GKDA Derg 2020;26(2):85-94
doi: 10.5222/GKDAD.2020.94824

Araştırma / *Research Article*

Comparison of Regional Cerebral Oxygen Saturation Values by Using Near-Infrared Spectroscopy in Patients Who Underwent Coronary Artery Bypass Graft with and Without Internal Carotid Artery Stenosis§

Hale Kefeli Çelik
Zahide Doğanay
Atilla Kanca

Koroner Arter Baypas Greft Cerrahisi Uygulanan Hastalarda İnternal Karotis Arter Darlığı Olan ve Olmayanların Near İnfrared Spectroscopy ile rSO_2 Değerlerinin Karşılaştırılması

Etik Kurul Onayı: Ondokuz Mayıs Üniversitesi Klinik Araştırmalar Etik Kurulu (tarih: 25,4,2014, No.985).
Çıkar çatışması: Yazarlar, bu makalenin yazarlığı ve / veya yayınına ilişkin herhangi bir çıkar çatışması bildirmemişlerdir.
Finansal destek: Yazarlar bu makalenin araştırılması ve / veya yazarlığı için herhangi bir finansal destek almamışlardır.
Hasta onamı: Hastalardan ameliyat öncesinde aydınlatılmış onam formu alınmıştır.

Ethics Committee: Ondokuz Mayıs University Clinic Research Ethics Committee (date: 25,4,2014, Number.985).
Conflict of interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.
Funding: The authors received no financial support for the research and/or authorship of this article.
Informed consent: Informed consent forms were obtained from all patients before the surgery.

Cite as: Kefeli Çelik H, Doğanay Z, Kanca A. Comparison of regional cerebral oxygen saturation values by using near-infrared spectroscopy in patients who underwent coronary artery bypass graft with and without internal carotid artery stenosis. GKDA Derg. 2020;26(2):85-94.

ABSTRACT

Objective: *In the study, the regional cerebral oxygen saturation (rSO_2) of patients with and without carotid artery stenosis was monitored to see whether or not NIRS can be used routinely in CABG operations.*
Methods: *Eighty patients undergoing CABG were divided into two groups. Following the preoperative colour Doppler ultrasonography, the patients with internal carotid artery stenosis or with stable plaque were included in Group I (n=40), while the patients having no internal carotid artery stenosis were included in Group II (n=40). Pulse rates, systolic and diastolic blood pressures, mean arterial blood pressures, nasopharyngeal temperatures, haematocrit, PaO_2, $PaCO_2$, SpO_2, BIS, right, and left rSO_2 values, and relative changes in rSO_2 from baseline of the two groups were compared.*
Results: *The male/female ratios in both groups were 27/13. The mean age was 60.82±9.63 (39-79) years in Group I and 59.95±9.54 (41–80) years in Group II. No differences were observed in terms of demographic data, preoperative laboratory and bispectral index (BIS) values, and time of operation and CPB. In addition, no differences were observed between the arterial blood gas values or the right and left rSO_2 values of the groups at all measurement time points (p=0.309 and p=0.114, respectively). In both groups, the decrease in rSO_2 values was not higher than 20% at all measurement time points. However, the relative changes in rSO_2 from baseline in Group I were statistically different compared to those in Group II (right p=0.031, left p<0.001). No stroke occurred in the groups postoperatively.*
Conclusion: *In patients undergoing CABG, brain perfusion reduces when a CPB pump is put into operation, and the monitoring of intraoperative cerebral perfusion with NIRS is crucial. In patients with carotid artery stenosis, relative changes in rSO_2 from baseline are higher.*

Keywords: *stroke, CABG, NIRS, carotid artery stenosis, rSO_2*

ÖZ

Amaç: *Çalışmada, karotis arter darlığı olan ve olmayan hastaların serebral oksijen satürasyonu (rSO_2) takip ederek NIRS'ın KABG ameliyatlarında rutin olarak kullanılabilirliliği araştırıldı.*
Yöntem: *KABG uygulanacak olan 80 hasta iki gruba ayrıldı. Preoperatif yapılan renkli doppler ultrasonografi ile internal karotis arterlerinde darlık ya da stabil plağı olan hastalar Grup I (n=40), internal karotis arterde darlık tespit edilmeyen hastalar Grup II'yi (n=40) oluşturdu. Her iki grupta; nabız, sistolik ve diyastolik kan basıncı, ortalama arteriyel kan basıncı, nazofarengeal ısı, hematokrit, PaO_2, $PaCO_2$, SPO_2, BİS, sağ ve sol rSO_2 değerleri ve rSO_2 yüzde değişim oranları karşılaştırıldı.*
Bulgular: *Her iki grupta da erkek/kadın oranı 27/13 şeklindeydi. Hastaların ortalama yaşı grup I'de 60.82±9.63 (39-79) yıl, grup II'de 59.95±9.54 (41-80) yıl idi. Gruplar arasında demografik veriler, preoperatif labaratuar ve BİS değerleri, ameliyat ve pompa süresi açısından bir fark izlenmedi. Arteriyal kan gazı değerleri, sağ ve sol rSO_2 değerlerinde tüm ölçüm zamanlarında gruplar arasında fark bulunmadı (sırasıyla p=0,309, p=0,114). Her iki grupta tüm ölçüm zamanlarında rSO_2 değerlerinde %20'ten fazla azalma izlenmedi. Ancak grup I'de rSO_2 yüzde değişim oranları grup II'ye göre istatistiksel olarak anlamlı bulundu (sağ p=0,031, sol p<0,001). Postoperatif dönemde her iki grupta da inme izlenmedi.*
Sonuç: *KABG uygulanan hastalarda kalp akciğer pompasına geçildiğinde beyin perfüzyonunda düşme olmaktadır ve NIRS ile peroperatif serebral perfüzyonun takibi önemlidir. rSO_2'deki yüzde değişim oranları karotis arterde darlık olan hastalarda daha fazla olmaktadır.*

Anahtar kelimeler: *inme, KABG, karotis arter darlığı, NIRS, rSO_2*

Received: 27 May 2020
Accepted: 15 June 2020
Publication date: 30 June 2020

Hale Kefeli Çelik
Samsun Eğitim ve Araştırma Hastanesi,
Anesteziyoloji ve Reanimasyon Kliniği
Samsun - Türkiye
halecelik@gmail.com
ORCİD: 0000-0002-0850-4524

Z. Doğanay 0000-0001-8057-5530
Samsun Eğitim ve Araştırma Hastanesi,
Anesteziyoloji ve Reanimasyon Kliniği
Samsun - Türkiye

A. Kanca 0000-0003-1933-0467
Samsun Eğitim ve Araştırma Hastanesi,
Kalp ve Damar Cerrahisi Kliniği
Samsun - Türkiye

§ Presented as oral presentation in 22th National Congress of Thoracic Cardio-vascular Anesthesia and Intensive Care Association, 21-24 April 2016, Fethiye.

INTRODUCTION

Coronary artery bypass grafting (CABG) is one of the most commonly used procedures in coronary artery disease, and every year it is performed on more than 800.000 patients worldwide. Although the mortality rate for this surgical procedure is less than 2%, it has a remarkable morbidity rate, particularly affecting the central nervous system [1,2]. Atherosclerosis is a generalized disease, and it is often accompanied by carotid artery stenosis in patients undergoing CABG. The most important factor causing mortality, morbidity, prolonged hospitalization, and poor life quality after cardiac surgery is cerebral injury due to carotid artery stenosis. The incidence of cerebrovascular attack (stroke) after CABG surgery ranges from 1.3% to 4.3% [3,4].

In patients operated under extracorporeal circulation, the risk of developing cerebral thromboembolic events and cerebral hypoperfusion is high because of nonpulsatile blood flow, mediator oscillation due to foreign surface contact, acute and deep thermodilution, changes in the blood clotting system, and the patient's comorbid disorders (carotid artery or cerebral artery stenosis). The most important risk factor is reported to be extracranial carotid artery stenosis [5,6]. Carotid artery lesions can be detected by radiological methods, and they are a preventable risk factor, so preoperative detection is crucial [7,8]. Cerebral perfusion impairment and the risk of cerebral damage depend on the degree of the stenosis in the carotid artery. The presence of stenosis in the carotid artery disrupts the balance between cerebral oxygen demand and supply during CABG [9-11].

Near-infrared spectroscopy (NIRS) is a non-invasive monitoring method used for measuring cerebral oxygen saturation. It receives the reflections from the middle cerebral artery junction, called the 'water shed zone'. Since NIRS generally measures venous oxygen saturation, it does not need pulsatile signals, and thus it enables the monitoring of oxygen saturation at all stages of CABG surgery [8,12].

The aim of this study was to monitor the cerebral oximetry values with NIRS during on-pump CABG surgery in patients with and without carotid artery stenosis and to compare the results.

MATERIAL AND METHOD

After obtaining the permission of the local ethical committee and written consent from the patients, the study was conducted on 80 patients (54 males, 26 females) 39 to 80 years of age. All patients were admitted to the Hospital due to coronary artery disease and underwent CABG surgery following coronary angiography. The study was conducted prospectively and nonrandomized. After preoperative colour Doppler ultrasonography (USG), the patients with internal carotid artery stenosis or with stable plaque were included in Group I (n=40), and the patients having no internal carotid artery stenosis were included in Group II (n=40).

Selection of Patients

The exclusion criteria were as follows; history of myocardial infarction within the 15 days prior to the surgery, an ejection fraction below 40%, emergency surgery, presence of atrial fibrillation, patients under the age of 18 and weighing less than 40 kg, history of cerebral ischemic attack or ischemic stroke, skin lesions and/or haematoma at the probing site, patients who received methylene blue or an equivalent colouring agent before the surgery, patients with chronic renal insufficiency or a serum creatine value higher than 1.5 mg/dL, and patients for whom colour Doppler USG revealed vertebrobasilar failure.

All CABG patients included in the study underwent colour Doppler USG preoperatively to be investigated for carotid artery lesions and vertebrobasilar failure. The patients with severe carotid artery stenosis (70% and higher) as well as those with occlusion were excluded from the study.

Anaesthesia

A standardized anaesthetic technique was used. The night before the surgery, the patients received premedication with 5 mg of diazepam (Diazem® 5 mg caps, Deva, Turkey). On the morning of the operation, the patients received premedication with 0.05 mg/kg im. of midazolam (Demizolam® 15 mg amp, Dem Pharmaceutical, Turkey) and were allowed to receive their routine treatments. The patients were monitored with electrocardiography, pulse oximetry, and the bispectral index (BIS) in the operation room. Radial artery catheterization was performed on the non-dominant arms of the patients before the induction. NIRS monitoring (INVOS 5100, Covidien, Mansfield, MA) was provided prior to the induction by placing electrodes on the right and left sides of the patients' foreheads, and the basal oximetry values were recorded.

During anaesthesia induction, the patients were administered 0.05 mg/kg of midazolam (Demizolam® 15 mg amp, Dem Pharmaceutical, Turkey), 0.5-5 mcg/kg of fentanyl (Fentanyl®, 0.5 mg amp, Johnson & Johnson, Turkey), 3–5 mg/kg of thiopental sodium (Pental®, 1 g, İbrahim Etem Ulagay, Turkey), and 1 mg/kg of rocuronium (Esmeron® 50 mg/5 mL, Organon, Turkey) prior to intubation. Following the endotracheal intubation, mechanical ventilation was started using 50% oxygen and 50% air mixture, with a 5-7 ml/kg tidal volume and $ETCO_2$ of 35-45 mmHg. Central venous catheterization was performed on the right internal jugular vein. Rectal and nasopharyngeal temperature probes were placed to monitor the body temperature. The cardiopulmonary bypass (CPB) technique was performed under moderate systemic hypothermia (28-32°C). Anaesthesia maintenance was established by titrating the remifentanil infusion (0.1-0.5 mcg/kg/min) (Ultiva® 1 mg, Glaxo Smith Kline, UK) and propofol infusion (4-10 mg/kg/h) (Pofol®, 200 mg/20 mL amp, Sandoz, Turkey) to keep the BIS level between 40 and 50.

Anticoagulation for the cardiopulmonary bypass was provided by administering 300 U/kg of heparin (Nevparin® 5 ml, Mustafa Nevzat, Turkey). During CPB, activated coagulation time (ACT) values were checked every 30 minutes. The pump blood flow rate was 2-2.5 L/m²/min. Hypertension and hypotension were avoided during CPB, and the mean arterial pressure was kept between 50 and 80 mmHg. The patients were cooled between 28 and 32°C. The CPB pump and operation times were recorded.

Although the anaesthetic depth was sufficient, a vasodilator (nitroglycerin, 100-200 mcg) was given to the patients with high blood pressure, and a vasopressor (ephedrine, 10 mg) was given to the patients with low blood pressure. Haematocrit values were kept between 22 and 28% during the CPB pump. Regional cerebral oxygen saturation was continually measured with cerebral oximetry sensors placed on the forehead. In the study, we planned to raise FiO_2 to 100%, to keep $PaCO_2$ between 40 and 45 mmHg, and then to increase the pump blood flow rate to keep the mean artery pressure within the range of 70-80 mmHg if the rSO_2 values decreased more than 20% from the baseline values. When the haematocrit level fell under 22%, the patient was given erythrocyte suspension. Following the surgery, intubated patients were sent to cardiovascular surgery intensive care.

Pulse rate, mean arterial blood pressure, rectal and nasopharyngeal temperature, haematocrit in arterial blood gas, PaO_2, $PaCO_2$, lactate, BIS, right and left rSO_2 values, and right and left rSO_2% (relative change in rSO_2 from baseline) were recorded at eight different time points: T0: before induction; T1: after induction; T2: 10th minute of extracorporeal circulation; T3: 20th minute of extracorporeal circulation; T4: before warming; T5: after warming; T6: at the end of extracorporeal circulation; and T7: at the end of operation.

Statistical Analysis

All data were expressed using mean±SD. In the power analysis performed with the values d=4, σ=5, α=0.05, and power=0.8, the minimum sample size for each group was found to be 26. Considering the possible data losses, 40 patients were included in both groups. Statistically, a Student's t-test was used to compare the demographic data, a Mann–Whitney U test was used to compare the preoperative blood values, and a repeated measures analysis of variance was used to compare the data differences between time series. Statistical significance was set at $p<0.05$.

RESULTS

Of the 80 patients included in the study, 54 (67.5%) were male and 26 (32.5%) were female. The mean ages in Group I and Group II were 60.82±9.63 (39-79) years and 59.95±9.54 (41-80) years, respectively. No statistical differences were observed in height, weight, or BMI between the groups. In terms of comorbid disorders, 23 patients had hypertension and 13 had DM in Group I, while in Group II, 24 had hypertension and 15 had DM. Surgery and cardiopulmonary bypass times were 243±50.69 min and 101.35±29.24 min in Group I and 228±39.69 min and 100.75±18.27 min in Group II, respectively. No statistical differences were observed in the surgery (p=0.145) and CPB pump (p=0.913) times of the groups (Table 1).

Preoperative carotid colour Doppler USG revealed that in Group I, 19 patients had stenosis in the right carotid artery, 21 had it in the left carotid artery, and 6 had it in both arteries. No postoperative stroke or neurologic sequel was observed in either group. There were no differences in the temperature, haematocrit in the arterial blood gas, or PaO_2, $PaCO_2$, lactate, and BIS values of the groups at any time points (Figure 1).

Evaluation of mean arterial pressure (MAP) within the groups revealed a statistically significant decrease in both groups throughout the period from intubation to leaving the CPB pump process. No statistically significant differences were observed in the

Table 1. Demographic data of the patients.

	Group I (n=40)	Group II (n=40)	p
Sex	40	40	NS
Male	27 (67.5%)	27 (67.5%)	
Famale	13 (32.5%)	13 (32.5%)	
Age (year)	60.82±9.63 (39-79)	59.95±9.54 (41-80)	NS
Height (cm)	162.05±7.99 (145-175)	163.6±8.49 (146-180)	NS
Weight (kg)	82.92±11.01 (53-100)	81.32±10.73 (65-109)	NS
Body mass index (kg/m^2)	31.58±3.87 (23.56-41.62)	30.48±4.27 (23.88-43.72)	NS
Operation time (min)	243±50.69 (150-340)	228±39.69 (150-320)	NS
CPB time (min)	101.35±29.24 (45-180)	100.75±18.27 (60-140)	NS
Comorbidities			NS
HT	23 (57.5%)	24 (60%)	NS
DM	13 (32.5%)	15 (40%)	NS

Abbreviations: CPB, cardiopulmonary bypass; HT, hypertension; DM, diabetes mellitus; NS, not significant. Data were expressed using mean±SD

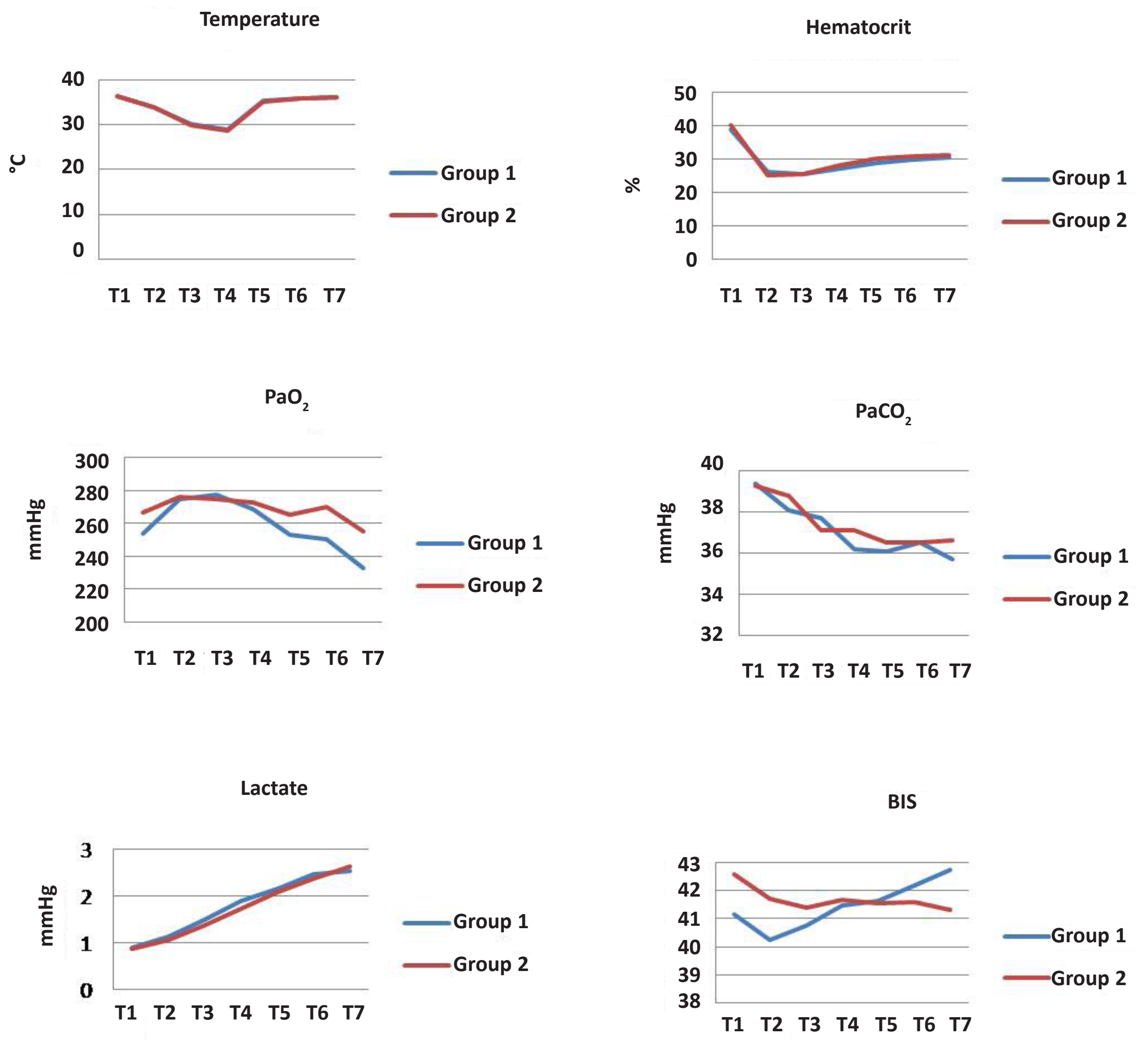

Figure 1. Comparison of the temperature, hematocrit, PaO_2, $PaCO_2$, lactat and BIS values of both groups.

other follow-up periods. In the evaluation of MAP for both groups, no statistical differences were observed in all follow-up periods.

Before anaesthesia, the mean percentage of cerebral oxygen saturation was 71.5±5.71 for Group I and 72.2±5.55 for Group II in the right side (p=0.621) and 71.7±6.19 for Group I and 72.2±4.93 for Group II in the left side (p=0.691). There were no statistically significant differences in the right and left side rSO_2 values of the groups at any other time points (Table 2).

There were statistical differences between Group I and Group II at the T4, T5, T6, and T7 time points in rSO_2 relative to the baseline ratios in the right side. However, there were statistical differences at all time points in the left side. The differences were observed as a decrease from the baseline values in rSO_2 (Figure 2, 3). The decrease for both sides was higher in Group I (Table 3). Postoperative mortality and morbidity were followed for 30 days, and no mortality or morbidity was observed.

Table 2. The values of cerebral cortical oxygen saturation and hematocrit.

Time	Group I $RScO_2$ (%)	Group II $RScO_2$ (%)	p	Group I $LScO_2$ (%)	Group II $LScO_2$ (%)	p	Group I Hct (%)	Group II Hct (%)	p
T0	71.5±5.71	72.2±5.55	NS	71.7±6.19	72.2±4.93	NS	38.9±5.47	40.2±5.35	NS
T1	68.8±6.8	69.7±6.35	NS	68.3±7.2	71.3±5.3	NS	38.9±5.47	40.2±5.35	NS
T2	65.3±7.82	66.5±5.94	NS	64.9±6.88	67.7±4.91	NS	26.3±5.9	25±3.35	NS
T3	65.5±7.88	66.3±5.44	NS	65.3±7.16	67.7±4.62	NS	25.5±3.53	25.4±2.98	NS
T4	67.4±7.33	70±5.36	NS	67.7±6.92	70.4±5.15	NS	27.1±2.98	28±2.77	NS
T5	68.3±6.75	70.4±5.48	NS	68.5±6.68	70.5±5.37	NS	28.8±2.93	30±2.29	NS
T6	68.9±6.86	70.6±5.71	NS	69.1±6.4	70.7±5.02	NS	30±2.33	30.8±1.78	NS
T7	69.1±6.53	70.7±5.54	NS	69.6±6.05	71.2±5.04	NS	30.6±2.03	31.1±1.74	NS

Abbreviations: $RScO_2$, right cerebral oxygen saturation; $LScO_2$, left cerebral oxygen saturation; Hct, Hematocrit; NS, not significant. Data were expressed using mean±SD

Table 3. Comparison of the percentage change ratio of rSO_2 from the baseline of both groups.

Time	Group I $RScO_2$ (%)	Group II $RScO_2$ (%)	p	Group I $LScO_2$ (%)	Group II $LScO_2$ (%)	p
T1	-3.92±3.75	-3.53±2.94	NS	-4.83±3.86	-1.3±1.98	<0.001
T2	-8.95±5.46	-7.91±2.82	NS	-9.63±3.9	-6.19±2.37	<0.001
T3	-8.76±5.43	-8.14±2.57	NS	-9.03±3.97	-6.26±2.61	<0.001
T4	-6.01±4.64	-3±2.77	0.001	-5.7±3.33	-2.52±2.61	<0.001
T5	-4.59±3.59	-2.39±2.76	0.003	-4.58±3.29	-2.37±2.72	0.002
T6	-3.76±3.73	-2.22±2.29	0.029	-3.59±3.37	-2.06±2.62	0.026
T7	-3.46±3.62	-1.99±2.29	0.033	-2.86±2.8	-1.41±2.02	0.01

Abbreviations: $RScO_2$, right cerebral oxygen saturation; $LScO_2$, left cerebral oxygen saturation; NS, not significant. Data were expressed using mean±SD

DISCUSSION

CABG is the most frequently performed surgery in cardiovascular surgery clinics. The mean age of the patients undergoing CABG has increased over the years, and this has led an increase in the vascular complications encountered in the postoperative period. Atherosclerosis is one of the most common diseases encountered in older ages. It exhibits a systemic involvement and affects all vessels. Carotid artery disease, which is the leading cause of preventable postoperative stroke, is diagnosed in most of the patients undergoing CABG surgery [1-4].

In cardiac surgery, the main mechanisms that cause neurological complications are cerebral hypoperfusion and thromboembolism arising from carotid artery [7,13]. Carotid Doppler USG is routinely used in patients who will undergo CABG to identify possible carotid artery disease preoperatively. Carotid angiography is the 'gold standard' in the diagnosis of carotid artery disease. However, carotid Doppler USG is preferred in clinical practice because it is a non-invasive and easy-to-apply method. The accuracy of Doppler USG in identifying carotid artery stenosis is 91-100% [13]. In our clinic, all CABG-planned patients routinely undergo preoperative carotid Doppler USG, and the presence and degree of carotid artery stenosis are determined prior the surgery.

Taillefer and Denault [14] reported the preoperative NIRS values of 250 patients undergoing CABG surgery as 47-83. These results are similar to those of Baikoussis et al. [15], who designed their study to

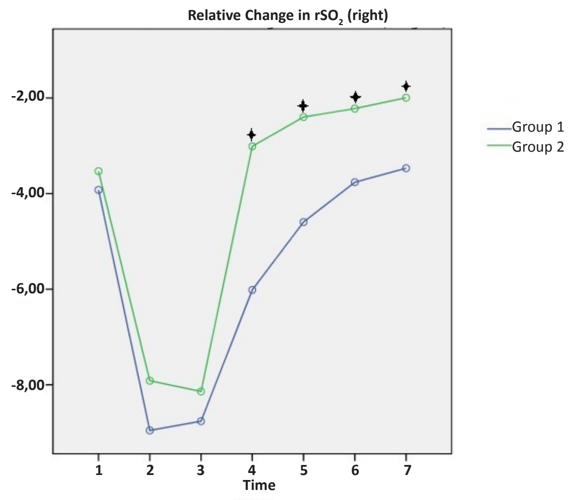

Figure 2. Graphic of the percentage change ratio of rSO_2 from the baseline in the right side of both groups. ✦ Indicated differences.

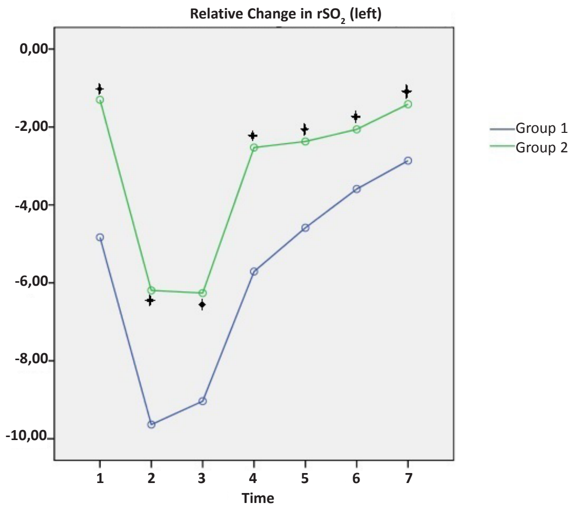

Figure 3. Graphic of the percentage change ratio of rSO_2 from the baseline in the left side of both groups. ✦ Indicated differences.

determine the baseline NIRS values of patients who underwent CABG. When we compared the patients with and without carotid artery stenosis in our study, the baseline NIRS values of Group I and Group II were 72.2±5.5 and 71.7±6.1, respectively, and there were no statistically significant differences between them. These values were found to be similar to the results of the studies of Taillefer and Baikoussis. Unlike our study, however, those studies did not take into consideration whether or not the patients had carotid artery stenosis [14,15].

In most cases, the decrease in regional cerebral oxygen saturation occurs at the beginning of CPB. During CPB the level is lower than at baseline, but it reaches the baseline value postoperatively. The causes of this decrease are haemodilution due to the priming solution, relatively low MAP, and pump flow. In their study, Kadoi et al. [16] reported low rSO_2 values during CPB. These findings are similar to those reported by Koç et al. [17]. The factors that affect cerebral oxygenation during CPB are the haematocrit and MAP. In this study, we tried to keep the haematocrit value at 20-28% and the MAP at 50-80 mmHg with the pump flow control. In both groups, it was observed that rSO_2 values remained low during CPB but reached the baseline values in the post-CPB period. Additionally, the comparison between the groups revealed no statistically significant differences in the rSO_2 values in the pre-, during-, and post-CPB periods.

Many studies in the literature have reported that the possibility of cerebral oximetry desaturation is higher in off-pump than on-pump CABG surgery. The main reasons for this are the positional changes employed in off-pump CABG and the decrease in the MAP caused by these positional changes. Additionally, when this surgical approach is performed on patients with carotid artery stenosis, the risk for cerebral oximetry desaturation will be higher [18,19]. Tyoma et al. [20] conducted a retrospective study in which they compared patients who had undergone CABG with and without carotid artery stenosis and reported that the maximum decreases in cerebral oximetry occurred due to the position of the patient. Unlike previous studies, they found that the rSO_2 values of the patients with and without carotid artery stenosis were not different and also reported that carotid artery stenosis was not a risk factor for cerebral desaturation and cerebral dysfunction. Furthermore, they observed that there was a correlation between decreased rSO_2 values and decreased cardiac index, increased central venous pressure, and low haemoglobin concentration, reporting that this phenomenon was independent of carotid artery stenosis [20].

In their prospective study, Ardanaki et al. [10] compared the rSO_2 values of 96 patients with and without carotid artery stenosis and found that the decreases in rSO_2 values during anastomoses in off-pump CABG surgery were not statistically different in both groups. The authors stated that a new study should be conducted with a greater number of patients having carotid artery stenosis over 70%.

Another CABG study on patients with carotid artery stenosis was conducted by Tovedal et al. [21]. The cerebral oximetry values of patients with and without carotid artery stenosis were compared with both pulsatile and non-pulsatile flows, and it was found that the cerebral oximetry values decreased more in pulsatile flow. However, they reported that this decrease in cerebral oximetry values did not differ between patients with and without carotid artery stenosis. This study yielded two significant results. First, pulsatile flow does not increase cerebral oxygen saturation more than non-pulsatile flow. Second, MAP is lower in pulsatile flow. However, neither of these is related to carotid artery stenosis. In our study, on-pump CABG surgery was performed with non-pulsatile flow. No statistically significant differences were observed in the cerebral oximetry values of the groups at all time points throughout CPB.

Unlike other studies, in our study, cerebral oximetry values were compared using the ratios of relative change in rSO_2 from baseline, and statistically significant differences were observed between the groups. In the group with carotid artery stenosis, the ratio of the percentage changes in rSO_2 was significantly higher than that of the group without carotid artery stenosis. However, there was no change higher than 20% in either group, and no interventions were required. Slater et al. [22] conducted a prospective randomized controlled study on patients who underwent CABG surgery and reported that a 20% decrease from the baseline in rSO_2 should not be considered significant. Instead, they used a value that they referred to as the 'desaturation score'. To obtain this value, the percentage change in rSO_2 is multiplied by the time elapsed. Slater et al. [22] found that patients with high desaturation scores had significantly high postoperative cognitive dysfunction. One of the limitations of our study is that the desaturation score was not measured.

In the study conducted on patients with symptomatic carotid stenosis, Palozzo et al. [23] reported that NIRS was ineffective in predicting stroke and vascular death when the neurological prognoses of the patients were determined with cerebral oximetry. They argued that the measurement of cerebral vasomotor activity with transcranial Doppler in patients with carotid artery stenosis was the most important determinant in predicting the prognosis, and they suggested that cerebral oximetry should not be used alone in patients with carotid artery stenosis [23].

CONCLUSIONS

In conclusion, as shown in many studies, cerebral oximetry is a non-invasive monitoring method that provides significant information about cerebral oxygenation and haemodynamic. When compared with patients without carotid artery stenosis, the NIRS method yields no significant results in patients with carotid artery stenosis up to 70% in on-pump or off-pump surgery. During cardiopulmonary bypass, monitoring the ratio of relative change in rSO_2 from baseline is more significant than monitoring a single numerical value in patients with carotid artery stenosis. However, it is necessary to measure the neurocognitive functions with postoperative tests to benefit from these ratios of relative change in rSO_2 from baseline in neurological prognoses. We believe that in patients with carotid artery stenosis, the use of multimodal monitorization together with cerebral oximetry in monitoring cerebral perfusion would be significant for the perioperative prognosis.

Limitations:

1) The participants in our study were patients with carotid artery stenosis under 70% because according to the surgical procedures of our cardiovascular surgery clinic, only these patients can undergo CABG surgery. Patients with carotid artery stenosis greater than 70% first undergo carotid artery surgery and then CABG surgery.
2) In our study, measurements were performed at eight different time points. The desaturation score measurement proposed by Slater et al. was not performed.
3) In our study, postoperative mortality and morbidity were followed for 30 days, and no mortality or morbidity was observed. No sensitive neurocognitive tests were performed in the postoperative period.

REFERENCES

1. De Feo M, Renzulli A, Onorati F, Marmo J, Galdieri N, De Santo LS, et al. The risk of stroke following CABG: one possible strategy to reduce it? Int J Cardiol. 2005;98:261-6. https://doi.org/10.1016/j.ijcard.2003.10.044
2. Bucerius J, Gummert JF, Borger MA, Walther T, Doll N, Onnasch JF, et al. Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. Ann Thorac Surg. 2003;75:472-8. https://doi.org/10.1016/S0003-4975(02)04370-9
3. Likosky DS, Marrin CA, Caplan LR, Baribeau YR, Morton JR, Weintraub RM, et al. Northern New England Cardiovascular Disease Study Group. Determination of etiologic mechanisms of strokes secondary to coronary artery bypass graft surgery. Stroke 2003;34:2830-4. https://doi.org/10.1161/01.STR.0000098650.12386.B3
4. Kara I, Erkin A, Saclı H, Demirtas M, Percin B, Diler MS, et al. The effects of near-infrared spectroscopy on the neurocognitive functions in the patients undergoing coronary artery bypass grafting with asymptomatic carotid artery disease: a randomized prospective study. Ann Thorac Cardiovasc Surg. 2015;21:544-50. https://doi.org/10.5761/atcs.oa.15-00118
5. Roach GW, Kanchuger M, Mangano CM, Newman M, Nussmeier N, Wolman R, et al. Adverse cerebral outcomes after coronary bypass surgery. Multicenter Study of Perioperative Ischemia Research Group and the Ischemia Research and Education Foundation Investigators. N Engl J Med. 1996;335:1857-63. https://doi.org/10.1056/NEJM199612193352501
6. Toraman F. The role of monitorization of regional cerebral oxygen saturation in adult cardiac surgery. GKD Anest Yoğ Bak Dern Derg. 2010;16:82-95.
7. Naylor AR, Mehta Z, Rothwell PM, Bell PR. Carotid artery disease and stroke during coronary artery bypass: a critical review of the literature. Eur J Vasc Endovasc Surg. 2002;23:283-94. https://doi.org/10.1053/ejvs.2002.1609
8. Tan ST. Cerebral oximetry in cardiac surgery. Hong Kong Med J. 2008;14:220-5.
9. Ricotta JJ, Faggioli GL, Castilone A, Hassett JM. Risk factors for stroke after cardiac surgery: Buffalo Cardiac-Cerebral Study Group. J Vasc Surg 1995;21:359-63. https://doi.org/10.1016/S0741-5214(95)70276-8
10. Ardakani MS, Heidari M, Moghaddam RN, Haddadzadeh M, Moshtaghion H, Rahimianfar AA. The relationship between carotid artery colour Doppler finding and cerebral oximetry. Adv Biomed Res 2015 May 11;4:90. https://doi.org/10.4103/2277-9175.156654
11. Powers WJ. Cerebral hemodynamics in ischemic cerebrovascular disease. Ann Neurol 1991;29:231-40. https://doi.org/10.1002/ana.410290302
12. Madsen PL, Secher NH. Near-infrared oximetry of the brain. Prog Neurobiol. 1999;58:541-60. https://doi.org/10.1016/S0301-0082(98)00093-8
13. Huston J, James EM, Brown RD Jr, Lefsrud RD, Ilstrup DM, Robertson EF, et al. Redefined duplex ultrasonographic criteria for diagnosis of carotid artery stenosis. Mayo Clin Proc. 2000;75:1133-40. https://doi.org/10.4065/75.11.1133
14. Taillefer MC, Denault AY. Cerebral near-infrared spectroscopy in adult heart surgery: systematic review of its clinical efficacy. Can J Anaesth 2005;52:79-87. https://doi.org/10.1007/BF03018586
15. Baikoussis NG, Karanikolas M. Baseline cerebral oximetry values in cardiac and vascular surgery patients: a prospective observational study. J Cardiothorac Surg. 2010;5:41. https://doi.org/10.1186/1749-8090-5-41
16. Kadoi Y, Kawahara F, Saito S, Morita T, Kunimoto F, Goto F, et al. Effects of hypothermic and normothermic cardiopulmonary bypass on brain oxygenation. Ann Thorac Surg. 1999;68:34-9. https://doi.org/10.1016/S0003-4975(99)00306-9
17. Koç M, Unger S, Aydınlı B, Guclu CY, Kazanci D, Balaban F, et al. The effects of three different anesthetic techniques on cerebral oxygenation and postoperative neurocognitive function in heart surgery. GKDA Derg. 2014;20:77-84. https://doi.org/10.5222/GKDAD.2014.077
18. Moritz S, Rochon J, Völkel S, Hilker M, Hobbhahn J,

Graf BM, et al. Determinants of cerebral oximetry in patients undergoing off-pump coronary artery bypass grafting: an observational study. Eur J Anaesthesiol. 2010;27:542-9.
https://doi.org/10.1097/EJA.0b013e3283343ef8
19. Atasever B, Boer C, Speekenbrik R, Seyffert J, Goedhart P, de Mol B, et al. Cardiac displacement during off-pump coronary artery bypass grafting surgery: effect on sublingual microcirculation and cerebral oxygenation. Interact Cardiovasc Thorac Surg. 2011;13:573-7.
https://doi.org/10.1510/icvts.2011.272047
20. Toyama S, Matsuoka K, Tagaito Y, Shimoyama M. Retrospective evaluation of the effect of carotid artery stenosis on cerebral oxygen saturation during off pump coronary artery bypasses grafting in adult patients. BMC Anesthesiology 2015;15:180-92.
https://doi.org/10.1186/s12871-015-0164-z
21. Tovedal T, Thelin S, Lennmyr F. Cerebral oxygen saturation during pulsatile and non-pulsatile cardiopulmonary bypass in patients with carotid stenosis. Perfusion 2016;31:72-7.
https://doi.org/10.1177/0267659115586280
22. Slater JP, Guarino T, Stack J, Vinod K, Bustami RT, Brown JM III, et al. Cerebral oxygen desaturation predicts cognitive decline and longer hospital stay after cardiac surgery. Ann Thorac Surg. 2009;87:36-45.
https://doi.org/10.1016/j.athoracsur.2008.08.070
23. Palazzo P, Tibuzzi F, Pasqualetti P, Altamura C, Silvestrini M, Passarelli F, et al. Is there a role of near-infrared spectroscopy in predicting the outcome of patients with carotid artery occlusion? J Neurolog Sciences 2010;292:36-9.
https://doi.org/10.1016/j.jns.2010.02.011