



(RESEARCH ARTICLE)



# Cognitive Outcome in Patients with Asymptomatic Carotid Artery Disease Undergoing Off-Pump Coronary Artery Bypass Graft Surgery with or without Near Infrared Spectroscopy Monitoring: A Randomized Study

Manjusree Guha \*, Arun Maheshwari and Sandeep Joshi

*Sir Gangaram Hospital, New Delhi, India.*

International Journal of Science and Research Archive, 2025, 17(01), 1281–1289

Publication history: Received on 10 September 2025; revised on 25 October 2025; accepted on 27 October 2025

Article DOI: <https://doi.org/10.30574/ijrsra.2025.17.1.2841>

## Abstract

**Aim:** To assess the effect of NIRS monitoring on the cognitive outcome of asymptomatic carotid artery disease patients undergoing off-pump coronary artery bypass grafting.

**Methods:** This randomized controlled trial was carried out at Sir Ganga Ram Hospital, New Delhi, among 50 asymptomatic carotid artery disease patients undergoing OPCAB. Fifty patients were randomized to either an NIRS monitored group or a control group to receive standard monitoring. Cognitive performance was measured with the MOCA score at preoperative, 24 hours, and 6 days after the operation. Duration of ICU stay was also documented and examined through SPSS software.

**Results:** Both groups had a decrease in MOCA scores at 24 hours post-surgery, with partial recovery by day 6. The NIRS group had a slightly lower percentage change in MOCA scores than the control group, but without statistical significance. There was no significant difference in ICU stay between the groups. Overall, NIRS monitoring revealed a trend toward improved cognitive outcomes, although without statistical significance.

**Conclusion:** Near Infrared Spectroscopy did not demonstrate statistically significant cognitive protection, trends did suggest slightly better cognitive preservation in the NIRS group. The study provides evidence for the viability of NIRS as an adjunct to monitoring, though further studies with larger samples might be required to determine its efficacy.

**Keywords:** Asymptomatic Carotid Artery Disease; Cognitive Outcome; Moca Score; Near Infrared Spectroscopy (NIRS); Off-Pump Coronary Artery Bypass Graft (OPCAB)

## 1. Introduction

Postoperative cognitive dysfunction (POCD) is a well-recognized yet frequently underdiagnosed complication following cardiac surgery, particularly among older patients and those with pre-existing cerebrovascular comorbidities [1-3]. The consequences of POCD can be severe, affecting the patient's quality of life, prolonging hospitalization, increasing healthcare costs, and significantly burdening caregivers. One of the most critical contributing factors to POCD is asymptomatic carotid artery stenosis, which may predispose patients to cerebral hypoperfusion during cardiopulmonary bypass procedures. While off-pump coronary artery bypass (OPCAB) surgery was introduced to

\* Corresponding author: Manjusree Guha

reduce neurocognitive dysfunction rates, cognitive decline has still been observed in these patients, suggesting that other intraoperative factors, such as cerebral oxygenation, may play a role.

Near-infrared spectroscopy (NIRS) is an intraoperative tool that has gained popularity for its ability to monitor regional cerebral oxygen saturation (rSO<sub>2</sub>) non-invasively. NIRS provides real-time feedback on cerebral oxygenation levels, enabling immediate adjustments to hemodynamic and ventilatory management during surgery. This proactive approach is believed to reduce the risk of cerebral injury and postoperative cognitive decline [4,5]. Although NIRS monitoring has been widely implemented in on-pump cardiac surgeries, its benefits in OPCAB procedures, particularly for high-risk patients with carotid artery disease, remain underexplored and inconclusive. This lack of evidence is significant since asymptomatic carotid artery stenosis can impair cerebral autoregulation, decrease cerebral perfusion reserve, and increase the risk of perioperative ischemic events, which can lead to subtle cognitive declines that often go undetected [6,7].

Cognitive decline in these patients is often subtle and goes unnoticed because of the absence of overt symptoms. To address this, sensitive cognitive assessment tools, such as the Montreal Cognitive Assessment (MoCA) scale, are essential for detecting mild cognitive impairments that might otherwise be overlooked [8-10]. Despite the utility of these assessments, there is a paucity of randomized controlled trials directly comparing the cognitive outcomes of patients with asymptomatic carotid artery stenosis undergoing OPCAB surgery with or without NIRS guidance. This study aims to fill this gap in the literature by assessing the neuroprotective effects of cerebral oximetry in OPCAB surgery for high-risk patients [11-14]. The study's objectives include evaluating whether NIRS-guided monitoring can reduce the incidence of cognitive dysfunction and providing evidence that can inform future clinical guidelines on perioperative care for patients with cerebrovascular risk factors.

Given the high prevalence of carotid artery stenosis in coronary artery bypass graft (CABG) patients, this study also seeks to contribute to the development of a gold standard for intraoperative monitoring that can minimize the occurrence of neurocognitive deficits in these high-risk patients. By providing significant insights into the neuroprotective function of cerebral oximetry, the findings could guide clinical practices, ultimately enhance patient outcomes and reduce the burden of cognitive morbidity following cardiac surgeries.

---

## 2. Materials and methods

### 2.1. Study Design and Setting

This randomized controlled trial was conducted in the Department of Cardiac Surgery at Sir Ganga Ram Hospital, New Delhi. Data collection began following approval from the Institutional Ethics Committee and continued until December 31, 2023. Follow-up was conducted until March 2024. The study adhered to the ethical standards of the responsible institutional committee and the Declaration of Helsinki (2000 revision).

### 2.2. Research Question

What is the neuro-cognitive outcome in patients with asymptomatic carotid artery disease undergoing off-pump coronary artery bypass graft surgery with or without near infrared spectroscopy monitoring?

### 2.3. Research Hypothesis

We hypothesize that the group receiving NIRS monitoring intra-operatively will have a better cognitive function in the immediate post-operative period in patients with asymptomatic carotid artery disease posted for off-pump coronary artery bypass graft surgery.

#### *Objective*

To compare neuro-cognition as assessed by MOCA score in patients with asymptomatic carotid artery disease undergoing off-pump coronary artery bypass graft surgery with or without near infrared spectroscopy monitoring during perioperative period.

To compare the length of ICU, stay in patients receiving near infrared spectroscopy monitoring versus standard monitoring technique in off pump coronary artery bypass graft surgeries patients with asymptomatic carotid artery disease.

#### 2.4. Patient Selection and Consent

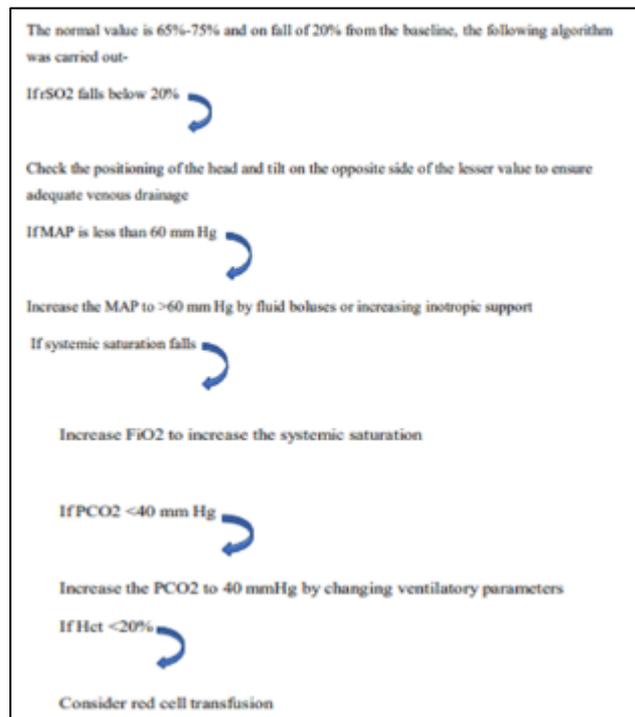
The study included adult patients (>18 years) diagnosed with asymptomatic carotid artery disease scheduled for off-pump coronary artery bypass grafting (CABG). Inclusion criteria comprised patients classified as ASA grade I to IV who provided informed written consent. Exclusion criteria included refusal to participate, requirement for on-pump CABG, concurrent surgical procedures, or any history of preoperative stroke, seizures, or psychiatric illness. All participants received detailed information about the study and provided informed consent. Confidentiality and anonymity were maintained. Ethical approval was granted by the Institutional Ethics Committee.

#### 2.5. Sample Size Calculation

Sample size estimation was based on a previous study which reported mean MOCA scores of  $26.8 \pm 1.9$  in the NIRS group and  $23.6 \pm 2.5$  in the control group. A sample of 11 patients per group was required to achieve a 90% power with  $\alpha = 0.05$ . To enhance statistical robustness, 25 patients were included per group.

- Randomization and Group Allocation
- Participants were randomized into two groups:
- Group A (Intervention): Monitored with Near-Infrared Spectroscopy (NIRS) using the INVOS system (INVOS 5100C; Semantics Corp, Troy, MI, USA).
- Group B (Control): Received conventional monitoring including arterial blood gas (ABG) analysis, mean arterial pressure (MAP), pulse oximetry, and urine output.

#### 2.6. Procedures and Monitoring



**Figure 1** Algorithm to manage cerebral desaturation

In Group A, baseline NIRS readings were recorded before induction of anesthesia. A reduction of more than 20% from the baseline prompted corrective interventions, including optimizing hematocrit and patient positioning. (Figure 1) The INVOS system monitored bilateral regional cerebral oxygen saturation continuously throughout the surgery. Absolute

values were recorded before induction, during graft placement, aortic cross-clamping, and post-clamp release. The lowest NIRS value at each stage was noted, and the mean for each hemisphere was calculated.

Neurocognitive function was assessed using the Montreal Cognitive Assessment (MOCA) at three time points: pre-operatively, 24 hours postoperatively, and on postoperative day 6. The MOCA evaluates multiple cognitive domains, with a maximum score of 30; scores  $\geq 26$  is considered normal. Changes in median (interquartile range) MOCA scores across the time points were compared between the groups.

## 2.7. Statistical Analysis

Statistical analysis was performed using SPSS for Windows, version 17.0 (SPSS Inc., Chicago, IL, USA). Continuous variables were expressed as mean  $\pm$  standard deviation (SD), and categorical variables as frequencies and percentages. Data distribution was assessed for normality. Unpaired t-tests were used for normally distributed continuous variables, while the Mann–Whitney U test was applied for non-normally distributed variables. Chi-square or Fisher’s exact tests were employed for categorical comparisons. P-values were reported precisely; values  $<0.05$  were considered statistically significant. Confidence intervals were provided for key outcome measures.

## 3. Results

The demographic traits of the sample population were non-statistically significant for the comparison between the non-NIRS group and the NIRS group. Participants in the NIRS group had a mean age of  $59.20 \pm 7.49$  years, while for the non-NIRS group the mean age was  $60.68 \pm 7.53$  years ( $p = 0.489$ ). Average height and weight were also comparable between both groups, with weights of  $56.88 \pm 9.82$  kg and  $56.04 \pm 8.90$  kg ( $p = 0.753$ ) and heights of  $153.96 \pm 10.84$  cm and  $154.60 \pm 10.07$  cm ( $p = 0.830$ ) for the NIRS and Non-NIRS groups respectively. The BMI of the NIRS group was marginally more ( $23.82 \pm 1.68$  kg/m<sup>2</sup>) than that of the non-NIRS group ( $23.29 \pm 1.42$  kg/m<sup>2</sup>), although not significantly ( $p = 0.240$ ). Likewise, the mean operating time ( $97.40 \pm 17.86$  min vs.  $94.20 \pm 17.78$  min;  $p = 0.528$ ) and pre-operative MOCA scores ( $28.40 \pm 1.08$  vs.  $28.52 \pm 1.16$ ;  $p = 0.707$ ) between the groups were similar and showed demographic homogeneity. The mean MOCA scores at 24 hours were equal between groups ( $25.92 \pm 1.44$  vs.  $25.88 \pm 1.36$ ;  $p=0.920$ ), as the scores at 6 days were ( $27.64 \pm 1.11$  vs.  $27.44 \pm 1.08$ ;  $p=0.523$ ), showing no cognitive difference by time. The mean duration of ICU stays also did not differ significantly between the groups ( $5.88 \pm 1.20$  vs.  $5.52 \pm 1.33$  days;  $p=0.320$ ). In addition, the percentage change in MOCA scores at both 24 hours ( $8.76 \pm 3.00\%$  vs.  $9.26 \pm 2.85\%$ ;  $p=0.545$ ) and 6 days ( $2.63 \pm 3.37\%$  vs.  $3.72 \pm 3.51\%$ ;  $p=0.267$ ) was not different between the groups, indicating similar trends in cognitive recovery and ICU stay (Table 1).

**Table 1** MOCA Scores and ICU Stay

| Variable                   | NIRS Group (n=25) | Non-NIRS Group (n=25) | p-value |
|----------------------------|-------------------|-----------------------|---------|
| Pre-op MOCA Score          | $28.40 \pm 1.08$  | $28.52 \pm 1.16$      | 0.707   |
| MOCA at 24 hrs             | $25.92 \pm 1.44$  | $25.88 \pm 1.36$      | 0.920   |
| MOCA at 6 days             | $27.64 \pm 1.11$  | $27.44 \pm 1.08$      | 0.523   |
| % Change in MOCA at 24 hrs | $8.76 \pm 3.00$   | $9.26 \pm 2.85$       | 0.545   |
| % Change in MOCA at 6 days | $2.63 \pm 3.37$   | $3.72 \pm 3.51$       | 0.267   |

The gender distribution in the NIRS and Non-NIRS groups, there were 14 (56%) males and 11 (44%) females in the NIRS group, while there were 16 (64%) males and 9 (36%) females in the non-NIRS group. Between-group comparison gave a p-value of 0.564, suggesting that gender distribution between the two groups was not statistically different.

At 24 hours post-surgery, the rate of Post-Operative Cognitive Dysfunction (POCD) was lower in the NIRS group than in the non-NIRS group. In the NIRS group, 88% of patients had no POCD, 12% had mild POCD, and none had severe POCD. Conversely, the non-NIRS group presented with a slightly lower percentage of patients free from POCD (80%) and a greater incidence of mild POCD (20%), but no severe cases of POCD in either group (as shown in Table 2). This would indicate that NIRS monitoring use could be related to a decrease in early postoperative mild cognitive impairment.

**Table 2** Post-Operative Cognitive Dysfunction (POCD) at 24 Hours

| Group          | No POCD  | Mild POCD | Severe POCD |
|----------------|----------|-----------|-------------|
| NIRS Group     | 22 (88%) | 3 (12%)   | 0           |
| Non-NIRS Group | 20 (80%) | 5 (20%)   | 0           |

Table 3 illustrates the distribution of patients with no postoperative cognitive dysfunction (POCD), mild POCD, and severe POCD in both study groups. In the NIRS group, all 25 patients (100%) had no evidence of POCD, with neither mild nor severe cases identified. Conversely, the non-NIRS group consisted of 24 patients (96%) with no POCD and one patient (4%) with mild POCD; there were no severe cases in this group as well. The results indicate a possibly protective role of NIRS monitoring in the prevention of POCD.

**Table 3** Number of patients in both our study groups with no POCD, mild POCD and Severe POCD

| Group          | No POCD   | Mild POCD | Severe POCD |
|----------------|-----------|-----------|-------------|
| NIRS Group     | 25 (100%) | 0         | 0           |
| Non-NIRS Group | 24 (96%)  | 1 (4%)    | 0           |

Table 4 shows the correlation between MOCA scores and age and BMI at three intervals—preoperatively, at 24 hours, and at 6 days postoperatively—in NIRS and non-NIRS groups. Age displayed a statistically significant negative correlation with MOCA scores at every time point in both groups, with more robust correlations being found preoperatively (NIRS:  $r = -0.716$ ,  $p < 0.001$ ; non-NIRS:  $r = -0.706$ ,  $p < 0.001$ ) and progressively lessening by day 6 (NIRS:  $r = -0.401$ ,  $p = 0.047$ ; non-NIRS:  $r = -0.391$ ,  $p = 0.053$ ), indicating that higher age is related to lower cognitive scores. On the other hand, BMI did not show any notable correlation with MOCA scores at any time point within either group, as supported by low correlation coefficients with high p-values. This implies that though age can impact cognitive results following surgery, BMI seems to have no significant effect.

**Table 4** Correlation Coefficient of age, BMI, with MOCA scores at baseline, at 24 hours and at 6 days

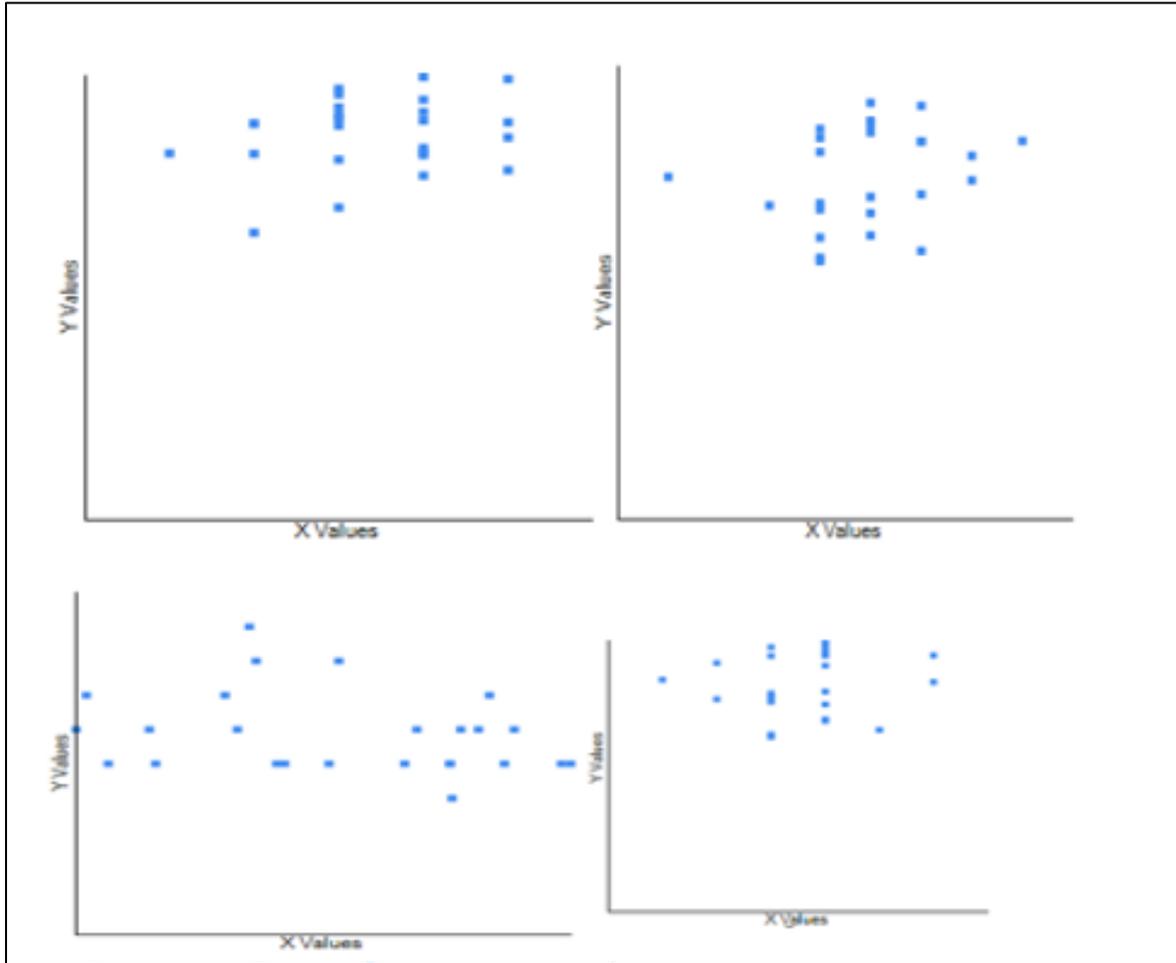
| GROUP    |         | PRE-OP MOCA                 | MOCA AT 24 HRS | MOCA AT 6 DAYS |
|----------|---------|-----------------------------|----------------|----------------|
| NIRS     | AGE     | Pearson Correlation: -0.716 | -0.547         | -0.401         |
|          | p Value | <0.001                      | 0.005          | 0.047          |
|          | BMI     | Pearson Correlation: -0.195 | -0.140         | -0.100         |
|          | p Value | 0.350                       | 0.506          | 0.635          |
| NON-NIRS | AGE     | Pearson Correlation: -0.706 | -0.540         | -0.391         |
|          | p Value | <0.001                      | 0.005          | 0.053          |
|          | BMI     | Pearson Correlation: 0.065  | 0.144          | -0.079         |
|          | p Value | 0.756                       | 0.491          | 0.708          |

Statistically significant ( $p < 0.05$ )

#### 4. Discussion

In our research, we assessed 50 patients with asymptomatic carotid disease that is  $\geq 50\%$  carotid artery stenosis without a history of syncope or TIA or CVA in the past 6 months necessitating OPCAB surgery under general anaesthesia. Neuropsychological assessment with MoCA score was done on all patients pre- and post-surgery. NIRS follow-up was done for 25 patients (NIRS group) and NIRS follow-up was not done for 25 patients (non-NIRS group). It was a total

score of 30 points. A MoCA score of  $\geq 26$  is within normal limits, 19-25 mild dementia, and below 19 severe dementia. Both groups did not differ significantly based on demographic parameters, medical conditions, and working variables.



**Figure 2:** X represents baseline cerebral SO<sub>2</sub>, and Y denotes baseline MOCA score, and it indicates a positive correlation.

Figure 3: X-axis denotes the average minimum rso<sub>2</sub> during the intra-operative period, and Y-axis denotes the MOCA scores at 24 hours in the post-operative period.; Figure 4. X shows min Rso<sub>2</sub>, and the Y-axis denotes MOCA at 6 days. ; Figure 5: X-axis is the minimum rSO<sub>2</sub>, and Y-axis is the length of ICU stay, and both variables have an inverse correlation

There were no differences of statistical significance in all groups for age, gender, height, weight, BMI, educational level, initial MoCA score and surgical duration, as presented in Tables 1 and 2. In our study at the 24th hour after surgery, in the NIRS-tested group, 22/25 patients(88%) showed no cognitive impairment,12% showed mild POCD, and none showed severe cognitive impairment [15-17]. As in the non-NIRS-examined group,20 out of 25 patients showed no postoperative cognitive impairment (80%), 20% showed mild impairment, and no patient showed postoperative severe neurocognitive impairment. On the 6th day, in the NIRS monitoring group, all of the patients i.e. 100% patients did not show cognitive impairment. On the contrary, 24 out of 25 patients were free from any impairment and merely 1/25 patients experienced mild impairment.

Newman et al., [18] investigated the cognition in 261 CABG patients in whom they observed nearly 55% patients with early cognitive impairment on discharge. But our study did not show the same. Our study groups had no significant dysfunction at discharge compared to their study. It might have been that their assessment parameter was far more complicated and multilayered which likely identified impairment than our MOCA score (which is a better test to identify subtle or mild impairment). Tourney Jette et al., [19] also studied CABG patients, but their mean age was 70 years compared to our 59.2±7.9 and 60.6±7.5 years. Considering that their study population had elderly patient characteristics and 46/61 patients were done on pump CABG, their results, being incompatible with our results of early

onset POCD, might be accounted for. They encountered in their patients nearly 80% of their patients with an early onset of POCD. Sahan Cenk et al., [20] also operated on the elderly population with a mean age of >60 years undergoing on-pump CABG. They also detected that early POCD was found among 10 of 21 (45%) of the control patients and among 7 of 19 (37%) of the intervention patients, but the development of POCD in either the two groups (intervention versus control group) was not found to be significant ( $p > 0.05$ ), thus results were similar to ours. Both of our groups' MOCA scores were nearly comparable at baseline. The mean preoperative MOCA scores in the NIRS group were  $28.4 \pm 1.08$  (95% CI; 27.95- 28.85) and in the non-NIRS group  $28.52 \pm 1.16$  (95% CI; 28.05- 28.99), with a  $p$ -value  $> 0.001$  and thus not significant. The MOCA score at 24 hours post-surgery was  $25.92 \pm 1.4$  (95% CI; 25.33 – 26.51) in the NIRS group, whereas it was  $25.88 \pm 1.36$  (95% CI; 25.32- 26.44) in the non-NIRS group. But again, this too was not a highly important difference. The MOCA score at 6 days post-surgery was  $27.6 \pm 1.11$  (95% CI; 27.18- 28.1) in the NIRS group, whereas in the non-NIRS group, it was  $27.4 \pm 1.08$  (95% CI; 26.99- 27.89). In addition, to determine the percentage change in the mean MOCA score from pre-op to 24 hours post-op, we discovered that the percentage change was higher for the mean MOCA score in the non-NIRS group, which was 9.25 per cent versus 8.73 per cent in the NIRS group. Comparable findings were noted with the average change in MOCA score from pre-surgery to 6 days post-surgery (2.6% in the NIRS group and 3.7% in the non-NIRS group).

Kara et al., [21] identified that the MOCA scores in the post-operative period were significantly reduced in the non-NIRS monitoring group ( $23.6 \pm 2.5$ ) compared to the NIRS group (MOCA score of  $26.8 \pm 1.9$ ). The only significant distinction between their research and the present research is that they performed a study among patients who had on-pump CABG, while our research involved patients who were administered OPCAB. Umesh S et al [22] also examined the impact on neurocognition among patients who had asymptomatic carotid artery disease with >70% stenosis and who had OPCAB. There were many similarities in our research such as the age group range and the population of the patients. They also were unable to ascertain noteworthy differences between the intervention and control groups. Sacli Hakan et al., [23] investigated on diabetic patients who had lower pre-operative MOCA scores ( $24.8 \pm 2.2$  and  $25.2 \pm 2.0$ ). They discovered that the post-operative mean MOCA score in the group which was followed by the standard protocol was significantly lower than the group followed intraoperative  $rSO_2$  values by NIRS monitor ( $24.8 \pm 2.2$  vs.  $23.6 \pm 2.6$ ,  $P = 0.02$ ), which was contrary to our result. This difference between their study and ours may be due to the already cognitive dysfunction present pre-operatively. In our study we also observed that there was a negative weak correlation between age and MOCA scores, with a maximum at the pre-operative time. There appears to be no positive or negative correlation between BMI and MOCA scores at baseline, as well as at 24 hours or 6 hours of surgery. There was a weak positive correlation between baseline  $rSO_2$  and baseline MOCA score. (Figure 2) When comparing the correlation between minimum  $rSO_2$  and MOCA at 24 hours and at 6 days, both occasions there was a weak positive correlation, but both occasions were statistically not significant. (Figure 3, 4) In our research, ICU STAY was  $5.88 \pm 1.20$  days in the NIRS group and  $5.52 \pm 1.33$  days in the non-NIRS group, with  $p$ -value = 0.320 and therefore was not statistically significant. (Figure 5) There was a negative correlation between minimum recorded  $rSO_2$  and ICU length of stay. In some studies, the group monitored with normal protocol also had a significantly higher hospital length of stay, which was statistically significant compared to our results when it came to ICU length of stay, which was statistically insignificant. However, as a result of very comparable demographics, our study was comparable in findings in the case of ICU length of stay to Umesh Set al's study [24]. The present study looked for any correlation of age, BMI and MOCA scores. While there was no correlation between the MOCA scores and BMI, researchers did certainly see a negative correlation between age and MOCA scores with strongest with pre-operative MOCA scores. Present study finds a correlation between min  $rSO_2$  with age and BMI.

In research conducted by Lian [25], they also have reported a negative correlation between baseline  $rSO_2$  values and age which is consistent with our results. The same results were reaffirmed by Jette et al [26] who concluded that NIRS monitoring is an effective tool for the diagnosis of POCD in the elderly population. Yet, we established a weak positive correlation when dealing with the mean of the recorded minimum  $rSO_2$  values and age. Regarding a correlation between weight and BMI and  $rSO_2$  values, we observed a weak positive correlation similar to the result of Valencia [27] who reported that BMI influences  $rSO_2$  values with baseline  $rSO_2$  showing a positive correlation with body weight ( $r = 0.347$ ,  $P = 0.014$ ) and therefore must be taken into consideration while monitoring its value by NIRS monitor.

---

## 5. Conclusion

The monitoring of cerebral perfusion through methods like near-infrared spectroscopy (NIRS) will enable interventions in mean arterial pressure monitoring to be based on alterations in NIRS. Thus, unnecessary use of medication and invasive interventions can be prevented by cerebral oxygen saturation monitoring ( $rSO_2$ ). While our research

demonstrated its limited application in the diagnosis of postoperative cognitive dysfunction in coronary bypass graft patients, however, the application of NIRS in such cases is advisable and more research must be conducted to determine its full potential.

---

## References

- [1] Mohr FW, Morice MC, Kappetein AP, Feldman TE, Ståhle E, Colombo A, Mack MJ, Holmes DR, Morel MA, Van Dyck N, Houle VM. Coronary artery bypass graft surgery versus percutaneous coronary intervention in patients with three-vessel disease and left main coronary disease: 5-year follow-up of the randomised, clinical SYNTAX trial. *The lancet*. 2013 Feb 23;381(9867):629-38.
- [2] Sun X, Lindsay J, Monsein LH, Hill PC, Corso PJ. Silent brain injury after cardiac surgery: a review: cognitive dysfunction and magnetic resonance imaging diffusionweighted imaging findings. *Journal of the American College of Cardiology*. 2012 Aug 28;60(9):791-7.
- [3] de Weerd M, Greving JP, Hedblad B, Lorenz MW, Mathiesen EB, O'Leary DH, Rosvall M, Sitzer M, Buskens E, Bots ML. Prevalence of asymptomatic carotid artery stenosis in the general population: an individual participant data meta-analysis. *Stroke*. 2010 Jun 1;41(6):1294-7.
- [4] Mao Z, Zhong X, Yin J, Zhao Z, Hu X, Hackett ML. Predictors associated with stroke after coronary artery bypass grafting: a systematic review. *Journal of the Neurological Sciences*. 2015 Oct 15;357(1-2):1-7.
- [5] Steinvil A, Sadeh B, Arbel Y, Justo D, Belei A, Borenstein N, Banai S, Halkin A. Prevalence and predictors of concomitant carotid and coronary artery atherosclerotic disease. *Journal of the American College of Cardiology*. 2011 Feb 15;57(7):779-83. 33. Sulženko J, Pieniazek P. The cardiovascular risk of patients with carotid artery stenosis. *Cor et Vasa*. 2018 Feb 1;60(1):e42-8.
- [6] de Tournay-Jetté E, Dupuis G, Bherer L, Deschamps A, Cartier R, Denault A. The relationship between cerebral oxygen saturation changes and postoperative cognitive dysfunction in elderly patients after coronary artery bypass graft surgery. *Journal of cardiothoracic and vascular anesthesia*. 2011 Feb 1;25(1):95-104
- [7] . Fasnacht JS, Wueest AS, Berres M, Thomann AE, Krumm S, Gutbrod K, Steiner LA, Goettel N, Monsch AU. Conversion between the Montreal Cognitive Assessment and the Mini-Mental Status Examination. *Journal of the American Geriatrics Society*. 2023 Mar;71(3):869-79. 38. Obrig H. NIRS in clinical neurology—a 'promising' tool?. *Neuroimage*. 2014 Jan 15;85:535-46.
- [8] Obrig H, Steinbrink J. Non-invasive optical imaging of stroke. *Philosophical transactions of the royal society a: mathematical, physical and engineering sciences*. 2011 Nov 28;369(1955): 4470- 94
- [9] Palazzo P, Tibuzzi F, Pasqualetti P, Altamura C, Silvestrini M, Passarelli F, Rossini PM, Vernieri F. Is there a role of near-infrared spectroscopy in predicting the outcome of patients with carotid artery occlusion?. *Journal of the neurological sciences*. 2010 May 15;292(1-2):36-9.
- [10] Bochmann K, Meineri M, Ender JK, von Aspern K, Forner AF, Janai AR, Zakhary WZ. Interventions triggered during routine use of NIRS cerebral oxygenation monitoring in cardiac surgical patients. *Journal of Cardiothoracic and Vascular Anesthesia*. 2022 Jul 1;36(7). 42. Yu Y, Zhang K, Zhang L, Zong H, Meng L, Han R. Cerebral near-infrared spectroscopy (NIRS) for perioperative monitoring of brain oxygenation in children and adults. *Cochrane Database of Systematic Reviews*. 2018(1).
- [11] Willcox TW, Mitchell SJ. Microemboli in our bypass circuits: A contemporary audit. *The Journal of Extra-corporeal Technology*. 2009 Jul;41(4):P31
- [12] Pezzato S, Govindan RB, Bagnasco F, Panagopoulos EM, Robba C, Beqiri E, Smielewski P, Munoz RA, d'Udekem Y, Moscatelli A, du Plessis A. Cerebral autoregulation monitoring using the cerebral oximetry index after neonatal cardiac
- [13] Sood ED, Benzaquen JS, Davies RR, Woodford E, Pizarro C. Predictive value of perioperative near-infrared spectroscopy for neurodevelopmental outcomes after cardiac surgery in infancy. *The Journal of thoracic and cardiovascular surgery*. 2013 Feb 1;145(2):438-45.
- [14] Akpek EA. Cerebral monitoring in cardiac surgery. *J Anesth-JARSS*. 2008;16:117-24.

- [15] Ahlgren E, Lundqvist A, Nordlund A, Aren C, Rutberg H. Neurocognitive impairment and driving performance after coronary artery bypass surgery. *European Journal of Cardio-thoracic Surgery*. 2003 Mar 1;23(3):334-40.
- [16] Diederik van Dijk MD, Jansen EW, Hijman R, Nierich AP, Diephuis JC, Moons KG, Lahpor JR, Borst C, Keizer AM, Nathoe HM, Grobbee DE. Cognitive outcome after off-pump and on-pump coronary artery bypass graft surgery: a randomized trial. *Outcomes after off-pump coronary bypass surgery*. 2002;287:49.
- [17] Rudolph JL, Schreiber KA, Culley DJ, McGlinchey RE, Crosby G, Levitsky S, Marcantonio ER. Measurement of post-operative cognitive dysfunction after cardiac surgery: a systematic review. *Acta Anaesthesiologica Scandinavica*. 2010 Jul;54(6):663-77
- [18] Newman MF, Kirchner JL, Phillips-Bute B, Gaver V, Grocott H, Jones RH, Mark DB, Reves JG, Blumenthal JA. Longitudinal assessment of neurocognitive function after coronary-artery bypass surgery. *New England Journal of Medicine*. 2001 Feb 8;344(6):395-402
- [19] de Tournay-Jetté E, Dupuis G, Bherer L, Deschamps A, Cartier R, Denault A. The relationship between cerebral oxygen saturation changes and postoperative cognitive dysfunction in elderly patients after coronary artery bypass graft surgery. *Journal of cardiothoracic and vascular anesthesia*. 2011 Feb 1;25(1):95-104.
- [20] Şahan C, Sungur Z, Çamcı E, Sivrikoz N, Sayin Ö, Gurvit H, Şentürk M. Effects of cerebral oxygen changes during coronary bypass surgery on postoperative cognitive dysfunction in elderly patients: a pilot study. *Revista Brasileira de Anestesiologia*. 2018 Mar;68:142-8
- [21] Kara I, Erkin A, Sacli H, Demirtas M, Percin B, Diler MS, Kirali K. 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. *Annals of Thoracic and Cardiovascular Surgery*. 2015;21(6):544-50
- [22] Umesh S, Nayak VB, Hiremathada S. Impact of Asymptomatic Carotid Artery Disease on Cognitive Functions in Patients Undergoing Off-pump Coronary Artery Bypass Grafting with and without Near-infrared Spectroscopy Monitoring and Intervention Intraoperatively. *The Journal of Medical Sciences*. 2019 Jun 1;5(2):43-8
- [23] Sacli H, Kara I. Are standard follow-up parameters sufficient to protect neurocognitive functions in patients with diabetes mellitus who underwent coronary artery bypass grafting?. *Brazilian Journal of Cardiovascular Surgery*. 2020 Mar 23;35:75-81.
- [24] Umesh S, Nayak VB, Hiremathada S. Impact of Asymptomatic Carotid Artery Disease on Cognitive Functions in Patients Undergoing Off-pump Coronary Artery Bypass Grafting with and without Near-infrared Spectroscopy Monitoring and Intervention Intraoperatively. *The Journal of Medical Sciences*. 2019 Jun 1;5(2):43-8.
- [25] Lian C, Li P, Wang N, Lu Y, Shanguan W. Comparison of basic regional cerebral oxygen saturation values in patients of different ages: a pilot study. *J Int Med Res*. 2020 Aug;48(8):300060520936868. doi: 10.1177/0300060520936868. PMID: 32833525; PMCID: PMC7448148.
- [26] de Tournay-Jetté E, Dupuis G, Bherer L, Deschamps A, Cartier R, Denault A. The relationship between cerebral oxygen saturation changes and postoperative cognitive dysfunction in elderly patients after coronary artery bypass graft surgery. *Journal of cardiothoracic and vascular anesthesia*. 2011 Feb 1;25(1):95-104
- [27] Valencia L, Rodríguez-Pérez A, Ojeda N, Santana RY, Morales L, Padrón O. Baseline cerebral oximetry values depend on non-modifiable patient characteristics. *Anaesthesia Critical Care and Pain Medicine*. 2015 Dec 1;34(6):345-8.