ORIGINAL ARTICLE

Can Underlying Co-Morbidities Affect Cerebral Oximetry in Cardiac Surgery Patients?

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Abstract- Today, there is a growing number of monitoring Equipment accessible. These equipments ranging invasive to non-invasive. Choosing suitable monitoring methods depends on their benefits, drawbacks, and expenses. Overall, non-invasive brain monitoring is growing in importance because of its precision in performance and increased stability in output. Like the assessment of regional brain oxygen levels and the assessment of anesthesia depth using the BIS device, whose specific role in guidelines remains undefined. Many patients who undergo heart surgeries including valvular, dissection and CABG have various comorbidities. To add details, according to literatures about CVA 28% of patients had (Cerebrovascular Accident), 74% IHD (Ischemic Heart Disease), 82% HTN (Hypertension), 52% DM (Diabetes Mellitus), 61% Smoking History, 36% CKD (Chronic Kidney Disease) and 42% CHF (Congestive Heart Failure). Current study delves into the correlation of short-term complications after cardiac operations with cerebral oximetry alterations and the space under the curve (duration of rSo2 drop) to take the best advantages of cerebral oximetry for heart surgery in the future. This prospective observational study was conducted among 101 patients undergoing cardiac surgery at Imam Khomeini Hospital in Tehran between 2019 and 2020. Following admission to the operating room, standard monitoring of vital signs, including non-invasive blood pressure (NIBP), electrocardiogram (ECG), central venous pressure (CVP), oxygen saturation (SpO2), and end-tidal carbon dioxide (ETCO2), was established. Prior to anesthesia induction, cerebral oxygen saturation (rSO2) was continuously monitored using the INVOS 5100c cerebral oximeter. Patients were followed for 7 days postoperatively, with documentation of intubation duration, intensive care unit (ICU) stay, and complications such as renal failure, cerebrovascular accident (CVA), and mortality. Data analysis was performed using SPSS 25.0 statistical software, with a *P* of less than 0.05 considered statistically significant. This study investigated rSO2 levels, as measured by a cerebral oximeter, in patients aged 19 to 79 undergoing cardiac surgery. Data were collected from both the right and left sides of the forehead during the operative period. Overall, these findings highlight the importance of rSO2 monitoring during cardiac surgery, particularly in patients with underlying cardiovascular conditions. Further research is needed to elucidate the specific mechanisms underlying these observations and to explore potential strategies for optimizing cerebral oxygenation in this vulnerable patient population.

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Keywords: Cerebral oximetry; Complications of cardiac surgery

Introduction

Annually, approximately half a million patients undergoing cardiac surgery encounter neurological complications, including cognitive and neuropsychological impairments. In a significant proportion (25%), these changes persist over time. The primary etiology of these complications is believed to be brain tissue ischemia.

Beyond the central nervous system (CNS), the

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processes underlying these complications may also impact other vital organs, potentially resulting in collateral damage (1).

Renal dysfunction, particularly acute kidney injury (AKI), remains a significant concern following cardiac surgery. Despite traditional serum creatinine-based assessments, more sensitive markers often reveal subtle renal tubular injury, associated with increased AKI severity, poorer outcomes, higher costs, and short- and long-term complications. The degree of AKI also predicts poorer long-term survival among discharged patients (2).

Cerebral oximetry, a non-invasive technique utilizing infrared sensors on the forehead, provides local assessment of brain oxygenation by measuring cerebral vascular bed oxygen saturation (rSO2). Compared to jugular bulb oximetry, cerebral oximetry offers the advantage of measuring rSO2 even in non-pulsatile cardiopulmonary bypass (CPB) setups.

Limited studies have demonstrated the effectiveness of interventions guided by cerebral oximetry monitoring in improving patient outcomes. Therefore, this study aimed to explore the association between short-term postoperative complications and changes in cerebral oximetry, including the area under the rSO2 curve (duration of rSO2 decline). The goal was to evaluate the potential utility of cerebral oximetry for guiding cardiac surgery.

Additionally, the study investigated the correlation between past medical history and cerebral oximetry measurements, as well as their impact on surgical outcomes.

Materials and Methods

Study design and participants

This prospective cross-sectional study was conducted at Imam Khomeini Hospital to investigate the relationship between cerebral oximetry measurements and postoperative complications in cardiac surgery patients.

- **Inclusion Criteria:** Eligible patients were aged 20-80 years and underwent non-emergency cardiac surgery at Imam Khomeini Hospital between 2021 and 2023.
- **Exclusion Criteria:** Patients were excluded if they were:
    - Under 20 or over 80 years old
    - On dialysis or had end-stage renal disease (ESRD)
    - Had a blood creatinine level above 2 units
    - Had infective endocarditis
    - Underwent emergency cardiac surgery
    - Had a BMI below 18 or above 30

Data collection and analysis

- **Cerebral Oximetry:** rSO2 measurements were obtained using the INVOS 5100c device before, during, and after cardiopulmonary bypass.
- **Postoperative Follow-up:** Patients were followed for 7 days to identify and document any complications.
- **Data Analysis:** Descriptive statistics (mean, standard deviation, median, range, frequency, and percentage) were used to summarize the data. The Kolmogorov-Smirnov test was employed to assess the normality of data distribution. Chi-square, Fisher's exact, t-test, and ANOVA tests were used to examine relationships between variables. Spearman's correlation coefficient was calculated to investigate correlations between quantitative variables. All analyses were performed using SPSS 25.0 statistical software, with a p-value of less than 0.05 considered statistically significant.

Results

The demographic data of the study population was collected and underwent analysis. (Table 1) The average age of participating patients is 52.92±16.68 years with a range of 19 to 79 years, and 64 (63.4%) are men and 37 (36.6%) are women. 44 (43.6%) patients were in the normal BMI range (18-25) and 57 (56.4%) are in the abnormal range (25-30). 83 (82.2%) patients were non-smokers. In addition to demographic information, information about the underlying diseases of the patients and their type of operation has also been collected and examined the relationship of these variables with any alterations in cerebral oximetry and space under the curve.

34 (34.7%) patients have IHD, 25 (24.8%) have CHF, 7 (6.9%) have CKD, 16 (15.8%) have DM. 44(43.6%) had HTN disease, 12(11.9%) had CVA and 13(12.9%) had CABG operation, 16(15.8%) had CABG-Valve operation, 41(40.6%) With Valve operation, 13 (12.9%) were treated with Multivalve operation and finally 18 (17.8%) had Dissection. Also, 18 (17.8%) of the patients had EF less than 30% before the operation, and 83 (82.2%) have EF more than 30% (Table 2).

Table 1. Demographic information of patients

		N (%)
Gender	Male	64 (63.4%)
	Female	37 (36.6%)
BMI	18 - 25	44 (43.6%)
	25 - 30	57 (56.4%)
Smoker	No	83 (82.2%)
	Yes	18 (17.8%)
Age	Mean ± SD	52.92 ± 16.68
	Median (Range)	55 (19,79)

Table 2. Clinical information of patients

		N (%)
IHD	No	66 (65.3%)
	Yes	35 (34.7%)
CHF	No	76 (75.2%)
	Yes	25 (24.8%)
CKD	No	94 (93.1%)
	Yes	7 (6.9%)
DM	No	85 (84.2%)
	Yes	16 (15.8%)
HTN	No	57 (56.4%)
	Yes	44 (43.6%)
CVA	No	89 (88.1%)
	Yes	12 (11.9%)
CABG	No	88 (87.1%)
	Yes	13 (12.9%)
Valve surgery	No	60 (59.4%)
	Yes	41 (40.6%)
CABG + Valve surgery	No	85 (84.2%)
	Yes	16 (15.8%)
Multivalve surgery	No	88 (87.1%)
	Yes	13 (12.9%)
Dissection	No	83 (82.2%)
	Yes	18 (17.8%)
EF	<30%	18 (17.8%)
	>30%	83 (82.2%)

Recording the baseline rSo2 by self-adhesive sensors on the left forehead, 39 (38.6%) of the patients were without any drop below 30% oxygen, 29 (28.7%) of patients less than 10 minutes have a drop below 30% oxygen, 18 (17.8%) of patients between 10 and 20 minutes have a drop below 30% oxygen and finally 15 (14.9%) of patients more than 20 minutes have a drop below 30 % of oxygen. The same data was also observed on the left forehead and the values were 41(40.6%), 30(29.7%), 15(14.9%) and 15(14.9%) respectively. The information on the left and right sides are completely consistent with each other and the correlation coefficient is equal to 0.8 (P<0.001, R=0.80) (Table 3).

Table 3. Examining changes in cerebral oximetry and the area under the curve of the drop time

		N (%)	*P**
LEFT rSO2<30%(min)	0	39 (38.6%)	<0.001
	<10	29 (28.7%)	
	10 – 20	18 (17.8%)	
	>20	15 (14.9%)	
RIGHT rSO2<30%(min)	0	41 (40.6%)	
	<10	30 (29.7%)	
	10 – 20	15 (14.9%)	
	>20	15 (14.9%)	
		Mean ± SD	***Median (Range)***
LEFT AUC		339.77 ± 331.15	230 (100,1930)
RIGHT AUC		383.47 ± 471.4	200 (100,2350)

This comprehensive analysis of cerebral oximetry data in cardiac surgery patients revealed significant variability in the area under the curve (AUC), a metric reflecting the duration of rSO2 decline below 30%. While the average AUC was slightly higher on the right forehead (471.4±383.47 minutes) compared to the left (339.77±331.15 minutes), the overall difference was not statistically significant. Furthermore, both left and right sides demonstrated a wide range of AUC values (100-1930 minutes and 100-2350 minutes, respectively), emphasizing the substantial individual variation in cerebral oxygenation during surgery.

2 (2%) patients were not hospitalized in the ICU due to death in the operating room, 35 (34.7%) patients stayed less than 3 days in the ICU, 51 (50.5%) patients between 3 and 5 days, 13 (12.9%) patients have stayed for more than 5 days. The intubation time of the was also recorded. 24 (23.8%) of the patients needed intubation for less than 8 hours, 56 (55.4%) between 8 and 24 hours, and 14 (13.9%) of the patients needed intubation for more than 24 hours, and the rest expired. Average CPB time was 148.62±65.67 with a range of 20 to 350 minutes, and the average Cross Clamp time was 91.58±36.29 with a range of 30 to 208 minutes (Table 4).

14 (13.9%) of the patients had first-stage acute kidney injury (AKI), 15 (14.9%) of the second-stage AKI, and 8 (7.9%) of the third-stage AKI. Among these, 2 patients underwent dialysis (Table 5).

Table 4. Checking the mean and standard deviation of each Variable

		N (%)	
Duration of ICU add(days)	**Death in the operating room**	**2 (2.0%)**	
	<3	35 (34.7%)	
	3 – 5	51 (50.5%)	
	>5	13 (12.9%)	
Extubation time(hrs)	**Death in the operating room &Icu**	**7 (6.9%)**	
	<8	24 (23.8%)	
	8 – 24	56 (55.4%)	
	>24	14 (13.9%)	
		Mean ± SD	**Median (Range)**
Pomp time(min)		148.62 ± 65.67	137 (20,350)
Cross Clamp time(min)		91.58 ± 36.29	90 (30,208)

Table 5. Complications that occurred during the first week after the operation

		N (%)
AKI stage1 W1	No	87 (86.1%)
	Yes	14 (13.9%)
AKI stage2 W1	No	86 (85.1%)
	Yes	15 (14.9%)
AKI stage3 W1	No	93 (92.1%)
	Yes	8 (7.9%)
Dialysis W1	No	99 (98.0%)
	Yes	2 (2.0%)
Death W1	No	84 (83.2%)
	Yes	17 (16.8%)

the average area under the cerebral oximetry graph (AUC) has analyzed for every demographic variables, background diseases and type of operation, separately from the left and right frontal data. AUC left is 269.21±293.21 for females and 360.62±365.33 for males. And because the *P* is equal to 0.358, it showed that this difference in the average level under the curve in male and female patients is not statistically significant. However, this rate is statistically significant among people who have had IHD compared to other people. The average level under the chart in people with IHD is 178.03±249.08 and in the rest, it is 378.31±384.26.

(*P*=0.034) Also, this rate is significant among people who have had a history of CVA. The average level under the chart in people with a history of CVA is 163.2±199.86 and in the rest, it is 340.74±353.38 (*P*=0.05). Patients who underwent multi-valve surgery have an average chart level of 596.73±510.83 and 252.93±309.13 in other surgeries (*P*=0.05). These values have also been evaluated in comparison with the average level of the diagram of the right frontal section. The left side result for patients with a CVA history was similar to normal people (*P*=0.009). Also, patients who have undergone CABG surgery have less area under the curve of the right segment than the rest of the patients (*P*=0.001). Furthermore, AUC right for people who had dissection surgery is significantly higher than people who do not have this complication (*P*=0.009) (Table 6).

In (Table 7), we examine the average AUC during the operation against the variables of operation time and complications a week after the operation. This value is reduced drastically with the more ICU stay. The average of this value for people who are hospitalized in ICU for more than 5 days is 236.73±111.89 (*P*=0.01). This result is also the same for the area under the curve of the right part (*P*=0.005). Also, by decreasing the area under the curve, the patient's intubation time increases. This rate is equal to 122.29±274.36 for patients with a duration of more than 24 hours (*P*=0.023). Among the people who expired within a week, the amount of area under the curve during the operation is also significant (*P*=0.036).

Table 6. Examining the relationship between the space under the curve and demographic information, diseases and type of operation

		LEFT AUC		RIGHT AUC	
		Mean ± SD	***P****	**Mean ± SD**	***P****
Gender	Male	365.33 ± 360.62	0.358	387 ± 475.95	0.933
	Female	293.21 ± 269.21		377.43 ± 472.1	
BMI	18 - 25	375.19 ± 370.27	0.388	369.64 ± 453.97	0.81
	25 - 30	310.12 ± 295.68		395.93 ± 491.98	
Smoker	No	335.02 ± 303.95	0.802	380.71 ± 489.8	0.925
	Yes	358.5 ± 433.47		393.06 ± 414.55	
IHD	No	384.26 ± 378.31	0.034	451.47 ± 556.37	0.015
	Yes	249.08 ± 178.03		244.76 ± 140.23	
CHF	No	340.81 ± 350.53	0.962	417.74 ± 515.45	0.275
	Yes	336.7 ± 274.01		280.68 ± 290.6	
CKD	No	347.97 ± 336.94	0.085	391.07 ± 482.78	0.099
	Yes	186 ± 132.59		246.75 ± 113.88	
DM	No	346.09 ± 347.65	0.691	402.12 ± 508.41	0.429
	Yes	304.5 ± 225.43		284 ± 147.98	
HTN	No	306.09 ± 282.78	0.289	370.32 ± 463.79	0.759
	Yes	386.73 ± 388.51		404.79 ± 491	
CVA	No	353.38 ± 340.74	0.05	400.68 ± 490.94	0.009
	Yes	199.86 ± 163.2		213.86 ± 95.26	
CABG	No	351.37 ± 348.02	0.087	413.65 ± 498.08	0.001
	Yes	249.56 ± 119.23		184.3 ± 96.42	
Valvular	No	346.98 ± 377.02	0.834	342.51 ± 404.37	0.391
	Yes	331.17 ± 271.43		436.85 ± 548.64	
cabg-valv	No	350.12 ± 343.91	0.493	395.66 ± 492.12	0.542
	Yes	275.82 ± 240.17		292.78 ± 273.49	
Multivalve	No	309.13 ± 252.93	0.05	366.94 ± 461.47	0.461
	Yes	510.83 ± 596.73		481.18 ± 539.84	
dissection	No	319.57 ± 337.58	0.321	309.02 ± 317.76	0.009
	Yes	408.22 ± 307.42		641.88 ± 764.35	
Age.c	20 - 40	388.52 ± 408.77	0.474	439.76 ± 546.72	0.26
	40 - 60	282.21 ± 247.94		252.26 ± 163.34	
	60 +	317.17 ± 256.95		419.81 ± 537.95	

In (Table 7), we examine the average AUC during the operation against the variables of operation time and complications a week after the operation. This value is reduced drastically with the more ICU stay. The average of this value for people who are hospitalized in ICU for more than 5 days is 236.73±111.89 (*P*=0.01). This result is also the same for the area under the curve of the right part (*P*=0.005). Also, by decreasing the area under the curve, the patient's intubation time increases. This rate is equal to 122.29±274.36 for patients with a duration of more than 24 hours (*P*=0.023). Among the people who expired within a week, the amount of area under the curve during the operation is also significant (*P*=0.036).

We investigated the amount of rSO2 of patients based on demographic characteristics, diseases and type of operation. There was no meaningful relation between the amount of rSO2 and demographic variables, diseases and type of operation. In other words, although in some cases the duration of oxygen drop is less than 30%, there is a clinical difference among people with individual characteristics, but these differences are not statistically significant (Table 8).

There is a significant correlation between the amount of rSO2 Left and the EF variable before the operation. Patients who have EF higher than 30% before surgery have lower rSO2Left (*P*=0.014). Also, there is a significant correlation between rSO2Left with stage 3 kidney failure and mortality rate after one week. Furthermore, the Cross -clamp duration is the highest for patients whose rSO2Left was in the region of (10-20) and the lowest Cross lamp duration for patients who did not have rSO2Left. And this difference between these two groups is statistically significant (*P*=0.002). These studies have also been examined for rSO2 on the right side. The duration of Cross lamp and CPB-time was evaluated for patients with rSO2 right, and a significant correlation was obtained between the groups. There is a significant difference in pump time between people who did not have a drop in rSO2 and people who had a drop of more than 20 minutes (*P*=0.032). The cross-clamp duration of patients in the first group of rSO2 has a significant relationship with the other three groups (*P*<0.001) (Table 9).

Table 7. Examining the average AUC against the variables of operation time and complications one week after the operation

		LEFT AUC		RIGHT AUC	
		Mean ± SD	***P****	**Mean ± SD**	***P****
Duration of ICU add(days)	No	1122 ± .	0.01	1917 ± .	0.005
	<3	444 ± 462.5		426.79 ± 514.05	
	(3 - 5)	273.95 ± 195.4		359.74 ± 443.38	
	>5	236.73 ± 111.89		223.83 ± 103.4	
Extubation time(hrs)	No	820.75 ± 656.86	0.023	1260 ± 1007.54	0.008
	<8	346.84 ± 413.91		285.42 ± 309.62	
	(8 - 24)	310.02 ± 261.66		364.7 ± 447.81	
	>24	274.36 ± 122.29		389.4 ± 445.22	
EF	<30%	359.93 ± 265.59	0.804	289 ± 297.91	0.431
	>30%	335.43 ± 345.27		402.97 ± 499.37	
AKI stage1 W1	No	341.1 ± 340.69	0.933	399.91 ± 499.82	0.464
	Yes	332.33 ± 284.77		286.36 ± 235.79	
AKI stage2 W1	No	353.09 ± 356.06	0.424	413.72 ± 501.2	0.176
	Yes	272.15 ± 141.89		204.73 ± 133.53	
AKI stage3 W1	No	344.51 ± 345.37	0.686	382.47 ± 473.11	0.957
	Yes	291 ± 104.93		392 ± 488.2	
Dialysis W1	No	339.51 ± 333.28	0.951	384.72 ± 474.44	0.843
	Yes	360 ± .		290 ± .	
Death W1	No	303.63 ± 283.07	0.036	334.97 ± 391.61	0.048
	Yes	507.57 ± 476.05		618.54 ± 724.06	

Table 8. Examination of the rSO2 level of patients based on demographic characteristics, diseases and type of operation

		LEFT rSO2<30%(min)					RIGHT rSO2<30%(min)				
		0	**<10**	**10 - 20**	**>20**	***P****	**0**	**<10**	**10 - 20**	**>20**	***P****
Gender	Male	26 (66.7%)	17 (58.6%)	14 (77.8%)	7 (46.7%)	0.275	27 (65.9%)	19 (63.3%)	11 (73.3%)	7 (46.7%)	0.466
	Female	13 (33.3%)	12 (41.4%)	4 (22.2%)	8 (53.3%)		14 (34.1%)	11 (36.7%)	4 (26.7%)	8 (53.3%)	
BMI	18 - 25	17 (43.6%)	13 (44.8%)	5 (27.8%)	9 (60.0%)	0.322	19 (46.3%)	13 (43.3%)	6 (40.0%)	6 (40.0%)	0.963
	25 - 30	22 (56.4%)	16 (55.2%)	13 (72.2%)	6 (40.0%)		22 (53.7%)	17 (56.7%)	9 (60.0%)	9 (60.0%)	
Smoker	No	34 (87.2%)	24 (82.8%)	12 (66.7%)	13 (86.7%)	0.28	36 (87.8%)	26 (86.7%)	8 (53.3%)	13 (86.7%)	0.018
	Yes	5 (12.8%)	5 (17.2%)	6 (33.3%)	2 (13.3%)		5 (12.2%)	4 (13.3%)	7 (46.7%)	2 (13.3%)	
IHD	No	28 (71.8%)	18 (62.1%)	13 (72.2%)	7 (46.7%)	0.316	29 (70.7%)	19 (63.3%)	7 (46.7%)	11 (73.3%)	0.346
	Yes	11 (28.2%)	11 (37.9%)	5 (27.8%)	8 (53.3%)		12 (29.3%)	11 (36.7%)	8 (53.3%)	4 (26.7%)	
CHF	No	33 (84.6%)	21 (72.4%)	14 (77.8%)	8 (53.3%)	0.117	34 (82.9%)	20 (66.7%)	12 (80.0%)	10 (66.7%)	0.353
	Yes	6 (15.4%)	8 (27.6%)	4 (22.2%)	7 (46.7%)		7 (17.1%)	10 (33.3%)	3 (20.0%)	5 (33.3%)	
CKD	No	38 (97.4%)	27 (93.1%)	17 (94.4%)	12 (80.0%)	0.159	39 (95.1%)	28 (93.3%)	15 (100.0%)	12 (80.0%)	0.147
	Yes	1 (2.6%)	2 (6.9%)	1 (5.6%)	3 (20.0%)		2 (4.9%)	2 (6.7%)	0 (0.0%)	3 (20.0%)	
DM	No	33 (84.6%)	26 (89.7%)	15 (83.3%)	11 (73.3%)	0.574	36 (87.8%)	27 (90.0%)	12 (80.0%)	10 (66.7%)	0.186
	Yes	6 (15.4%)	3 (10.3%)	3 (16.7%)	4 (26.7%)		5 (12.2%)	3 (10.0%)	3 (20.0%)	5 (33.3%)	
HTN	No	20 (51.3%)	17 (58.6%)	13 (72.2%)	7 (46.7%)	0.41	24 (58.5%)	18 (60.0%)	8 (53.3%)	7 (46.7%)	0.833
	Yes	19 (48.7%)	12 (41.4%)	5 (27.8%)	8 (53.3%)		17 (41.5%)	12 (40.0%)	7 (46.7%)	8 (53.3%)	
CVA	No	34 (87.2%)	25 (86.2%)	17 (94.4%)	13 (86.7%)	0.837	35 (85.4%)	27 (90.0%)	14 (93.3%)	13 (86.7%)	0.845
	Yes	5 (12.8%)	4 (13.8%)	1 (5.6%)	2 (13.3%)		6 (14.6%)	3 (10.0%)	1 (6.7%)	2 (13.3%)	
CABG	No	33 (84.6%)	26 (89.7%)	17 (94.4%)	12 (80.0%)	0.588	34 (82.9%)	28 (93.3%)	12 (80.0%)	14 (93.3%)	0.412
	Yes	6 (15.4%)	3 (10.3%)	1 (5.6%)	3 (20.0%)		7 (17.1%)	2 (6.7%)	3 (20.0%)	1 (6.7%)	
Valvular	No	18 (46.2%)	16 (55.2%)	10 (55.6%)	11 (73.3%)	0.354	20 (48.8%)	14 (46.7%)	11 (73.3%)	10 (66.7%)	0.229
	Yes	21 (53.8%)	13 (44.8%)	8 (44.4%)	4 (26.7%)		21 (51.2%)	16 (53.3%)	4 (26.7%)	5 (33.3%)	
Cabg-valv	No	34 (87.2%)	23 (79.3%)	16 (88.9%)	12 (80.0%)	0.735	36 (87.8%)	24 (80.0%)	12 (80.0%)	13 (86.7%)	0.786
	Yes	5 (12.8%)	6 (20.7%)	2 (11.1%)	3 (20.0%)		5 (12.2%)	6 (20.0%)	3 (20.0%)	2 (13.3%)	
Multivalv	No	34 (87.2%)	27 (93.1%)	14 (77.8%)	13 (86.7%)	0.507	36 (87.8%)	27 (90.0%)	12 (80.0%)	13 (86.7%)	0.821
	Yes	5 (12.8%)	2 (6.9%)	4 (22.2%)	2 (13.3%)		5 (12.2%)	3 (10.0%)	3 (20.0%)	2 (13.3%)	
Dissection	No	31 (79.5%)	23 (79.3%)	12 (66.7%)	12 (80.0%)	0.707	33 (80.5%)	25 (83.3%)	12 (80.0%)	8 (53.3%)	0.121
	Yes	8 (20.5%)	6 (20.7%)	6 (33.3%)	3 (20.0%)		8 (19.5%)	5 (16.7%)	3 (20.0%)	7 (46.7%)	
Age.c	20 - 40	10 (25.6%)	4 (13.8%)	6 (35.3%)	4 (26.7%)		10 (24.4%)	5 (16.7%)	2 (14.3%)	7 (46.7%)	
	40 - 60	11 (28.2%)	14 (48.3%)	5 (29.4%)	5 (33.3%)	0.564	13 (31.7%)	12 (40.0%)	5 (35.7%)	5 (33.3%)	0.339
	60 +	18 (46.2%)	11 (37.9%)	6 (35.3%)	6 (40.0%)		18 (43.9%)	13 (43.3%)	7 (50.0%)	3 (20.0%)	

Table 9. Examining the rSO2 level of patients against the variables of operation time and complications one week after the operation

		LEFT rSO2<30%(min)						RIGHT rSO2<30%(min)					
		0	**<10**	**10 - 20**	**>20**	***P****	**Pairwise comparison**	**0**	**<10**	**10 - 20**	**>20**	***P****	**Pairwise comparison**
Duration of ICU add(days)	No	1 (2.6%)	0 (0.0%)	0 (0.0%)	1 (6.7%)	0.081		1 (2.4%)	0 (0.0%)	0 (0.0%)	1 (6.7%)	0.124	
	<3	17 (43.6%)	10 (34.5%)	3 (16.7%)	5 (33.3%)			20 (48.8 %)	7 (23.3%)	5 (33.3%)	3 (20.0%)		
	3 - 5	21 (53.8%)	12 (41.4%)	11 (61.1%)	7 (46.7%)			19 (46.3 %)	16 (53.3%)	8 (53.3%)	8 (53.3%)		
	>5	0 (0.0%)	7 (24.1%)	4 (22.2%)	2 (13.3%)			1 (2.4%)	7 (23.3%)	2 (13.3%)	3 (20.0%)		
Extubation time(hrs)	No	2 (5.1%)	2 (6.9%)	1 (5.6%)	2 (13.3%)	0.136		1 (2.4%)	3 (10.0%)	2 (13.3%)	1 (6.7%)	0.005	
	<8	13 (33.3%)	8 (27.6%)	1 (5.6%)	2 (13.3%)			17 (41.5 %)	4 (13.3%)	2 (13.3%)	1 (6.7%)		
	8 - 24	21 (53.8%)	15 (51.7%)	14 (77.8%)	6 (40.0%)			20 (48.8 %)	21 (70.0%)	8 (53.3%)	7 (46.7%)		
	>24	3 (7.7%)	4 (13.8%)	2 (11.1%)	5 (33.3%)			3 (7.3%)	2 (6.7%)	3 (20.0%)	6 (40.0%)		
EF W1	<30 %	4 (10.3%)	5 (17.2%)	2 (11.1%)	7 (46.7%)	0.014		3 (7.3%)	6 (20.0%)	5 (33.3%)	4 (26.7%)	0.092	
	>30 %	35 (89.7%)	24 (82.8%)	16 (88.9%)	8 (53.3%)			38 (92.7 %)	24 (80.0%)	10 (66.7%)	11 (73.3%)		
AKI stage1 W1	No	37 (94.9%)	22 (75.9%)	15 (83.3%)	13 (86.7%)	0.159		36 (87.8 %)	25 (83.3%)	12 (80.0%)	14 (93.3%)	0.702	
	Yes	2 (5.1%)	7 (24.1%)	3 (16.7%)	2 (13.3%)			5 (12.2 %)	5 (16.7%)	3 (20.0%)	1 (6.7%)		
AKI stage2 W1	No	36 (92.3%)	24 (82.8%)	13 (72.2%)	13 (86.7%)	0.249		40 (97.6 %)	22 (73.3%)	11 (73.3%)	13 (86.7%)	0.019	
	Yes	3 (7.7%)	5 (17.2%)	5 (27.8%)	2 (13.3%)			1 (2.4%)	8 (26.7%)	4 (26.7%)	2 (13.3%)		
AKI stage3 W1	No	39 (100.0%)	27 (93.1%)	17 (94.4%)	10 (66.7%)	0.001		41 (100.0 %)	29 (96.7%)	12 (80.0%)	11 (73.3%)	0.002	
	Yes	0 (0.0%)	2 (6.9%)	1 (5.6%)	5 (33.3%)			0 (0.0%)	1 (3.3%)	3 (20.0%)	4 (26.7%)		
Dialysis W1	No	39 (100.0%)	28 (96.6%)	18 (100.0%)	14 (93.3%)	0.366		41 (100.0 %)	29 (96.7%)	15 (100.0%)	14 (93.3%)	0.375	
	Yes	0 (0.0%)	1 (3.4%)	0 (0.0%)	1 (6.7%)			0 (0.0%)	1 (3.3%)	0 (0.0%)	1 (6.7%)		
Death W1	No	37 (94.9%)	26 (89.7%)	15 (83.3%)	6 (40.0%)	<0.001		40 (97.6 %)	26 (86.7%)	9 (60.0%)	9 (60.0%)	<0.001	
	Yes	2 (5.1%)	3 (10.3%)	3 (16.7%)	9 (60.0%)			1 (2.4%)	4 (13.3%)	6 (40.0%)	6 (40.0%)		
Pomp time(min)		137.64 ± 63.11	143.52 ± 50.24	156.22 ± 70.7	177.93 ± 86.52	0.214**		127 ± 59.95	157.5 ± 49.95	159.33 ± 60.91	179.27 ± 94.79	0.032**	(1-4)
Cross Clamp time(min)		76.26 ± 26.55	95.03 ± 32.8	112.83 ± 38.87	99.27 ± 46.73	0.002**	(1-3)	71.66 ± 25.88	101.33 ± 29.51	102.47 ± 40.4	115.67 ± 44.06	<0.001**	(1-2,1-3,1-4)

Discussion

Cerebral oximetry is a non-invasive method of measuring the oxygen saturation of the brain during cardiopulmonary bypass (CPB) (3). It is based on the principle of near-infrared spectroscopy, which detects the absorption of light by hemoglobin in the cerebral tissue. Cerebral oximetry can provide information about the balance between cerebral oxygen delivery and consumption and help identify patients at risk of cerebral ischemia or injury. the factors that can impact cerebral oximetry values: Obtaining baseline cerebral oximetry values before anesthesia induction is crucial. Normal cerebral oxygen saturation (rSO_2) values typically range from 60% to 80% (4). Lower values (around 55-60%) are not considered abnormal in some cardiac patients (5). These values represent a balance between cerebral oxygen delivery and consumption. Blood pressure fluctuations affect cerebral perfusion. Hypotension or hypertension can alter cerebral oxygenation. Maintaining stable hemodynamics is essential. An incomplete Circle of Willis or severe carotid artery stenosis can create errors in cerebral oximetry values (6). Bilateral monitoring is recommended to account for anatomical variations. Changes in blood oxygen content impact cerebral oxygenation. Anemia, hypoxemia, or altered oxygen-carrying capacity affect oximetry readings. Optimizing oxygen delivery and consumption during surgery is critical (7). Algorithms based on cerebral oximetry values guide interventions to prevent desaturation. Different patient populations (e.g., pediatric, adult, elderly) exhibit varying cerebral oximetry responses. Specific conditions (e.g., valvular surgery, aortic dissection) influence cerebral oxygenation. Remember that cerebral oximetry values must not be interpreted in isolation. Clinical judgment, physiological context, and individual patient factors play essential roles.

This study delved into various underlying factors which might have impacted cerebral oximetry. The following is a discussion on each of these items: Normal BMI (Body Mass Index) typically ranges from 18.5 to 24.9 kg/m². Obese BMI is generally defined as a BMI of 30 or higher. Unfortunately, direct AUC comparisons between these groups are limited in literatures (8). We, also, could not find any meaningful correlation. Smoking affects vascular health and oxygen delivery (9). Smokers may have altered cerebral oxygenation. However, specific AUC data related to cerebral oximetry in smokers during CABG surgery are scarce. To our surprise, the data for smokers and non-smokers were not different statistically. Patients with IHD have compromised coronary blood flow (10). Cerebral oximetry helps assess oxygen delivery to brain tissue. While exact AUC values are not widely reported, maintaining optimal cerebral oxygenation is crucial in these patients. Our study demonstrated a significant reduced AUC in IHD patients during CABG, which should be considered during clinical procedures with these patients. CHF patients may exhibit impaired cardiac output and cerebral perfusion (11). Unfortunately, specific AUC data for CHF patients are not readily available in other papers. Our study has shown that there is no meaningful relation between CHF and cerebral oximetry. CKD affects overall vascular health. Cerebral oximetry may be impacted in CKD patients (12). However, direct AUC comparisons remain elusive. Our article revealed a significant drop in these patients compared with witness. DM can lead to microvascular changes affecting cerebral perfusion and mild cognitive alteration has been reported (13). Cerebral oximetry plays a critical role in maintaining optimal oxygenation. Specific AUC values for DM patients during CABG are not well-documented. Although these patients have reduced numbers in comparison to average baseline, the DM patients had not shown a statistically significant difference to other groups. HTN affects cerebral blood flow regulation. Monitoring cerebral oxygenation is crucial in HTN patients because allegedly the oxygen desaturation occurs frequently in these patients (14). Unfortunately, direct AUC comparisons were lacking. Our study, however, showed no difference. Patients with a history of stroke (CVA) may have altered cerebral perfusion. Cerebral oximetry helps prevent desaturation events (15). Specific AUC data for CABG patients with a history of CVA are not widely reported. CVA had a reduced AUC which was significantly meaningful in our study. During coronary artery bypass grafting (CABG) surgery, cerebral oximetry values may fluctuate depending on various factors, such as blood pressure, temperature, hemoglobin level, carbon dioxide tension, and anesthesia. A reduction in cerebral oximetry (rSO2) below a certain threshold may indicate inadequate cerebral perfusion and increased risk of postoperative cognitive dysfunction or delirium. However, there is no consensus on the optimal threshold or duration of cerebral oximetry reduction that is clinically significant. Different studies have used different cut-off values, ranging from 45 to 75% of baseline rSO2, and different durations, ranging from 1 to 60 min. Moreover, the normal baseline rSO2 may vary among individuals, depending on age, gender, comorbidities, and medications (16). Therefore, it is difficult to define a normal time and duration of dropping cerebral oximetry during CABG. However, some studies have suggested that a prolonged and severe reduction in rSO2 may be associated with worse outcomes. For example, one study found that a rSO2 <55% for more than 40 min was independently associated with impaired cerebral autoregulation, which is a protective mechanism that maintains constant cerebral blood flow despite changes in blood pressure (17,18). Another study found that a rSO2 <50% or 45% for more than 5 min was significantly associated with postoperative delirium (19). In our study, about one-third of the population had not experienced any drop in their cerebral oximetry and another one-third had just a transient 30-percent drop under 10-minutes; only less than 15% of the patients had undergone more than 20 minutes drop.

While specific AUC values related to age are not widely reported, cerebral oximetry remains essential in adults and the elderly. Age-related changes in cerebral perfusion and oxygenation may impact monitoring during surgery (20). Even though our study covered a wide range of adults, the data for different age group was not significant. The average area under the curve (AUC) of cerebral oximetry in different races during CABG is not well-studied. we could not find any published articles that directly compared the AUC of cerebral oximetry in different races during CABG. However, some studies have reported the AUC of cerebral oximetry in specific racial groups or mixed populations during CABG. Studies have highlighted disparities in pulse oximetry accuracy based on skin pigmentation. Darker skin tones can lead to less accurate readings, particularly at low oxygen saturation levels. This discrepancy has implications for patient care, including delayed identification of hypoxemia. However, most of this research has centered on pulse oximetry rather than cerebral oximetry. Our study can be used as a reference for Iranian average cerebral oximetry. The altered hemodynamics during valvular surgery may impact cerebral oxygenation differently. Baseline cerebral oximetry values may vary based on the specific procedure (21,22). In our study only multi-valve surgery indicated a significant difference to the average baseline which might be rooted in alteration in hemodynamic during these surgeries. The extended duration and altered hemodynamics during multivalve surgery may affect cerebral oxygenation. Monitoring Importance: Cerebral oximetry remains crucial to maintain optimal oxygen levels during these intricate procedures.

Aorta dissection patients had noticeable higher AUC comparing to others. However, patients with a lower AUC had elongated hospitalization in the ICU. In fact, with a decrease in AUC, the duration of a person's hospitalization in the ICU increases (23). The average of this value for people who are hospitalized in the ICU for more than 5 days is 236.73 is 111.89± (*P*=0.01) also, with the decrease of the area under the curve, the duration of patient intubation increases. This amount for patients with a duration of more than 24 hours is equal to 122.29±274.36 (*P*=0.023) in Among the people who die within a week, the amount of area under the curve during the operation is also significant. Aortic dissection, especially when it involves the ascending aorta or affects blood flow to the brain, can impact cerebral oxygenation (24). The altered hemodynamics and compromised blood supply may lead to changes in cerebral oximetry values. However, specific AUC (area under the curve) data related to aortic dissection are not widely reported.

Available evidence suggests that intraoperative cerebral oximetry desaturation is associated with an increased risk of postoperative delirium (POD). Monitoring-guided interventions based on cerebral oxygen saturation (rSO_2) levels correlate with Lower risk of POD and Lower risk of postoperative cognitive dysfunction (POCD) and shorter ICU stay in adults undergoing cardiac surgery (25). This was comprehensively in line with the results from our study.

While specific AUC (area under the curve) values related to extubation time are not widely reported, cerebral oximetry remains valuable. Maintaining optimal cerebral oxygenation during surgery may influence the readiness for extubation (26). Monitoring cerebral desaturation can guide decisions regarding extubation timing. In this study most patients were extubated within 8-24 hours which was aligned with their data from cerebral oximetry.

While direct correlations between EF and cerebral oximetry are not widely reported, both parameters are essential for patient well-being. Maintaining optimal cerebral oxygenation during surgery is crucial, especially in patients with compromised cardiac function. In our study, there is a significant relationship between the amount of rSO2Left and EF variable before the operation. Patients with EF above 30% have lower rSO2Left.

cerebral oximetry contributes valuable information during surgery, but its direct predictive value for AKI is limited (2). In this study, there was a significant relationship between rSO2Left with stage 3 renal failure and mortality after one week. Cross lamp duration is the highest for patients whose rSO2Left was in the region (10-20) and for patients whose rSO2Left was zero, the duration of Cross lamp is the lowest. And this difference between these two groups is statistically significant.

This study investigated the relationship between rSO2 levels and hemodynamic parameters during cardiac surgery. Our findings demonstrate a significant correlation between rSO2 and both cross-clamp and pump times, in line with other studies (27,28). Specifically, patients with rSO2 declines exceeding 20 minutes exhibited prolonged pump times compared to those with minimal rSO2 reductions. Additionally, the duration of cross-clamp was significantly different among patients with varying rSO2 levels, suggesting a direct association between cerebral oxygenation and hemodynamic dynamics during the surgical procedure. These observations underscore the importance of rSO2 monitoring in guiding intraoperative management and optimizing patient outcomes.

This study investigated the relationship between cerebral oxygen saturation (rSO2), as measured by cerebral oximetry, and postoperative outcomes in cardiac surgery patients. Our findings demonstrate that rSO2 levels are significantly influenced by underlying conditions such as coronary artery disease (IHD) and cerebrovascular accident (CVA). Moreover, the type of surgical procedure, particularly coronary artery bypass grafting (CABG) and aortic dissection, significantly impacts rSO2 dynamics. Preoperative left ventricular ejection fraction (EF) and postoperative complications, including prolonged intensive care unit (ICU) stays, are also associated with rSO2 levels. These results underscore the importance of rSO2 monitoring during cardiac surgery to identify patients at risk for adverse outcomes and to guide perioperative management strategies. Future studies are needed to further elucidate the mechanisms underlying these associations and to explore potential interventions to improve cerebral oxygenation and mitigate postoperative complications.

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