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Measurement of central venous pressure and pulse pressure variations in off-pump CABG surgeries and its correlation with lactate levels - an observational study

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ABSTRACT

Background: Hemodynamic instability in patients undergoing off-pump coronary artery bypass grafting (OPCABG) may predispose them to inadequate perfusion and poor outcomes. Central venous pressure (CVP), pulse pressure variation (PPV), and lactate are all valuable hemodynamic parameters, but the predictive nature of each of these parameters remains unclear.

Aim: To assess the relationship between intraoperative hemodynamic parameters and serial lactate levels; and the association with postoperative outcomes.

Methods: This prospective observational study was conducted in 88 patients undergoing elective OPCABG at SRM Medical College Hospital, India. Intraoperative cardiovascular parameters CVP, PPV, mean arterial pressure (MAP), vasoactive-inotropic score (VIS) and serial lactate levels were recorded. Postoperative outcomes included duration of ventilator support, duration of ICU stay, morbidity and mortality. Correlations were calculated using multiple linear regression analysis, with a significance level set at $p < 0.001$ to account for multiple comparisons.

Results: Lactate increased from 0.93 ± 0.38 mmol/L at baseline to 3.09 ± 0.65 mmol/L at 5 hours. Multiple linear regression analysis revealed that PPV ($\beta = 0.046$, $p < 0.001$) and VIS ($\beta = 0.069$, $p < 0.001$) were significant but weak independent predictors of lactate levels. CVP ($\beta = 0.003$, $p = 0.098$) and MAP ($\beta = -0.0001$, $p = 0.889$) demonstrated no clinically relevant correlation. Mean ventilation time was 12.4 ± 4.9 hours. Morbidity occurred in four patients with no mortality reported. Data regarding ICU stay was incomplete and could not be analyzed.

Conclusion: PPV and VIS correlated weakly but significantly with lactate, whereas CVP, MAP, and blood loss were not clinically meaningful predictors. While dynamic monitoring may contribute additional information during OPCABG surgery, the very small effect sizes indicate these variables are not strong standalone predictors in this context. Larger cohorts are needed to identify more robust associations.

KEY WORDS

OPCAB; Central venous pressure; Pulse pressure variation; Lactate; Hemodynamic monitoring; Vasoactive inotropic score

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Introduction

Hemodynamic stability remains one of the most difficult obstacles to overcome while performing OPCABG [1]. Unlike the on-pump techniques, OPCABG is performed on a beating heart and patients can have sustained acute hemodynamic variability to continuous cardiac movement and variability in loading conditions. Furthermore, it may take only minor disturbances in preload, after load, and/or contractility to severely impair tissue perfusion, impair oxygen delivery, increase risk of metabolic decompensation, and ultimately increase risk of adverse outcomes. Thus, in this context, careful perioperative monitoring is paramount in detecting possible complications, managing fluid needs, and improving recovery. Among many possible hemodynamic variables, CVP, PPV, and lactate, may be the most relevant descriptors of energy-loading state that can be assessed simultaneously in order to help provide a broader assessment of intraoperative hemodynamics and postoperative outcome.

CVP, a traditional static measure of right atrial pressure, has been used as a way of evaluating intravascular volume status for many years. However, high values for CVP have been associated with adverse outcomes, including mortality, decreased lactate clearance, and inadequate cellular metabolism [2]. Conversely, PPV offers a more dynamic, reliable measure of fluid responsiveness, which is particularly useful during mechanical ventilation. In OPCABG, the heart's position and often large amounts of fluid instituted will vary the cardiac index. This is where PPV can offer a continuing read of CVP function while also commencing goal-directed fluid therapy. Likewise, blood lactate is a well-established biomarker of tissue hypoperfusion and metabolic stress. High lactate indicates inadequate oxygen delivery compared with oxygen demand, and increased lactate translates to higher likelihood of adverse events (longer mechanical ventilation, length of ICU stay, time to recovery etc) [3]. Taken together, these three measures convey information regarding the exercise aspects of hemodynamic and metabolic performance.

The combined use of CVP, PPV, and lactate may provide a better way to manage perioperative load in OPCABG than any of the measures alone. By identifying the relationships of the three data points, it is probable that practitioners will have greater strength to identify incipient hemodynamic instability, potential adverse postoperative events, and also potentially respond sooner to impacts recovery. Understanding the relationships of the three data points also

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serves to identify better fluid management planning, decreased low cardiac output syndrome (LCOS), and even enhance surgical outcomes. This observational study examines the relationship of CVP, PPV, and lactate levels in patients undergoing OPCABG to provide an evidence-based monitoring protocol indicating safety and recovery in the postoperative phase.

Methodology

The prospective observational cohort study was carried out at SRM Medical College Hospital and Research Centre, Kanchipuram, Tamil Nadu, India for one year between February 2024 and February 2025 primarily to ascertain the relationship between intraoperative hemodynamic parameters and serum lactate levels in patients undergoing OPCAB surgery. The study focused on evaluating CVP, PPV and serum lactate levels with the primary objective of evaluating CVP and PPV correlation with serum lactate levels during the surgery and the secondary objective was to evaluate the effects of CVP and PPV on postoperative outcomes i.e., duration of mechanical ventilation, duration of ICU stay, morbidity and mortality. Ethical approval (SRMIEC-ST1024-1535) was obtained from the institution ethical committee, written informed consent for the study was obtained from all participants and the study was registered with the Clinical Trials Registry of India (CT-TRI/2019/04/018746).

Sample size calculation

The sample size of 88 patients was determined based on effect sizes reported in prior literature, assuming a correlation coefficient of at least 0.25 between lactate and intraoperative hemodynamic parameters, with 80% power and $\alpha = 0.05$. To maintain a robust analysis and account for multiple comparisons across the five intraoperative time points and several hemodynamic variables, a more stringent significance threshold of $p < 0.001$ was set for the final analysis.

Study population and recruitment

The total adult patients were recruited in the preoperative period after passing eligibility screening and provided informed consent for elective OPCAB surgery. The inclusion criteria were adults undergoing elective OPCAB surgery, while no chronic kidney disease (CKD ≥ Grade 3), left ventricular ejection fraction below 30% or inotropic support prior to surgery among exclusion criteria. Furthermore, patients who were screened and were included for analysis, but due to complications arising intraoperatively, such as intraoperative blood transfusion or hypothermia (core temperature <34° C) were also excluded from the final analysis. This was a deliberate decision to focus the analysis on a low-to-moderate risk cohort without the major confounders of transfusion (which affects both hemodynamics and lactate levels) or hypothermia, thereby allowing for a clearer assessment of the relationship between the primary hemodynamic variables and lactate.

Data collection

Preoperative data

The following baseline data were recorded:

- **Demographic variables:** age, sex, height, weight, body mass index (BMI).
- **Clinical parameters:** American Society of Anesthesiologists (ASA) classification, hemoglobin level, serum creatinine concentration, and left ventricular ejection fraction.

Anesthesia and intraoperative monitoring

All patients received standardized general anesthesia. Induction was achieved using intravenous fentanyl (2 µg/kg) and propofol (1-2 mg/kg), and muscle relaxation was induced with vecuronium (0.1 mg/kg). Anesthesia was maintained with isoflurane and an oxygen-air mixture, and supplemental medications of fentanyl and vecuronium as needed. Hemodynamic values were collected with a Philips IntelliVue MP70 multiparameter monitor (Philips Healthcare, Germany).

- **CVP:** Measured via a right internal jugular central venous catheter.
- **PPV:** Calculated automatically by the monitor in mechanically ventilated patients.
- **MAP:** Recorded continuously.
- **VIS:** Calculated using the formula:

  VIS = Dopamine (µg/kg/min) + dobutamine (µg/kg/min) + 100 × epinephrine (µg/kg/min) + 10 × milrinone (µg/kg/min) + 10,000 × vasopressin (U/kg/min)

- **Lactate Measurement:** Lactate levels were measured from serum at baseline, hourly during surgery, and at 0- and 2-hours post-operatively. Blood draw samples were performed at intra-arterial catheters for analysis with RADIOMETER ABL800 FLEX Blood Gas Analyzer.
- **Post-operative follow-up:** Patients were followed prospectively during their ICU stay and until either discharge or death to evaluate post-operative outcomes. The following data was collected; serial lactate trend data, duration of mechanical ventilation, length of ICU stay, and overall morbidity and mortality.

Statistical analysis

Data were entered in a standard database and analyzed using standard statistics software. Descriptive statistics were used to describe the demographic and clinical characteristics. Continuous variables were reported as mean ± SD. To assess the independent associations between hemodynamic parameters and lactate concentration, a multiple linear regression analysis was performed with lactate as the dependent variable. The significance level was set at $p < 0.001$ to control for the risk of Type I error due to multiple comparisons across the five time points and multiple predictors. We reported unstandardized regression coefficients (β values) and their 95% confidence intervals (CIs) to characterize the strength and direction of the associations, after adjusting for other variables in the model. This analysis was undertaken to determine independent predictors of elevated lactate concentrations in OPCAB surgery.

Results

The results of this study present baseline demographic and clinical characteristics of the study population, followed by intraoperative hemodynamic trends, along with associations of these hemodynamic trends with lactate trends. The main perioperative outcomes including blood loss, morbidity, and mortality are also presented to better demonstrate clinically relevant associations and predictors. Table 1 describes the demographic and baseline characteristics of the study population ($n = 88$). The mean age was 57.0 ± 8.8 years (37-77), with males being more predominant (60, 68.2%) than females (28, 31.8%). The cohort had a mean BMI of 26.2 ± 4.0 kg/m², among an average height of 157.9 ± 8.4 cm and average weight

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of 65.1 ± 8.9 kg. At baseline, laboratory parameters included mean hemoglobin of 12.0 ± 1.4 g/dL, and mean serum creatinine of 0.96 ± 0.27 mg/dL, reflecting values that were within normal physiological limits.

Table 1. Demographic and baseline characteristics of the study population (N=88).

Variable	Mean ± SD	Range (Min–Max)
Age (years)	57.0 ± 8.8	37–77
Gender, n (%)	Male: 60 (68.2%) Female: 28 (31.8%)	– –
BMI (kg/m²)	26.2 ± 4.0	18.8–36.2
Height (cm)	157.9 ± 8.4	140.0–175.0
Weight (kg)	65.1 ± 8.9	39.5–86.0
Hemoglobin (g/dL)	12.0 ± 1.4	8.1–15.7
Serum Creatinine (mg/dL)	0.96 ± 0.27	0.6–1.7

Table 2 shows the intraoperative hemodynamic and laboratory values for the cohort (n = 88) for 5 hours. The CVP baseline value was 6.03 ± 2.08 mmHg with a peak of about 8.28 ± 2.15 mmHg at 2 hours and returned to baseline by 5 hours. Mean PPV increased over time from 4.99 ± 1.47% (hour 1) to 11.01 ± 2.58% (hour 5). The VIS began with baseline values (0) and was 16.47 ± 5.06 at hour 5. Measurements of lactate also increased in parallel from a baseline of 0.93 ± 0.38 mmol/L to 3.09 ± 0.65 mmol/L. The MAP also decreased as shown by the baseline MAP also dropped from baseline (88.6 ± 7.3 mmHg) from baseline (88.6 ± 7.3 mmHg) to (80.2 ± 9.9 mmHg) at hour 5 suggesting general hemodynamic stability, while metabolic derangements steadily emerged during the operation.

Table 2. Intraoperative hemodynamic and laboratory parameters (N=88).

Parameter	Baseline	1 h	2 h	3 h	4 h	5 h
CVP (mmHg)	6.03 ± 2.08	6.50 ± 1.99	8.28 ± 2.15	8.09 ± 2.12	6.11 ± 2.60	5.65 ± 1.97
PPV (%)	4.99 ± 1.47	6.59 ± 1.57	7.12 ± 1.57	8.75 ± 3.20	10.77 ± 3.07	11.01 ± 2.58
VIS	0.00 ± 0.00	4.28 ± 1.65	7.15 ± 2.03	9.03 ± 3.19	13.38 ± 4.30	16.47 ± 5.06
Lactate (mmol/L)	0.93 ± 0.38	1.49 ± 0.37	1.97 ± 0.39	2.29 ± 0.50	2.75 ± 0.51	3.09 ± 0.65
MAP (mmHg)	88.6 ± 7.3	83.9 ± 9.2	80.4 ± 8.5	81.9 ± 10.4	81.8 ± 10.2	80.2 ± 9.9

Data are presented as Mean ± SD.

Table 3 presents the results of the multiple linear regression analysis examining the relationship between intraoperative hemodynamic variables and lactate levels. After adjusting for other factors in the model, there was a weak but statistically significant independent association of lactate with PPV (β = 0.046, 95% CI [0.021–0.071], p < 0.001) and with the VIS (β = 0.069, 95% CI [0.032–0.106], p < 0.001). Total blood loss was not a significant independent predictor in the model (β = 0.0015, 95% CI [-0.001–0.004], p = 0.312). CVP was not a significant predictor (β = 0.003, 95% CI [-0.001–0.007], p = 0.098), and MAP showed no meaningful association (β = -0.0001, 95% CI [-0.003–0.003], p = 0.889). While PPV and VIS reached statistical significance at our stringent threshold, the beta coefficients are extremely small. This indicates that although a linear relationship exists, these variables have a negligible effect on lactate levels and are not strong enough to be clinically useful as standalone predictors.

Table 3. Multiple linear regression analysis for prediction of lactate levels.

Parameter	β Coefficient	95% Confidence Interval (CI)	*p*-value	Interpretation
PPV	0.046	0.021 – 0.071	<0.001	Statistically significant, but extremely weak independent predictor
Vasoactive Inotropic Score (VIS)	0.069	0.032 – 0.106	<0.001	Statistically significant, but extremely weak independent predictor
Total Blood Loss	0.0015	-0.001 – 0.004	0.312	Not a significant independent predictor
CVP	0.003	-0.001 – 0.007	0.098	Not a significant independent predictor
MAP	-0.0001	-0.003 – 0.003	0.889	No meaningful independent association

Table 4 shows the postoperative data for the population that was studied. The mean postoperative duration of ventilation was 12.4 ± 4.9 hours with a range of 6 to 36 hours. Four patients had morbidity, and there was no mortality. Data on ICU stay duration could not be analyzed because of incomplete documentation in patient records. The absence of this key secondary outcome limits our ability to fully assess the Relationship between intraoperative parameters and the ful spectrum of postoperative recovery.

Table 4. Postoperative outcomes of the study population.

Outcome	Value
Ventilation duration (hours)	12.4 ± 4.9 (6–36)
ICU stay (days)	Data unavailable
Morbidity, n	4
Mortality, n	0

Note: ICU stay data unavailable due to incomplete documentation.

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Discussion

This study comprehensively evaluated demographic variables, intraoperative hemodynamic variables, lactate, and postoperative outcomes in patients undergoing cardiac surgery. The multiple regression analysis revealed that while dynamic measures (PPV, VIS) showed statistically significant independent associations with lactate levels, the static variables (CVP, MAP) did not. This suggests that dynamic measures may provide additional evidence about the adequacy of perfusion. However, it is critical to emphasize that the effect sizes for PPV and VIS were extremely weak ($\beta < 0.07$). Therefore, while a statistically significant relationship exists, these variables are not useful as strong, clinically meaningful predictors of lactate levels in this specific context. A small p-value combined with a tiny β coefficient indicates that the study's large sample size was sufficient to detect a non-zero but ultimately negligible linear relationship.

In contrast, Zhao et al. found that persistently elevated CVP after surgery was often associated with higher lactate levels and poor outcomes [4]. The discrepancy between our findings and those of Zhao et al. is likely explained by differences in the study cohorts. Our study focused on a low-to-moderate risk elective OPCABG population, explicitly excluding patients with severe LV dysfunction, pre-operative inotropes, and those requiring intraoperative transfusion. This healthier cohort may not have experienced the degree of right heart strain or venous congestion necessary for CVP to become a meaningful correlate of metabolic stress. Our observations are partially in line with Zhou et al. who found dynamic measures were superior to static measures, but the weak effect sizes in our cohort do not support strong claims of predictive ability for dynamic measures in this low-risk setting [5].

Lactate trends in our cohort showed a gradual intraoperative increase, nearly tripling from baseline. Previous studies have regarded lactate as a robust marker for tissue hypoperfusion and predictor of complications, which our findings support in terms of trend [6,7]. However, our regression model showed that blood loss was not a significant independent predictor of lactate. This finding strongly reinforces that in this specific, well-managed cohort, blood loss was not a major contributing factor to the observed rise in lactate, despite literature discussing the consequences of bleeding on oxygen delivery. It is likely that other processes, such as the metabolic response to surgical stress and inflammation, were more contributive to the lactate increase [8,9].

The gradual increases in VIS in our cohort drew attention to increasing pharmacological support requirements. This finding aligns with Hoang et al. who found higher VIS values predicted poor outcomes in pediatric congenital heart surgery, supporting VIS as a useful composite prognostic marker across groups, even if its direct correlation with a single biomarker like lactate is weak in adults [10].

The postoperative prognosis in our cohort was acceptable, with no deaths and minimal morbidity, despite 4 patients with complications. Lactate elevation could not be associated with mortality in this study, but previous authors have shown lactate's ability to predict morbidity, severity, and mortality in surgical and nonsurgical populations [11-14]. Our findings support the notion that dynamic monitoring (PPV, VIS) combined with metabolic parameters (lactate) can offer a more thorough picture of intraoperative perfusion than static parameters (CVP, MAP) alone. These results are in line with Michard who emphasized the use of dynamic monitoring to improve hemodynamic management [15]. Finally, ICU stay, a key measure of postoperative morbidity, could not be assessed due to incomplete documentation. This missing data is a significant drawback, as it prevents a full evaluation of postoperative recovery and could potentially have altered the observed associations had it been available.

Limitations

While this study is an extensive attempt to examine the relationship between intra-operative hemodynamic variables and lactate during OPCAB surgery, there are important limitations. The study excluded high-risk patients (severe LV dysfunction, chronic renal status, inotrope support in the past 24 hours, intraoperative transfusion), which limits the generalizability of the findings to a broader, more complex OPCABG population. The systemic hemodynamics, such as CVP and PPV are dynamic physiologic responses that risk transforming based on patient individual conditions and surgical factors, and as an observational single center study limits external validity. The time spent in the ICU was unable to be analyzed due to inconsistencies in documentation, therefore lessening the completeness of our outcomes and limiting conclusions about postoperative recovery. Although the associations for PPV and VIS were statistically significant, the extremely weak strength of association severely limits their clinical applicability, and they should be interpreted with caution.

Conclusion

Intraoperative PPV and VIS were statistically significant but extremely weak independent predictors of lactate levels in this low-risk OPCABG cohort, while CVP, MAP, and blood loss showed no meaningful association. This demonstrates that while dynamic monitoring may provide additional information about intraoperative perfusion, the very small effect sizes indicate these variables are not strong enough to be clinically useful predictors in this context. The study essentially proved a non-zero yet negligible relationship, highlighting the need for larger multi-center studies including higher-risk patients to find more robust predictors of intraoperative metabolic stress and adverse outcomes.

Disclosure Statement

No potential conflict of interest was reported by the author.

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