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Can near infrared spectroscopy predict stroke in coronary artery by-pass graft?

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ABSTRACT

Aim: Central nervous system may be affected after coronary artery by-pass graft (CABG) and carotid artery stenosis is an important risk factor. Near infrared spectroscopy (NIRS) is used to measure the regional cerebral oxygen concentration ($rScO_2$). The aim of this study is to determine the relationship of $rScO_2$ in patients with carotid artery lesion and to determine the relation of stroke with $rScO_2$ changes.

Material and Method: The patients who had cardiac bypass surgery were involved in the study. Demographic characteristics and presence of carotid artery stenosis, were collected from the files. Bilateral rSO_2 measurements performed by 2 sensors. $RScO_2$ values are detected in 5 minutes of cross-clamp (XCL5), XCL30, XCL60, XCL90, XCL120 and after the by-pass.

Results: 57 patients were involved in the study (40 male and mean age 62.54±13.08). 17 (29%) patients had carotid stenosis. $rScO_2$ levels are statistically significantly decreased in the patients with stenosis after post-clamp 30 minutes. Three patients had stroke after surgery (5.2%). Two of the patients had carotid stenosis while one patient did not have.

Conclusion: $RScO_2$ decreased in carotid artery stenosis irrespective of the degree of the stenosis after 30 minutes of cross-clamp. Cerebral perfusion follow-up is important during the CPB and NIRS is a method that can be used for this purpose.

Keywords: Coronary artery by-pass graft, carotid artery stenosis, near infrared spectroscopy

INTRODUCTION

Today, coronary artery bypass graft (CABG) surgeries are widely applied with the use of cardiopulmonary bypass (CPB) in coronary artery disease. Although CPB provides great advantages in surgery, it has undesirable side effects on the cerebral system, respiratory system, circulatory system, renal system, and many organs due to non-physiological and perioperative procedures. These undesirable side effects contribute to postoperative morbidity and mortality (1). The mortality of coronary artery by-pass graft (CABG) surgery used in the treatment of coronary artery disease is less than 2%. However, central nervous system may be affected as an important morbidity (2). The resulting cerebral disorders can range from cognitive dysfunction to stroke. Cerebral hypo-perfusion, hemo-dilution, cerebral micro embolism and inflammatory response are blamed in the etiology. Therefore, it is very important to use methods to prevent the deterioration of brain perfusion during CABG (3,4).

Near infrared spectroscopy (NIRS) is a method used to measure the regional cerebral oxygen concentration ($rScO_2$). Although it has been in use for more than 20 years, there is no standardization (5-7).

In previous studies, it was stated that carotid artery lesions were the most important risk factor for stroke in CABG (8).

The aim of this study is to determine the relationship of $rScO_2$ detected by NIRS in patients with and without carotid artery lesion and to determine the relation of stroke with $rScO_2$ changes during the operation.

MATERIAL AND METHOD

The study protocol was approved by the İstanbul Prof. Dr. Cemil Taşçıoğlu City Hospital Clinical Researches Ethics Commitee (Date: 06.06.2022, Decision No: 188). All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

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This is a retrospective clinical study. This study was carried out at Cardiovascular Surgery Department of the Prof. Dr. Cemil Tascioğlu City Hospital. The patients who had cardiac bypass surgery between January 2018 and December 2021 were involved in the study. Written informed consent was obtained from each patient before the operation.

Patients who previously had a persistent cerebrovascular event were not included in the study. Demographic characteristics (age and gender), clinical findings, presence of carotid artery stenosis, history of cerebrovascular event (CVE) and presence of peripheral arterial disease were collected from the patient files. We defined carotid stenosis as mild (30-50%), moderate (50-69%) and severe (70-99%) or total-occlusion (100%) by North American Symptomatic Trial Collaborators (NASCET) criteria (9).

Continuous bilateral rSO_2 measurements were performed using a Masimo Cerebral Oximeter (Masimo Corp, CA, USA), by 2 sensors placed on the forehead. $rScO_2$ values from both hemispheres were recorded simultaneously at certain time points and were compared with each other to evaluate the changes at different stages of operation as follows: before anesthetic induction, in 5 minutes of cross-clamp (XCL5), 30 minutes of cross-clamp (XCL30), 60 of cross-clamp (XCL60), 90 minutes of cross-clamp (XCL90), 90 minutes of cross-clamp (XCL120) and after the by-pass.

Intra-arterial monitarization is made by measuring oxygen saturation (SO_2), mean arterial blood pressure (MBP), hematocrit (Htc) and body temperature.

CABG Surgical Procedure

Coronary bypass was performed using a standard cardiopulmonary pump. CABG surgeries were performed under general anesthesia after central venous catheter, arterial catheter, foley catheter, nasopharyngeal probes and rectal temperature probes were inserted. All surgeries were performed with a median sternotomy incision. In all patients, the left pleura was opened, the left internal mammillary artery was extracted as a graft, and the vena saphenous magna vein was prepared as a graft. In CABG surgeries, arterial cannulation from the ascending aorta and two-stage venous cannulation from the right atrium were performed, then CPB was started. The Terumo Advanced Perfusion System 1 heart-lung machine (Terumo Terumo® Advanced Perfusion System 1, Terumo ®, Ann Arbor, Michigan, USA) and the Inspire 8 membrane oxygenator (Inspire 8, LivaNova Sorin Group, Modena, Italy) were used for CPB. The cross-clamp, diastolic cardiac arrest was achieved by antegrade cold blood cardioplegia from the ascending aorta, mild-moderate hypothermic systemic cooling (28-32°C), and local cooling with cold icy saline. For myocard protection, maintenance was performed with cold blood cardioplegia at 20-minute intervals. After the distal anastomoses were completed, just before the cross-clamp was removed, the heart was started by giving warm blood cardioplegia and providing systemic warming. In CABG surgeries, proximal anastomoses were performed under partial clamping. A drain was placed in the mediastinum and thoracic cavity. All patients were taken to the cardiovascular surgery intensive care unit while intubated and connected to ventilators.

Statistical Analysis

Data were analyzed in SPSS software version 25.0. Continuous data were shown as arithmetic means ± standard deviation. Categorical data were expressed as number (%). The Student's t-test was used for continuous data analysis and the chi-square test was used for categorical data analysis. Fisher's exact test was used for some analyses, if necessary. Statistical significance was considered as $P \leq 0.05$.

RESULTS

57 patients were involved in the study. 40 (61%) were male and 17 (29%) were female. Mean age was 62.54±13.08. MBP, oxygen saturation, temperature, hematocrit, $rScO_2$ left and $rScO_2$ right values before induction, in five minutes of cross clamp and after coronary bypass can be seen on **Table 1**.

Table 1. General findings of the patients

Age (years)	62.54±13.08
Gender (male)	40 (70%)
Before anesthetic induction	
Mean blood pressure (mmHg)	87.54±15.37
Oxygen saturation (%)	96.2±0.69
Temperature (C)	36.45±0.5
Hematocrit	37.44±5.5
$rScO_2$-right	61.2±6.1
$rScO_2$-left	62.1±7.2
Cross Clemp (5th minutes)	
Mean blood pressure (mmHg)	70±10
Oxygen saturation (%)	93.5±0.77
Temperature (C)	31.84±3.52
Hematocrit	26.7±5.4
$rScO_2$-right	60.8±5.6
$rScO_2$-left	59±5.4
Coronary by pass	
Mean blood pressure (mmHg	62.77±9.93
Oxygen saturation (%)	99±1.3
Temperature (C)	33.9±2.84
Hematocrit	30±6.5
$rScO_2$-right	60.98±7
$rScO_2$-left	61.11±6.73

$RScO_2$: regional cerebral oxygen concentration

Oxygen saturation before induction was 96.2±3.69, increased to 99.33±1.08 in XCL5 and decreased to 98.89±1.51 after CBP. The difference between induction and XCL5 and after CBP were statistically significantly different (p<0.05) (**Figure 1**).

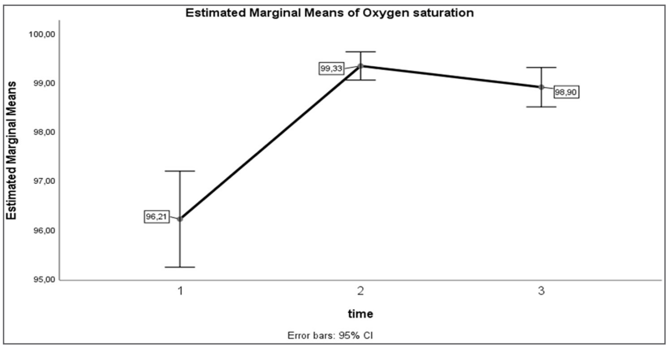

Figure 1. Oxygen saturation before induction, in XCL5 and after CABG

MBP before induction was 87.53±15.37, decreased to 68.28±11.25 in XCL5 and increased to 75.12±12.29 after CBP. The difference between all three groups were statistically significant (p<0.05) (**Figure 2**).

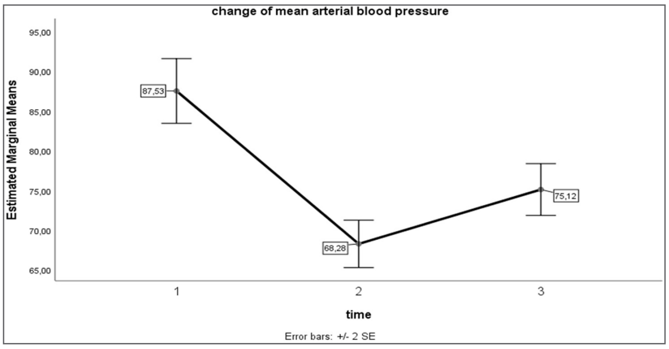

Figure 2. MAP before induction, in XCL5 and after CABG

Htc before induction was 37.44±5.32, decreased to 26.038±4.67 in XCL5 and increased to 27.12±2.72 after CBP. The difference between induction and XCL5 and after CBP were statistically significantly different (p<0.05) (**Figure 3**).

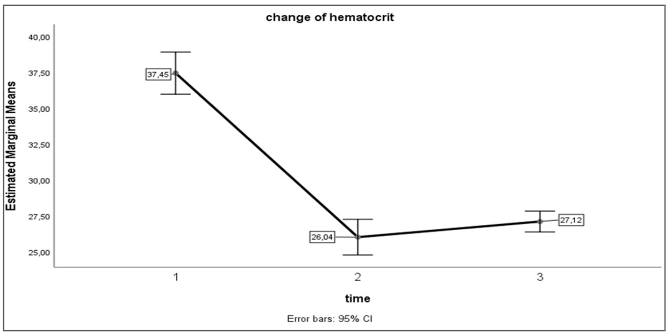

Figure 3. Htc before induction, in XCL5 and after CABG

$RScO_2$-right before induction was 61.39±8.91, decreased to 60.39±8.42 in XCL5 and increased to 63.84±6.9 after CBP. The difference between induction and after CBP were statistically significant (p<0.05) (**Figure 4**).

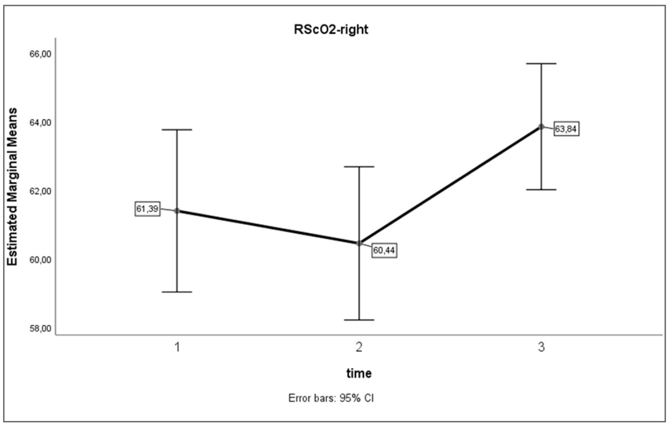

Figure 4. $RScO_2$-right before induction, in XCL5 and after CABG

$RScO_2$-left before induction was 61.84±9.04, decreased to 61.07±8.48 in XCL5 and increased to 63.7±6.1 after CBP. The difference between induction and after CBP were statistically significant (p<0.05) (**Figure 5**).

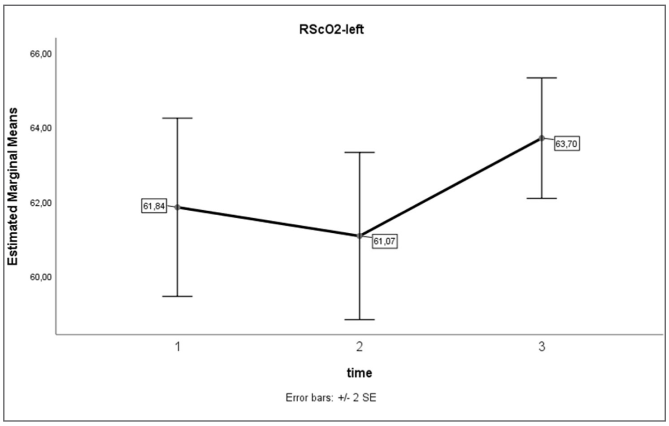

Figure 5. $RScO_2$-left before induction, in XCL5 and after CABG

Correlation analysis of $rScO_2$ right and left after XCL5 was made and they are found to be negatively correlated with age (R=-0.347, P=0.008 and R=-0.366, P=0.005, respectively) (**Table 2**).

Table 2. Correlation analysis of $rScO_2$ right and left after XCL5

	Age	
	R	P
$rScO_2$-right	-0.347	0.008
$rScO_2$-left	-0.366	0.005

$RScO_2$:regional cerebral oxygen concentration, XCL: Cross-clamp

Patients are grouped according to the presence of carotid stenosis. 27 (47.3%) patients had carotid stenosis while 30 (52.6%) did not have. When patients are grouped according to presence of carotid artery stenosis 4 of the patients (33.3%) had mild, 7 of the patients had moderate (58.1%) and one of the patient (8.3%) had severe stenosis in the right carotid artery. In left carotid artery 3 of the patients (20.6%) had mild, 9 of the patients had moderate (60.0%) and 3 of the patient (20.0%) had severe stenosis (**Table 3**).

Table 3. Presence of stenosis

	Right carotis stenosis	Left carotis stenosis	P
Total	12 (44.%)	15 (55.6%)	>0.05
Mild	4 (33.3%)	3 (20.6%)	>0.05
Moderate	7 (58.1%)	9 (60.0%)	>0.05
Severe	1 (8.3%)	3 (20.0%)	>0.05

$RScO_2$ right and left were analyzed during induction, XCL5, XCL30, XCL60, XCL90, and XCL120th minutes in patients with and without carotid artery stenosis. $RScO_2$ levels are statistically significantly decreased in the patients with stenosis after post-clamp 30 minutes (**Table 4**). In post clamp 30th minutes only $rScO_2$-left was statistically significantly decreased in the carotid artery stenosis group (56.88±7.37 vs. 62.08±8.81; p=0.038).

Table 4. Comparision of the groups in terms of carotid artery stenosis

	Carotid Stenosis				P
	(+)		(-)		
	Mean	SD	Mean	SD	
$rScO_2$-right-induction	63.06	9.14	60.65	8.8	0.239
$rScO_2$-left-induction	63.81	10.15	61.2	8.47	0.112
$rScO_2$-right-5	58.10	6.32	61.48	9.04	0.12
$rScO_2$-left-5	58.59	6.61	62.13	9.03	0.1
$rScO_2$-right-30	56.59	7.87	61.84	9.51	0.08
$rScO_2$-left-30	56.88	7.37	62.08	8.81	0.038
$rScO_2$-right-60	56.71	7.78	64.43	8.47	0.006
$rScO_2$-left -60	57.29	7.96	64.57	7.73	0.007
$rScO_2$-right-90	55.00	3.81	67.00	8.00	0.004
$rScO_2$-left -90	55.20	5.89	66.35	8.25	0.012
$rScO_2$-right-120	55.75	5.12	63.33	5.50	0.038
$rScO_2$-left -120	55.25	4.86	64.25	6.78	0.044

$RScO_2$:regional cerebral oxygen concentration, SD: Standard deviation

Three patients had stroke after surgery (5.2%). 2 of the patients had carotid stenosis while 1 patient did not have. The patients with carotid stenosis and stroke both had moderate unilateral stenosis (**Table 5**).

Table 5. Post-operative CVA

		Carotid Stenosis		P
		(+)	(-)	
		Count	Count	
Postoperative CVA	0	15	39	0.152
	1	2	1	

CVA: cerebrovascular accident

DISCUSSION

Major finding of this study is the decrease in $rScO_2$ levels in patients with carotid artery stenosis irrespective of the degree of the stenosis after 30 minutes of cross-clamp.

One of the main goals of anesthesia is to provide adequate tissue oxygenation. For this purpose, different monitoring techniques are used. This follow-up is even more important to minimize the effects of cardiopulmonary bypass during open heart surgery.

The brain is one of the most affected organs during CABG (10). In open heart surgery, cerebral protection was tried to be provided by methods such as increasing cardiac output, using inotropic agents, cooling the patient, using cerebral vasodilators and increasing hematocrit. Various methods have been used to monitor brain perfusion and evaluate metabolic activity. Cerebral ischemia markers such as mean arterial pressure, blood gas monitoring, jugular oxygen venous saturation, lactate, neuron-specific enolase (NSE) and S-100B were used (11-14). None of the traditional methods can show cerebral perfusion instantaneously and locally during CABG surgery. Near infrared spectroscopy (NIRS) noninvasively demonstrates real-time degradation of tissue oxygenation, allowing necessary interventions to be performed in a timely manner. $RScO_2$ measured by NIRS shows real-time changes in the supply-demand balance of area-specific tissue O_2 perfusion. Usually, perfusion disorder at the microvascular level can be detected before noticeable changes in systemic parameters. Clinical studies have shown that more than 20% reductions of $rScO_2$ from the patient's baseline are associated with neurological disorders. (15, 16).

Stenosis of 30-50% or more in the extracranial internal carotid arteries is defined as carotid artery stenosis (17). It is responsible for 10-15% of all strokes (18). Patients with a history of numbness, weakness, and transient ischemic attack in the face, arms, and legs in the previous six months are considered symptomatic (19).

Symptomatic patient, plaque structure, concomitant diseases and severity of stenosis are important in determining surgical indications (20). Surgical treatment is recommended for patients who are symptomatic and have stenosis greater than 50%, and patients who are asymptomatic but have stenosis greater than 70 % (21). In 2017, the European Society of Cardiovascular Surgery recommends routine CAS screening before CABG only for patients over 70 years of age, with a previous history of carotid stenosis and a previous central event (22). The reason for this may be the cost. However, since the coexistence of the two pathologies will increase mortality and morbidity, hence, many centers perform carotid artery screening before CABG (23). CAS was detected in a total of 17 (29%) patients with this screening, which was also performed in our clinic.

Since CABG surgery performed with CPB is carried out with lower arterial blood pressure and cardiac output, so cerebral perfusion decreases when CPB begins (24). In our study, a statistically significant difference was found between the MBP values measured preoperatively, XCL5 and after CPB. The significant decrease in MBP detected in XCL5 is an indicator of cerebral-hyperfusion as expected during CPB.

Decrease in patient's Htc level is a natural process which occurs during the initiation of cardiopulmonary bypass and its primary cause is the volume of fluid that fills the perfusion pump (priming). However, if the Htc level is too low it may result in complications originating from poor tissue oxygenation such as impaired renal function, increased risk of myocardial damage, perioperative stroke (25). In our study, a statistically significant difference was found in the Htc values measured preoperatively, XCL5 and after CPB. The decrease in the hematocrit value detected in XCL5 is an indication of decreased cerebral perfusion as expected during CPB. A statistically significant difference was found between preoperative, XCL5 and postoperative CPB oxygen saturations. The elevation in XCL5 is due to perfusion from the heart-lung machine with 60% oxygen. During CPB, blood PO_2 pressure is targeted to be 100-180 mmHg. Higher values may cause air embolism. (26).

Measuring regional cerebral oxygen saturation via near infrared spectroscopy (NIRS) has become a widely used tool for intraoperative neuromonitoring during CPB in cardiac surgery. As the duration of CPB is prolonged, a decrease in cerebral perfusion and a number of complications ranging from neurocognitive impairment to cerebrovascular accident are observed (27). In our study, $rScO_2$ right and left were analyzed during induction, XCL5, XCL30, XCL60, XCL90, and XCL120th minutes in patients with and without carotid artery stenosis. $RScO_2$ levels are statistically significantly decreased in the patients with stenosis after XCL30, XCL60, XCL90, and XCL120th minutes. In the study, the $rScO_2$ value was found to be low in patients with only $rScO_2$-left in the XCL30. We think that this may be due to the higher number of patients with left carotid stenosis, although this is not statistically significant. In our study irrespective of the degree of stenosis cerebral oxygen saturations decreased in the stenosis group after post-clamp 30 minutes. In order to avoid this situation, it may be appropriate to keep the post-clamp time short or to increase the perfusion pressure or mean arterial pressure regardless of the level of carotid stenosis. In a study by Sungurtekin et al. (28), they found that MAP was the most effective factor in cerebral perfusion. In the study conducted by Tufo et al. (29), they found that neurological findings occur three times more in patients with a MAP value below 40 mmhg than in patients with a MAP value above 60 mmhg. In a study by Coskun et al. (30), they found that the follow-up of cerebral perfusion with a method like near-infrared spectroscopy (NIRS) will ensure that MAP is adjusted with interventions that will be made according to changes in NIRS.

In our study, postoperative stroke developed in 3 patients (5.4%). Naylor et al. (8) reported the postoperative stroke rate of 1% to 2% in all patient groups undergoing CABG. In another study involving patients with critically asymptomatic carotid stenosis, the postoperative stroke rate was 3%. The postoperative stroke rate reaches 5% in patients with bilateral carotid stenosis and 11% in patients with total stenosis (31In our study, 2 of the patients who had moderate stenosis had stroke. These findings may suggest that there is a risk of stroke in moderate stenosis.

Cerebral oxygen sat values were correlated with age in patients. This may be due to the increasing rate of atherosclerosis with age (32). This may be concordant with the 2017 European Society of Cardiovascular Surgery guidelines which recommends investigating CAS over 70 years of age. In our study, there was a negative correlation between age and $rScO_2$. The result is similar to the literature.

The limitations of this study are the retrospective nature of the study, the small number of patients, and the evaluation of only major cerebrovascular events such as stroke. Future large-scale, multicenter studies with a longer follow-up duration are required.

CONCLUSION

Cerebral hypo-perfusion is the most important causes of stroke, which is an important cause of mortality and morbidity in patients undergoing CABG. We think that perfusion follow-up is important in the early detection of cerebral hypo perfusion. NIRS is a non-invasive and easy method that can be used for this purpose. We think that taking measures to increase cerebral perfusion, such as increasing pump cardiac output and using inotropic agents, may reduce the risk of stroke in patients with CAS, in patients with CABG found to have decreased $rScO_2$ with NIRS during CPB. Thus, unnecessary increases in the perfusion flow rate and unnecessary use of medication can be avoided by $rScO_2$ monitoring.

ETHICAL DECLARATIONS

Ethics Committee Approval: This study was carried out with the permission of İstanbul Prof. Dr. Cemil Taşçıoğlu City Hospital Clinical Researches Ethics Commitee (Date: 06.06.2022, Decision No: 188).

Informed Consent: All patients signed the free and informed consent form.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper and that they have approved the final version.

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