

CONTINUOUS GLUCOSE MONITORING VERSUS FINGER-PRICK MONITORING AFTER MAJOR ELECTIVE SURGERY IN ADULTS WITH TYPE 2 DIABETES: A PROSPECTIVE COMPARATIVE STUDY

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ABSTRACT

Background: Continuous glucose monitoring (CGM) provides dense postoperative glucose profiles, whereas finger-prick monitoring samples glucose intermittently. The aim and objective is to compare postoperative glycemic control between CGM and finger-prick monitoring in adults with type 2 diabetes undergoing major elective surgery. The primary objective was to compare follow-up in-range glucose percentage after baseline adjustment. Secondary objectives were to compare below-range and above-range percentages, day-14 glucose, hospital stay, wound healing, and direct monitoring costs. **Materials and Methods:** This prospective comparative study included 60 patients at Wockhardt Hospital, Mumbai, from December 2022 to May 2024; 30 underwent FreeStyle Libre monitoring and 30 finger-prick monitoring during two-week follow-up. Patient-level master-chart values were reanalyzed using baseline-adjusted analysis of covariance. **Results:** Follow-up in-range percentages were 82.60 +/- 4.26% with CGM and 76.07 +/- 6.09% with finger-prick monitoring. The adjusted CGM-associated difference was +4.26 percentage points (95% CI 1.99 to 6.54; P < 0.001). Adjusted differences were -1.39 points for below-range percentage (95% CI -2.31 to -0.47; P = 0.004) and -3.10 points for above-range percentage (95% CI -5.47 to -0.73; P = 0.011). Adjusted day-14 glucose did not differ significantly (-6.38 mg/dL; 95% CI -18.69 to 5.93; P = 0.304). Mean hospital stay was 8.63 +/- 1.19 versus 9.47 +/- 1.07 days (P = 0.006). Very good wound healing occurred in 28/30 patients in each group; direct monitoring costs were higher with CGM. **Conclusion:** CGM was associated with more favorable baseline-adjusted glucose-range measures and shorter hospital stay. However, differing sampling intensities and the prospective comparative design limit causal interpretation.

INTRODUCTION

Postoperative glucose control is complicated by surgical stress, changing nutritional intake and fluctuating insulin requirements. In noncardiac surgery, perioperative hyperglycemia has been associated with longer hospitalization and adverse clinical outcomes.^[1] Postoperative hyperglycemia has also been associated with surgical-site infection in general surgical patients.^[2] These findings make reliable glucose surveillance relevant to recovery, but they do not establish which monitoring strategy improves patient outcomes.

Monitoring is useful when its findings guide effective treatment without causing hypoglycemia. In the RABBIT 2 Surgery trial, basal-bolus insulin improved glucose control and reduced a composite of hospital complications compared with sliding-scale insulin, although glucose values below 70 mg/dL were more frequent.^[3] Mean glucose alone provides an incomplete account of this balance. Glycemic variability has been associated with mortality in critically ill adults, but the relevance of those findings to postoperative patients outside intensive care remains uncertain.^[4]

Finger-prick testing measures capillary glucose at discrete intervals and may miss excursions between checks. Continuous glucose monitoring measures

interstitial glucose repeatedly and provides a more detailed record of glucose exposure. In a general-ward study, CGM identified more hypoglycemia than point-of-care testing despite similar mean glucose concentrations.^[5] The factory-calibrated FreeStyle Libre platform offers up to 14 days of sensor wear and has undergone performance and usability evaluation.^[6] However, the percentage of intermittent readings within a range is not interchangeable with sensor-derived time in range.

An inpatient randomized trial by Fortmann et al. reported improved glucose measures with real-time CGM in a non-intensive-care setting.^[7] The applicability of these findings to patients recovering from different major operations, and to outcomes beyond glucose concentrations, requires evaluation. We therefore conducted a prospective comparative study of FreeStyle Libre CGM and finger-prick monitoring after major elective surgery in adults with type 2 diabetes. The study aimed to evaluate differences in postoperative glycemic control and associated clinical, patient-reported, and direct monitoring-cost outcomes.

Aim and objectives

Aim

To evaluate and compare postoperative glycemic control using continuous glucose monitoring and finger-prick glucose monitoring in adults with type 2 diabetes undergoing major elective surgery.

Primary objective

To compare the follow-up percentage of glucose observations within the target range of **70–180 mg/dL** between the CGM and finger-prick monitoring groups, accounting for baseline glucose-range values.

Secondary objectives

1. To compare the percentages of glucose observations below range (<70 mg/dL) and above range (>180 mg/dL) between the two monitoring groups.
2. To compare postoperative day-14 blood glucose levels between the groups.
3. To compare the frequency of insulin-dose adjustment during the postoperative monitoring period.
4. To assess and compare wound-healing outcomes.
5. To compare the duration of postoperative hospital stay.
6. To assess patient satisfaction with the monitoring methods.
7. To compare the recorded direct monitoring costs associated with CGM and finger-prick monitoring.

MATERIALS AND METHODS

Study design and setting: This prospective comparative study was conducted in the inpatient department of Wockhardt Hospital, Mumbai Central, India, over 18 months from December 2022 to May 2024. The protocol was reviewed by the Wockhardt

Hospitals Institutional Review Board (IRB; re-registration no. ECR/624/Inst/MH/2014/RR-20) at its meeting on 12 October 2022 and approved by letter dated 17 November 2022. The associated Thesis Protocol Approval reference was DNB/Thesis/2022/11-7. Written informed consent was obtained from all participants before enrollment.

Participants: Eligible participants were adults older than 18 years and younger than 75 years, receiving treatment for diabetes, who underwent major elective surgery and had an average glucose concentration above 140 mg/dL on postoperative day 1. Patients undergoing revision surgery, those who were euglycemic, those taking oral corticosteroids or immunosuppressive medication, patients with an immunocompromised state, and those with a prolonged postoperative intensive-care stay were excluded.

Study groups and sample size: The study included 60 participants in two monitoring groups, with 30 patients receiving CGM and 30 receiving finger-prick monitoring. The thesis records a computer-generated group-assignment sequence, but documentation sufficient to verify allocation concealment and implementation was not available in the supplied source material. Because sequence generation and allocation concealment are distinct safeguards in trial reporting,^[8,9] the study is conservatively reported here as a prospective comparative study rather than as a randomized trial. The thesis protocol specified a target of 30 participants per group, and all 60 participants were included in the analyzed master chart. Because the thesis contained internally inconsistent power assumptions, no retrospective power calculation was used in this report; interpretation emphasizes effect estimates and 95% confidence intervals.

Monitoring and follow up: In the CGM group, a FreeStyle Libre sensor was inserted aseptically into the posterior upper arm according to the manufacturer-recommended placement. Sensor placement and function were reviewed daily, and stored glucose measurements were downloaded for assessment of glycemic trends for up to 14 days. The comparator group underwent capillary glucose monitoring by finger prick. Insulin doses were reviewed and titrated at follow-up assessments every three to four days during the planned two-week monitoring period.

Outcome definitions

The principal glycemic outcome was the follow-up percentage of glucose observations within 70–180 mg/dL. Below-range glucose was defined as <70 mg/dL and above-range glucose as >180 mg/dL, consistent with consensus CGM terminology.^[10] Sensor-derived time in range (TIR) represents the percentage of monitored time within the target interval.^[11] In the finger-prick group, the corresponding percentage represents the proportion of intermittent capillary readings within range and therefore is not assumed to be measurement-equivalent to CGM-derived TIR. Baseline values

refer to postoperative day 1, and follow-up values to the final assessment window (days 12-14).

Other outcomes were postoperative day-14 glucose, insulin-adjustment frequency, wound-healing category, hospital stay, patient satisfaction and direct monitoring cost. Insulin adjustment was recorded as less frequent or very frequent, and wound healing as very good or healing taking time. The thesis annexure contained an eight-item study-specific CGM questionnaire addressing device use, ease of application, comfort, perceived accuracy, checking frequency, convenience, pain/discomfort and overall satisfaction; however, the derivation and validation of the reported numeric satisfaction score were not documented, so this outcome was considered exploratory. Direct monitoring costs were recorded in Indian rupees using the INR 2,000 and INR 6,000 categories in the master chart.

Statistical analysis

Patient-level values from the thesis master chart were used to verify group summaries and reanalyze outcomes. Continuous variables are presented as mean $\pm$ standard deviation and categorical variables as number (percentage). Baseline continuous variables were compared using Welch's t test and sex using Fisher's exact test. The principal follow-up in-range percentage was analyzed by ANCOVA with monitoring group and baseline in-range percentage as predictors; analogous baseline-adjusted models were used for below-range and above-range percentages. Postoperative day-14 glucose was adjusted for postoperative day-1 glucose. Adjusted group differences are reported as CGM minus finger-prick values with 95% confidence intervals. Hospital stay was compared using Welch's t test, with an exploratory linear model additionally adjusting for surgical procedure. Categorical outcomes were

compared using Fisher's exact test. All tests were two-sided with $P < 0.05$; secondary analyses were exploratory and no multiplicity adjustment was applied. The original thesis analyses used SPSS version 26.0; verification and reanalysis of the master chart used Python 3.13 with statsmodels 0.14.6 and SciPy 1.17.0. Statistical reporting follows established biomedical reporting principles.^[12]

RESULTS

Participant characteristics

The patient-level master chart included 60 patients, 30 in each monitoring group. Mean age was 58.57 ± 8.80 years in the CGM group and 59.63 ± 7.72 years in the finger-prick group. Men comprised 15/30 (50.0%) and 22/30 (73.3%) participants, respectively. Baseline postprandial glucose was lower with CGM (267.13 ± 44.04 versus 302.37 ± 57.89 mg/dL; $P = 0.010$), as was postoperative day-1 glucose (215.10 ± 25.62 versus 227.87 ± 19.03 mg/dL; $P = 0.033$). Baseline in-range and above-range percentages also differed between groups. [Table 1] Overall, hypertension was recorded in 45 patients, ischemic heart disease in five and chronic obstructive pulmonary disease in one.

Surgical case mix differed between groups. In the CGM and finger-prick groups, respectively, the master chart recorded laparoscopic hernia repair in 7 and 9 patients, coronary artery bypass grafting in 6 and 7, cervical spine surgery in 4 and 7, arthroplasty in 5 and 5, lumbar spine surgery in 2 and 2, craniotomy in 1 and 0, and pancreatic procedures in 5 and 0. Pancreatic procedures combined pancreaticoduodenectomy and Whipple surgery.

Table 1: Baseline characteristics by monitoring group

Characteristic	CGM (n = 30)	Finger-prick (n = 30)	P value
Age, years	58.57 ± 8.80	59.63 ± 7.72	0.619
Fasting glucose, mg/dL	218.60 ± 40.81	227.30 ± 36.28	0.386
Postprandial glucose, mg/dL	267.13 ± 44.04	302.37 ± 57.89	0.010
HbA1c, %	8.89 ± 1.38	9.02 ± 2.05	0.769
In-range glucose, %	78.97 ± 5.33	73.13 ± 10.66	0.010
Below-range glucose, %	7.47 ± 1.04	7.67 ± 0.96	0.442
Above-range glucose, %	13.57 ± 5.22	19.20 ± 10.78	0.014
Male sex, n (%)	15 (50.0)	22 (73.3)	0.110
Postoperative day-1 glucose, mg/dL	215.10 ± 25.62	227.87 ± 19.03	0.033

Glycemic outcomes

At follow-up, in-range percentages were $82.60 \pm 4.26\%$ with CGM and $76.07 \pm 6.09\%$ with finger-prick monitoring. ANCOVA adjusting for baseline in-range percentage estimated a CGM-associated follow-up difference of $+4.26$ percentage points (95% CI 1.99 to 6.54; $P < 0.001$). The mean within-

group changes calculated from patient-level master-chart pairs were $+3.63$ and $+2.93$ percentage points, respectively; the between-group difference in change was $+0.70$ points (95% CI -2.74 to 4.14; $P = 0.683$). Thus, the adjusted follow-up comparison and the simple change-score comparison yielded different inferential conclusions. [Table 2; Figure 1]

Table 2: Follow-up glucose outcomes and descriptive changes

Outcome	CGM (n = 30)	Finger-prick (n = 30)	Adjusted CGM - finger-prick difference (95% CI); P value
In-range glucose, %	82.60 ± 4.26	76.07 ± 6.09	$+4.26$ pp (1.99 to 6.54); $P < 0.001$
Below-range glucose, %	1.47 ± 1.43	2.83 ± 2.04	-1.39 pp (-2.31 to -0.47); $P = 0.004$

Above-range glucose, %	15.93 ± 4.59	21.10 ± 5.94	-3.10 pp (-5.47 to -0.73); P = 0.011
Postoperative day-14 glucose, mg/dL	191.47 ± 26.79	204.47 ± 24.20	-6.38 mg/dL (-18.69 to 5.93); P = 0.304

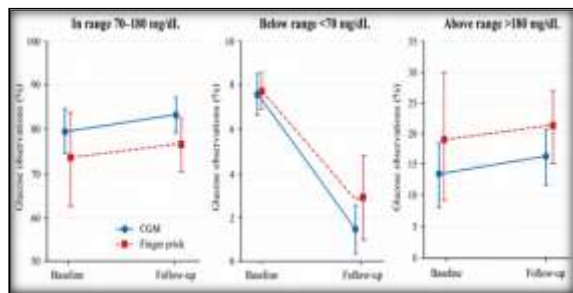


Figure 1: Baseline and follow-up glucose-range percentages

Follow-up below-range percentages were 1.47 +/- 1.43% with CGM and 2.83 +/- 2.04% with finger-prick monitoring. After adjustment for baseline below-range percentage, the difference was -1.39 percentage points (95% CI -2.31 to -0.47; P = 0.004). Follow-up above-range percentages were 15.93 +/- 4.59% and 21.10 +/- 5.94%, respectively; the baseline-adjusted difference was -3.10 percentage points (95% CI -5.47 to -0.73; P = 0.011). Because sensor-derived and intermittent percentages have different sampling bases, these estimates describe method-associated differences rather than interchangeable measures of glucose exposure. Mean postoperative day-14 glucose was 191.47 +/- 26.79 mg/dL with CGM and 204.47 +/- 24.20 mg/dL with finger-prick monitoring. The unadjusted

difference was -13.00 mg/dL (P = 0.053). After adjustment for postoperative day-1 glucose, the difference was attenuated to -6.38 mg/dL (95% CI -18.69 to 5.93; P = 0.304; [Figure 2])

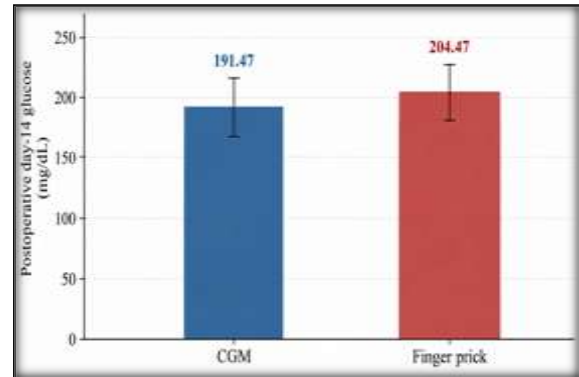


Figure 2: Blood glucose on postoperative day 14

Insulin adjustment and wound healing

Very frequent insulin adjustment was recorded in 3/30 CGM patients (10.0%) and 14/30 finger-prick patients (46.7%; Fisher exact P = 0.003). Recalculation from the patient-level master chart showed very good wound healing in 28/30 patients (93.3%) in each group and healing taking time in 2/30 (6.7%) in each group (Fisher exact P = 1.000; [Table 3]).

Table 3: Insulin adjustment and wound-healing categories

Outcome and category	CGM (n = 30)	Finger-prick (n = 30)	P value
Insulin adjustment Less frequent	27 (90.0)	16 (53.3)	0.003
Insulin adjustment Very frequent	3 (10.0)	14 (46.7)	
Wound healing Very good	28 (93.3)	28 (93.3)	1.000
Wound healing Healing taking time	2 (6.7)	2 (6.7)	

Hospital stays satisfaction and costs

Mean hospital stay was 8.63 +/- 1.19 days with CGM and 9.47 +/- 1.07 days with finger-prick monitoring, an unadjusted difference of -0.83 days (P = 0.006; Figure 3). In an exploratory model adjusting for surgical procedure, the difference remained -0.73 days (95% CI -1.35 to -0.12; P = 0.019). Recorded satisfaction scores were 9.47 +/- 1.20 and 6.20 +/- 0.41, respectively (P < 0.001), although the scoring derivation was not documented. All CGM patients had a recorded direct monitoring cost of INR 6,000; among finger-prick patients, 16/30 had INR 2,000 and 14/30 had INR 6,000 recorded (Fisher exact P < 0.001), corresponding to mean recorded costs of INR 6,000 and INR 3,866.67 per patient. No adverse or

untoward medical events were reported in the thesis. [Table 4]

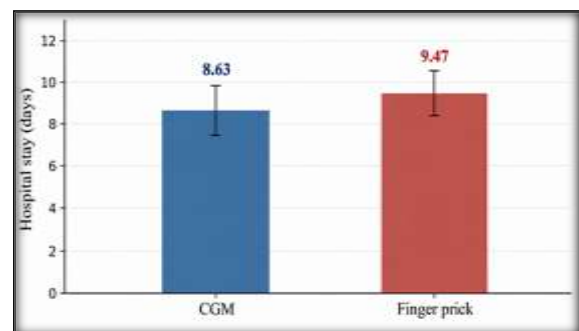


Figure 3: Duration of hospital stay

Table 4: Hospital stays satisfaction and direct monitoring costs

Outcome	CGM (n = 30)	Finger-prick (n = 30)	P value
Hospital stays, days	8.63 ± 1.19	9.47 ± 1.07	0.006
Recorded satisfaction score	9.47 ± 1.20	6.20 ± 0.41	<0.001
Monitoring cost INR 2,000, n (%)	0 (0.0)	16 (53.3)	<0.001
Monitoring cost INR 6,000, n (%)	30 (100.0)	14 (46.7)	
Mean direct monitoring cost, INR	6,000.00	3,866.67	Not estimated

DISCUSSION

In this prospective comparative study, baseline-adjusted analyses showed higher follow-up in-range percentages and lower below-range and above-range percentages in the CGM group. The primary ANCOVA estimate was +4.26 percentage points for follow-up in-range percentage. However, the simple between-group difference in mean TIR change was only +0.70 percentage points and was not statistically significant. This divergence is important: the groups differed at baseline, and ANCOVA and change-score analyses answer related but not identical questions. In addition, follow-up day-14 glucose was not significantly different after adjustment for postoperative day-1 glucose. The glycemic findings therefore support an association with more favorable monitored range profiles, but not an unqualified claim of global glycemic superiority.

The inpatient trial by Spanakis et al. illustrates why glucose outcomes require separate interpretation. Among 185 general medical and surgical patients receiving basal-bolus insulin, CGM-guided management did not significantly improve overall TIR relative to point-of-care-guided management, although recurrent hypoglycemia was reduced among patients who experienced hypoglycemia.^[13] Our lower baseline-adjusted below-range percentage is compatible with a potential benefit of more detailed glucose information. However, we did not establish a difference in symptomatic or severe hypoglycemic events, so the observed percentage difference should not be translated into an unmeasured clinical safety benefit.

Measurement remains a central limitation. Galindo et al. found differences in mean glucose and hypoglycemia detection between Freestyle Libre Pro and point-of-care testing in hospitalized adults with type 2 diabetes.^[14] Intermittent finger-prick readings may miss nocturnal or between-meal excursions and may overrepresent scheduled testing times, whereas CGM contributes many more interstitial observations. A monitoring strategy can therefore affect both clinical decisions and the probability of observing an excursion. Future comparative studies should ideally use a common blinded sensor outcome in both groups while differing only in whether CGM information is available to guide treatment.

Outpatient trials likewise show that the apparent benefit depends on the selected outcome. The REPLACE trial reported less hypoglycemia with flash monitoring without an overall between-group difference in HbA1c change at six months.^[15]

DIAMOND found a modest HbA1c benefit with CGM among adults receiving multiple daily insulin injections.^[16] Our two-week observation cannot establish sustained HbA1c improvement. The adjusted range results should therefore be interpreted as short-term postoperative monitoring findings rather than evidence of durable glycemic benefit.

Hospital stay was shorter in the CGM group by approximately 0.8 days, and the association persisted in an exploratory model adjusting for surgical procedure. Nevertheless, discharge timing may also reflect operation complexity, postoperative complications, local discharge practices and social factors. Mao et al. demonstrated that perioperative glucose profiles differ across pancreatic procedures,^[17] reinforcing the importance of case mix. The present estimate is therefore hypothesis-generating rather than evidence that CGM itself shortens admission.

Patient-level master-chart entries showed identical wound-healing distributions in the two groups: 28/30 patients had very good healing and 2/30 had healing taking time in each group. Huang et al. reported an association between TIR and postoperative wound healing in patients with diabetic foot ulcers,^[18] but that population and endpoint differ from the present mixed surgical cohort. The qualitative wound categories and short follow-up further limit inference; these data do not support a claim that CGM accelerates wound healing or prevents surgical-site infection.

Patient experience may still influence the choice of monitoring method. Yaron et al. reported improved treatment satisfaction with flash monitoring in insulin-treated outpatients.^[19] The recorded satisfaction score was substantially higher in the CGM group in our master chart. However, the thesis annexure contains a study-specific CGM questionnaire and does not document how the cross-group numeric score was derived or validated. The satisfaction result should therefore be regarded as exploratory rather than as a validated patient-reported outcome.

CGM increased recorded direct monitoring expenditure by approximately INR 2,133 per patient. Fonda et al. evaluated longer-term cost-effectiveness using modeled complications, costs and quality-adjusted survival.^[20] Our study did not include that level of economic analysis. The recorded cost categories do not capture staff time, total admission costs, postdischarge use or downstream complications, and the observed hospital-stay association cannot be assumed to translate directly

into savings. Accordingly, the economic finding is limited to higher recorded direct monitoring cost rather than cost-effectiveness.

Strengths of this study include prospective follow-up, a clinically relevant postoperative population, patient-level verification of the thesis master chart, baseline-adjusted glycemic analyses, and assessment of clinical, patient-experience and cost outcomes. Important limitations remain: the single-center sample was small; the study is reported as prospective comparative rather than randomized because allocation-concealment documentation was unavailable; CGM and finger-prick percentages have inherently different sampling intensities; the case mix was heterogeneous; the original sample-size assumptions were internally inconsistent; insulin-adjustment and wound-healing categories lacked detailed operational definitions; the satisfaction score was not validated; and secondary analyses were not multiplicity-adjusted. Future studies should prespecify a common glucose ascertainment method, standardized insulin and discharge protocols, objective wound outcomes, validated patient-reported measures and baseline-adjusted effect estimates with confidence intervals.

CONCLUSION

In adults with type 2 diabetes recovering from major elective surgery, CGM was associated with higher baseline-adjusted follow-up in-range percentage, lower below-range and above-range percentages, and a shorter hospital stay, while adjusted postoperative day-14 glucose did not differ significantly. Direct monitoring cost was higher with CGM, and wound-healing distribution was identical in the two groups. These findings support further evaluation of CGM-informed postoperative management, but the prospective comparative design and unequal glucose sampling preclude a definitive conclusion of causal superiority or cost-effectiveness.

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