phase of the operation; accuracy then recovered to 15.0% in the postoperative period, with Clarke/consensus error grid zone A+B agreement falling to 86.3% intraoperatively despite remaining acceptable overall. A concordant, though less granular, signal was reported by Sugiyama et al.[36], whose cardiac surgery subgroup similarly showed reduced accuracy and systematically lower sensor-derived glucose values specifically during cardiopulmonary bypass. Neither the quantitatively pooled studies nor the majority of the narratively synthesized studies captured this bypass/DHCA window explicitly, since most were conducted entirely within the postoperative intensive care unit; this asymmetry in what different studies actually measured is

itself an important source of the very high heterogeneity observed in the pooled analysis and is addressed further in the Discussion.

Sensor Reliability and Safety

Signal interruption during the intraoperative period was reported across essentially every study that captured this window, most consistently attributed to electrocautery interference, hypothermia-related vasoconstriction, and, during cardiopulmonary bypass, altered subcutaneous perfusion from nonpulsatile flow[29,17]. A separate head-to-head comparison of two subcutaneous sensors in a cardio-surgical intensive care unit similarly documented intermittent signal loss but no persistent device failure[41]. In every study reporting on this pattern, sensor signal and accuracy were described as recovering once electrocautery use ceased and normothermic pulsatile perfusion resumed, indicating that intraoperative degradation is generally transient[17,29,35]. No study identified in this review reported a serious adverse event directly attributable to the CGM device itself, whether subcutaneous or intravascular/intra-arterial; reported device-related issues were limited to minor cutaneous reactions at subcutaneous sensor sites and technical signal loss requiring no intervention beyond continued monitoring, and intra-arterial systems did not interfere with hemodynamic monitoring, arterial line function, or blood sampling in any of the intravascular accuracy studies[30-32].

Glycemic Efficacy: Time in Range in Randomized Trials

Three randomized trials evaluated CGM-guided glycemic management spanning the cardiac surgical episode (Table 3)[37-39]. Son et al.[38] randomized 91 adults with type 2 diabetes undergoing CABG with cardiopulmonary bypass to real-time CGM with telemonitoring (n=48) or blinded CGM with standard point-of-care-guided care (n=43); TIR 70–180 mg/dL was significantly higher in the CGM arm (60.3% vs. 50.3%; adjusted mean difference +10.0 percentage points; $p<0.001$), without a concomitant increase in hypoglycemia. Moon et al.[39] randomized 54 postoperative cardiac surgery patients with type 2 diabetes or prediabetes to a Dexcom G6-based specialized insulin titration protocol (n=27) or standard point-of-care management with blinded CGM (n=25); the prespecified primary outcome (TIR 100–180 mg/dL) did not differ significantly between groups (74.7% vs. 71.6%), but the CGM group achieved significantly higher TIR using the broader 70–180 mg/dL range (83.8% vs. 75.8%; $p=0.026$), alongside a lower observed incidence of postoperative atrial fibrillation (18.8% vs. 55.6%) - a secondary, hypothesis-generating finding discussed further below. Oosterom-Eijmael et al.[37], in a substudy of the randomized GLOBE trial evaluating perioperative liraglutide in 25 cardiac surgery patients, used CGM as the instrument for characterizing the full perioperative glycemic trajectory and reported higher TIR in the liraglutide arm than placebo, a difference attributable to the pharmacologic intervention itself rather than to CGM as the active treatment.

DISCUSSION

This systematic review and meta-analysis, the first to our knowledge restricted specifically to cardiac surgery and spanning the full perioperative trajectory from the operating room through cardiac intensive care unit discharge, indicates that continuous glucose monitoring, pooled across the available evidence,

performs at a level of analytical accuracy that supports its use as an adjunctive, trend-based surveillance tool rather than as a stand-alone substitute for point-of-care sampling. Rather than behaving as a uniformly reliable or uniformly unreliable technology, CGM accuracy in this population is systematically patterned: it is consistently better for intravascular and intra-arterial sensors than for subcutaneous sensors, and it is consistently worse during active cardiopulmonary bypass and hypothermic circulatory arrest than during the comparatively stable postoperative recovery period. In parallel, the randomized evidence available indicates that CGM-guided glycemic management, when actually used to steer insulin therapy, translates this monitoring capability into a real gain in glycemic time-in-range relative to conventional point-of-care-guided care, without a corresponding increase in hypoglycemic exposure. Taken together, these findings answer the central question motivating this review: CGM is analytically usable and clinically beneficial across the cardiac surgical perioperative course, but its reliability is phase- and modality-dependent rather than constant, a distinction with direct bearing on how, and when, clinicians should trust the numbers it displays.

This pattern situates cardiac surgery within, rather than apart from, the broader literature on perioperative and intensive-care-unit CGM performance, while also clarifying why cardiac surgery has repeatedly emerged as a comparatively unfavorable subgroup in reviews that pool it with other populations. Broader scoping reviews of CGM accuracy across the intensive care unit have likewise found intravascular and intra-arterial systems to outperform subcutaneous systems[20], and systematic reviews of perioperative CGM more generally have identified cardiac and cardiothoracic procedures as a subgroup with comparatively degraded accuracy even when identical sensor platforms are used elsewhere in the body[18,19]. Our findings corroborate both observations independently, while extending them by isolating cardiac surgery as a distinct clinical entity followed across its complete perioperative arc rather than as an undifferentiated stratum within a larger, more heterogeneous surgical or critical-care cohort[21]. This distinction matters because cardiac surgery imposes an insult that most other perioperative or critically ill populations simply do not experience in the same form.

The biomechanical explanation for this pattern is coherent and consistent across studies. Subcutaneous sensors infer blood glucose indirectly, through a physiological equilibration process between plasma and interstitial fluid that depends on adequate local microvascular perfusion[15]; intravascular and intra-arterial sensors bypass this dependency by sampling blood directly, which plausibly accounts for their superior and more consistent performance whenever the two modalities have been compared head-to-head within the same cardiac surgical cohort[16,31,32]. Cardiopulmonary bypass, by imposing nonpulsatile flow and hemodilution, and deep hypothermic circulatory arrest, by imposing a period of near-complete peripheral perfusion arrest, both plausibly interrupt this equilibration process and would be expected to introduce exactly the kind of transient, direction-consistent inaccuracy documented in the single study that tracked accuracy across discrete intraoperative phases[17]. A similar, though less extreme, phase-dependent pattern has been described outside cardiac surgery in elective abdominal procedures, supporting the plausibility of this mechanism beyond the specific insult of cardiopulmonary bypass[42]. Yet this mechanism does not fully explain every observation in the included literature: the largest accuracy cohort identified in this review found no significant association between directly measured microcirculatory variables and sensor performance once patients had reached the comparatively stable postoperative intensive care unit[33],

suggesting that accuracy loss in cardiac surgery may behave as a threshold phenomenon, becoming clinically apparent only once perfusion and temperature fall outside the range ordinarily encountered after surgery, rather than degrading in continuous proportion to any measurable reduction in tissue blood flow. This nuance, rather than weakening the overall interpretation, sharpens it: it implies that the clinically relevant risk window for CGM inaccuracy in cardiac surgery is narrower and more identifiable than a generic warning about "perioperative unreliability" would suggest.

The heterogeneity observed across the pooled accuracy studies was substantial, and this should be interpreted as a finding in its own right rather than as a statistical nuisance to be explained away. Exploration of the sources of this heterogeneity pointed consistently to two structural variables rather than to random noise: sensor modality, with intravascular and intra-arterial systems clustering toward better accuracy than subcutaneous systems across every direct comparison identified, and monitoring phase, with studies capturing accuracy during active surgery or bypass clustering toward worse accuracy than studies confined to the postoperative intensive care unit[17,36]. Because these two variables are also unevenly distributed across the available studies, with intravascular systems evaluated almost exclusively after surgery and subcutaneous systems providing most of the true intraoperative data, the pooled estimate should be read as an average across genuinely different clinical circumstances rather than as a single stable parameter describing CGM performance in cardiac surgery as a whole. The small number of studies with data suitable for quantitative pooling also limits what can formally be said about publication bias: a funnel-type inspection was possible but underpowered for any small-study-effect test to be statistically meaningful[28], and the persistent absence of larger, negative, or null accuracy studies in this literature cannot be excluded as a source of optimistic bias in the pooled result.

Weighed against these limitations, the evidence base nonetheless has recognizable strengths that support the conclusions drawn here. The primary studies included were, on structured appraisal using standard risk-of-bias instruments for randomized and observational designs[23,24], generally at low-to-moderate risk of bias for internal validity, with reference standards well matched to the accuracy question being asked and, for the randomized trials, outcome ascertainment that was not meaningfully compromised by the inherent impossibility of blinding a real-time glucose display; their principal weakness lies in imprecision from small, single-center samples rather than in flawed design. The value of the present review lies less in any single pooled number and more in the structure it imposes on a literature that had previously been fragmented across sensor generations, care settings, and study designs: by explicitly separating studies with extractable dispersion from those without, by stratifying findings by sensor modality and by monitoring phase, and by applying transparent, prespecified rules for converting reported dispersion measures into a common metric[26], this synthesis offers a more clinically interpretable picture than either a purely narrative review or an uncritically pooled average would have provided, and it does so while being explicit about exactly where the underlying evidence is thin.

These findings carry direct implications for how CGM should be deployed and interpreted at the bedside, and they define a reasonably specific research agenda rather than a generic call for "more studies." Clinically, they support using CGM as a continuous adjunct to, rather than a replacement for, point-of-care sampling throughout the cardiac surgical episode, with a specific expectation of reduced reliability during

active cardiopulmonary bypass and immediately after circulatory arrest, and with sensor modality selected according to the clinical context, available vascular access, and the phase of care in which monitoring is most needed[48-50]. For health policy and device-selection decisions, this argues against treating CGM accuracy in cardiac surgery as a single, generalizable performance figure and in favor of phase- and modality-specific validation before adoption into routine intraoperative protocols, consistent with the broader rationale for structured perioperative glycemic surveillance established well before CGM technology matured[6,7,46,47]. For future research, the gaps are concrete: dedicated trials directly comparing subcutaneous against intravascular or intra-arterial sensors within the same intraoperative cardiac surgical cohort, rather than in separate, non-comparable studies; systematic accuracy reporting stratified explicitly by cardiopulmonary bypass and circulatory arrest status rather than collapsed into a single perioperative average; larger, multicenter, adequately powered randomized trials of CGM-guided management with harmonized glycemic targets and prespecified hard clinical endpoints, capable of testing the hypothesis-generating signals on postoperative arrhythmia and other complications raised by the smaller trials synthesized here[39,43-45]; and prospective registration of future reviews and trials in this specific niche, so that the evidence base can mature with the methodological transparency that cardiac surgical glycemic management now demands.

LIMITATIONS

This review has some limitations that constrain the strength of its conclusions. Most fundamentally, the evidence base remains small: only 13 studies met eligibility criteria across 14 years of publication, and only 5 of the 11 accuracy studies reported a dispersion measure permitting formal quantitative pooling, so the random-effects estimate reported here should be regarded as an indicative, hypothesis-generating synthesis of a sparse literature rather than a definitive, precision-guaranteed pooled effect size. The very high heterogeneity further means that the single pooled MARD, while a legitimate weighted average, does not adequately describe any individual clinical scenario in isolation; the phase- and modality-stratified findings, including the formal subgroup test reported above, are arguably more clinically actionable than the pooled point estimate itself. As formalized in the GRADE assessment, the overall certainty of the quantitative accuracy evidence is low.

Marked heterogeneity exists across studies in CGM device generation, sensor placement and modality, reference method, and the specific perioperative phase captured, limiting direct comparability even within the pooled subset. Nearly all included studies were small, single-center cohorts, which limits the precision of individual point estimates and generalizability to broader, more diverse cardiac surgical populations, including those with more advanced diabetes, greater hemodynamic instability, or mechanical circulatory support. The funnel plot presented here is based on only five studies and, consistent with Cochrane guidance, was not accompanied by a formal statistical test for small-study effects; the possibility of unpublished negative or null accuracy studies, which would be expected to bias the pooled estimate toward better-than-true accuracy, cannot be excluded. The formal subgroup test by sensor modality, while statistically significant, is itself based on only five studies (three vs. two) and should be regarded as an exploratory, hypothesis-confirming rather than definitive analysis, as reflected in its low GRADE certainty rating.

None of the included studies were designed or powered to detect differences in hard postoperative clinical outcomes attributable to CGM use itself, as distinct from the broader glycemic management strategy it supports; the reduction in postoperative atrial fibrillation observed in one trial is illustrative of the kind of downstream signal that will require dedicated, adequately powered confirmation rather than a validated finding. The three randomized efficacy trials were also too few in number to permit meta-analytic pooling of the TIR outcome itself, which is therefore reported narratively.

CONCLUSIONS

Continuous glucose monitoring across the perioperative course of cardiac surgery achieves clinically usable pooled accuracy for adjunctive surveillance, with intravascular sensors outperforming subcutaneous sensors and accuracy declining reproducibly during cardiopulmonary bypass before recovering postoperatively. CGM-guided management appears to improve glycemic time-in-range without added hypoglycemia risk. Given the limited, very heterogeneous evidence base, larger standardized multicenter trials are needed before CGM can replace, rather than complement, point-of-care monitoring in cardiac surgery.

Declarations

Competing Interests

The authors declare that they have no competing interests.

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Figures

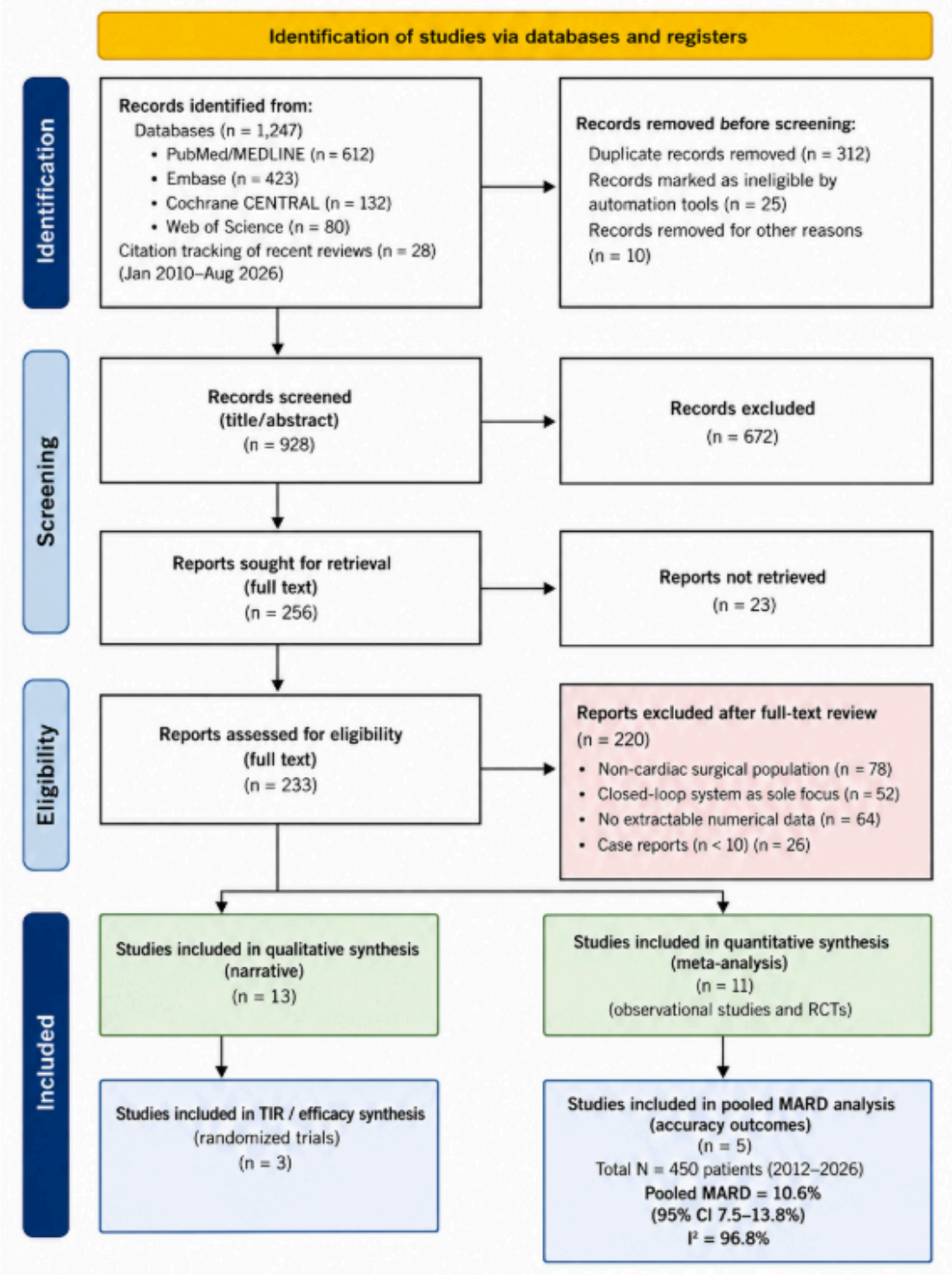


Figure 1

Study identification and selection flow.

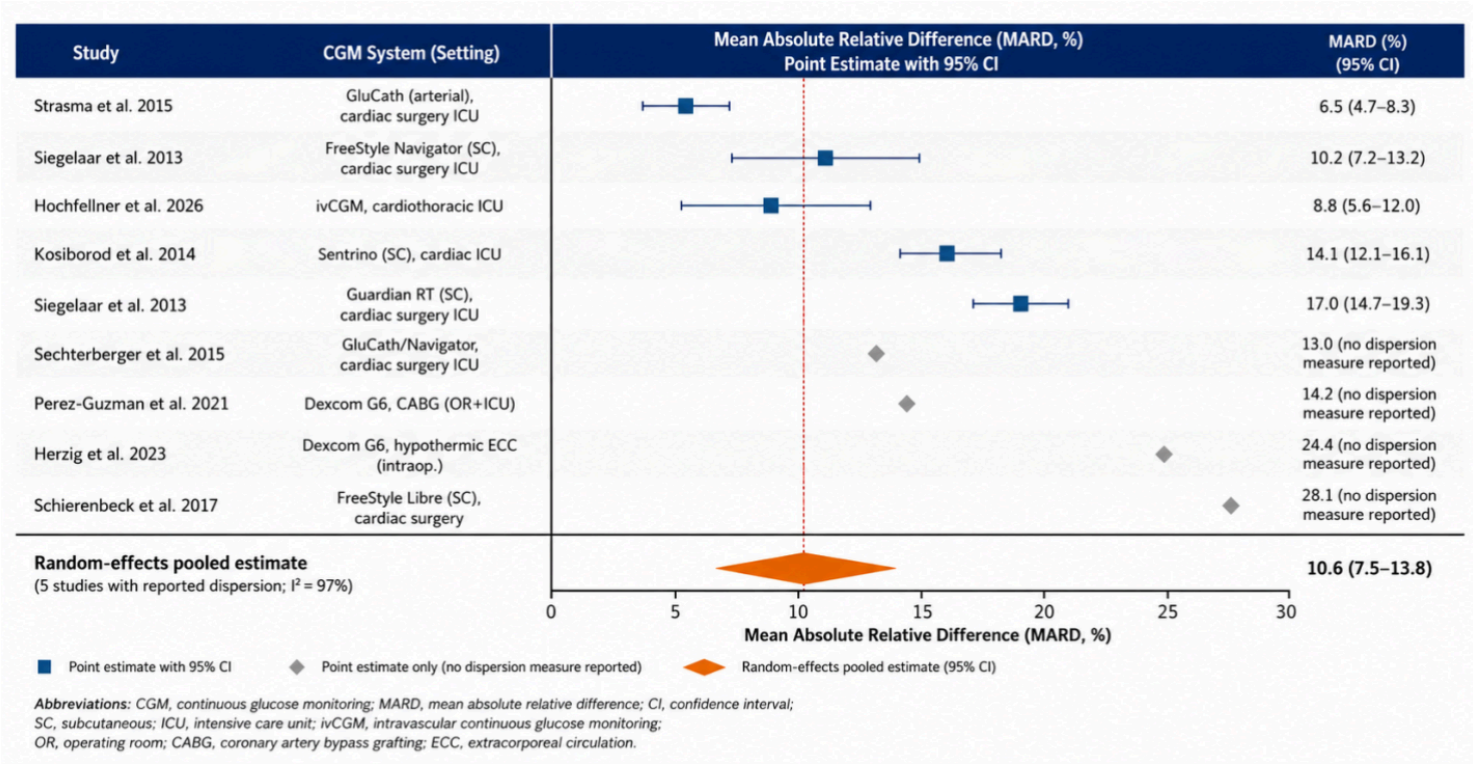


Figure 2

Forest plot of intraoperative/perioperative CGM accuracy (MARD) in cardiac surgery

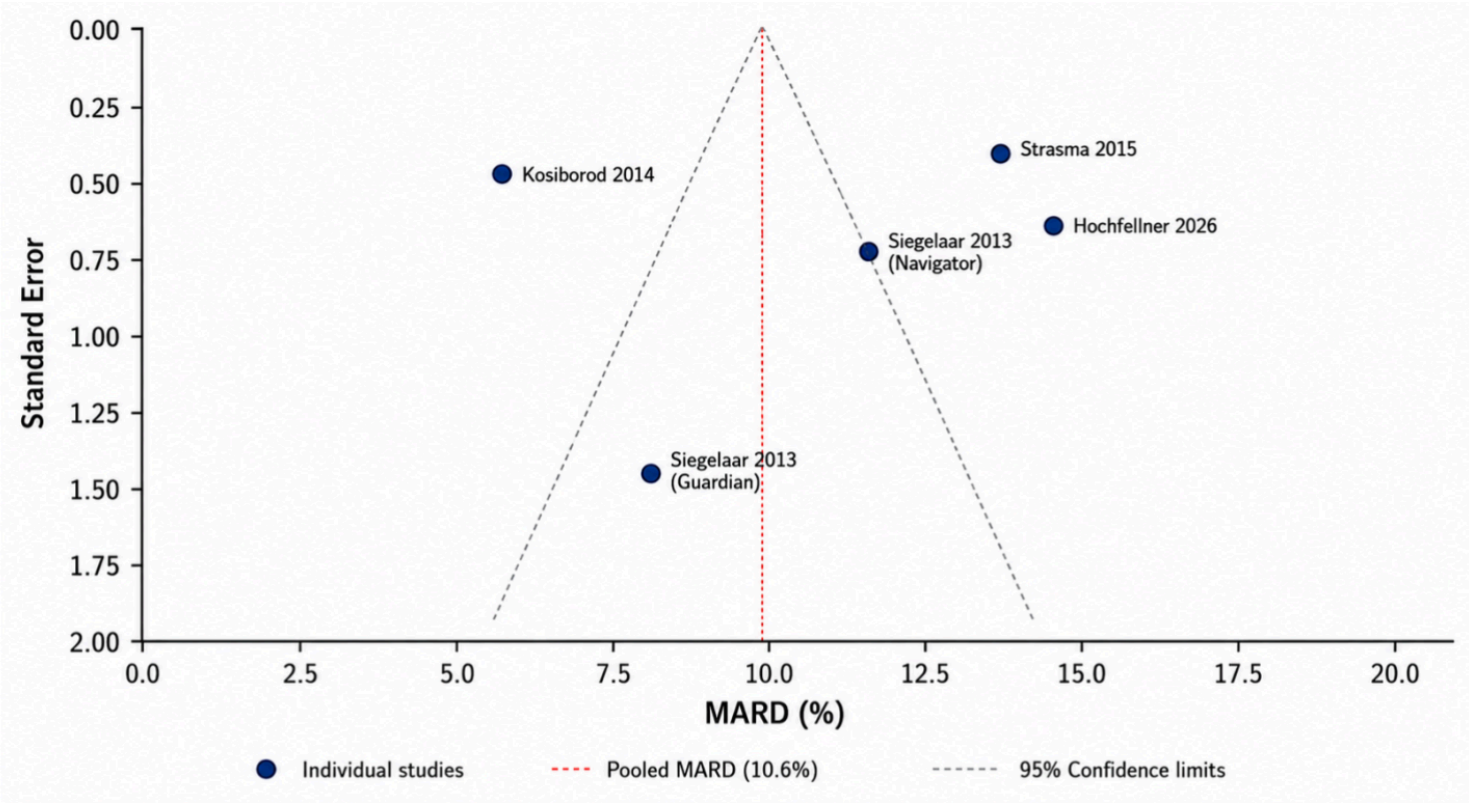


Figure 3

Funnel plot (MARD vs. standard error) for the five quantitatively pooled accuracy studies.

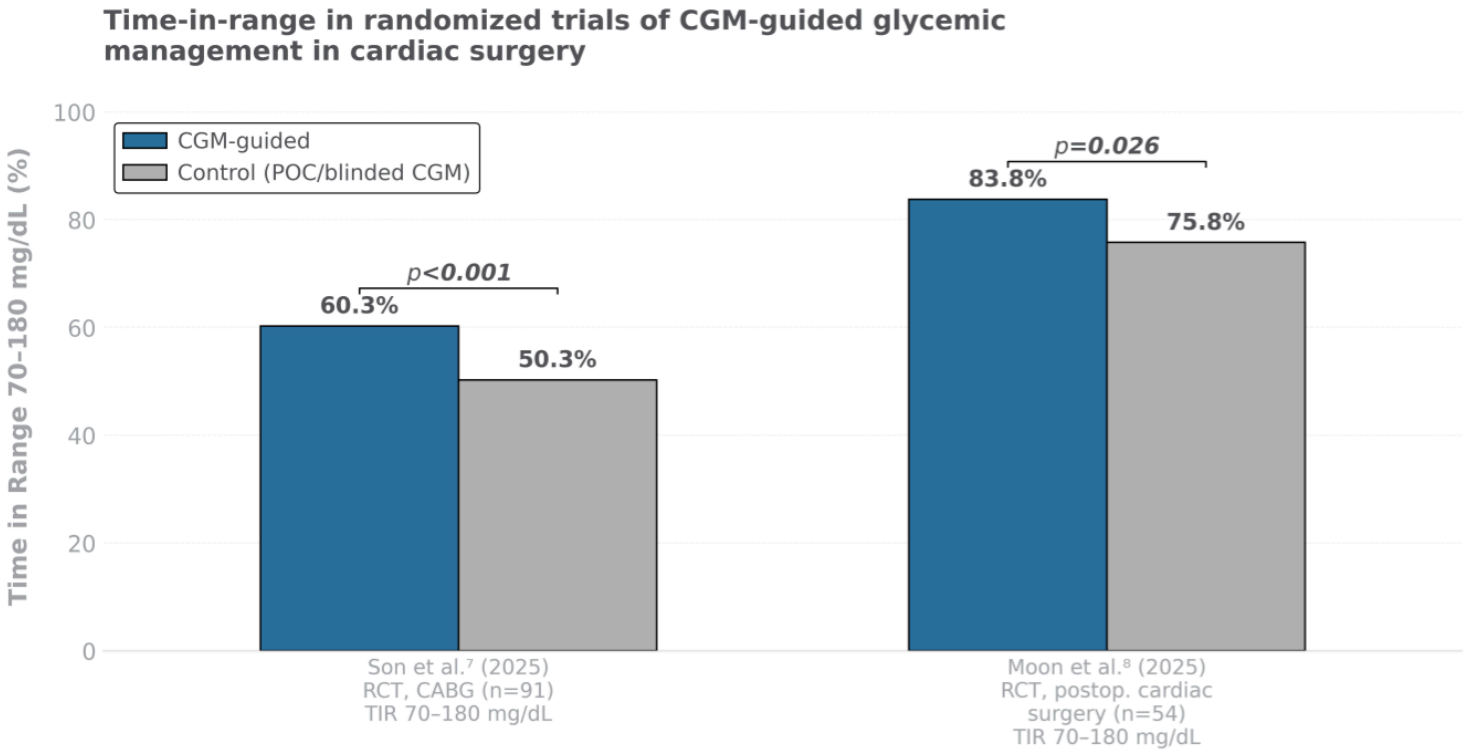


Figure 4

Time in range (70–180 mg/dL) achieved with CGM-guided glycemic management versus point-of-care/blinded-CGM standard care in the two randomized trials reporting this outcome on a comparable glucose range.