MEDICAL SCIENCE MONITOR

CLINICAL RESEARCH

e-ISSN 1643-3750
© Med Sci Monit, 2025; 31: e947462
DOI: 10.12659/MSM.947462

Received: 2024.11.29
Accepted: 2025.02.04
Available online: 2025.02.11
Published: 2025.03.23

Intraoperative Renal Near-Infrared Spectroscopy Monitoring as a Predictor of Renal Outcomes in Cardiac Surgery

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Financial support: None declared
Conflict of interest: None declared

Background: Acute renal failure (ARF) is a critical complication following open-heart surgery, significantly impacting morbidity and mortality. This study aimed to evaluate the association between intraoperative renal near-infrared spectroscopy (NIRS) findings and postoperative ARF in 357 patients undergoing cardiac surgery with cardiopulmonary bypass (CPB).

Material/Methods: This prospective study included 357 patients undergoing open-heart surgery with CPB. ARF diagnosis was based on KDIGO criteria. NIRS sensors were placed bilaterally at the T12/L2 level under ultrasound guidance, and renal oxygenation (rSO2) values were continuously monitored intraoperatively. Patients were categorized into ARF and non-ARF groups for comparative analysis.

Results: ARF developed in 12.3% (n=44) of patients. ARF patients were older (p=0.024) and had longer surgery (p<0.001), CPB (p=0.004), and aortic cross-clamping durations (p=0.013). They required more blood products (p<0.001) and intra-aortic balloon pump support (p=0.027). Intensive care unit stays were significantly longer in ARF patients (p=0.036). NIRS analysis showed significant rSO2 reductions in ARF patients. Time spent with rSO2 below 80%, 70%, and 60% was a strong predictor of ARF. Receiver operating characteristic (ROC) analyses demonstrated that time exceeding 30 minutes below the 60% threshold predicted ARF with 96.5% specificity and 86.4% sensitivity.

Conclusions: Intraoperative NIRS monitoring is crucial for detecting renal perfusion abnormalities during high-risk surgeries. Declines below 80%, 70%, and 60% thresholds strongly predict ARF. Timely interventions, such as fluid resuscitation and hemodynamic support, can mitigate risks. ARF patients require intensive postoperative monitoring due to prolonged ICU stays and complications.

Keywords: **Cardiopulmonary Bypass • Renal Insufficiency • Spectroscopy, Near-Infrared**

Full-text PDF: https://www.medscimonit.com/abstract/index/idArt/947462

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Introduction

ARF is a serious complication encountered after open-heart surgery. This condition significantly contributes to postoperative morbidity and mortality, making its prevention and management a critical aspect of patient care in cardiac surgery. Prolonged CPB times, defined as durations exceeding 70 minutes, and extended aortic cross-clamping times beyond 60 minutes have been consistently identified in the literature as significant risk factors for the development of ARF [1]. These prolonged durations can lead to compromised renal perfusion and tissue oxygenation, which are key contributors to renal injury and dysfunction [2].

The impairment of renal tissue oxygenation plays a crucial role in the development and progression of ARF during cardiac surgery. Effective monitoring of renal tissue oxygenation during surgery is therefore essential to identify patients at risk of ARF and to facilitate timely interventions. Early recognition and treatment of patients with compromised renal oxygenation have the potential to reduce both mortality and morbidity associated with this severe complication.

NIRS has emerged as a non-invasive and continuous monitoring technique that can measure regional tissue oxygenation (rSO2). NIRS is widely utilized in cardiac surgery to monitor cerebral and renal oxygenation, providing real-time data on tissue perfusion and oxygenation levels. Its potential as an early warning tool for complications such as ARF has been increasingly recognized in clinical practice [2,3]. However, the prognostic value of NIRS in predicting ARF is still being questioned. Studies in this area have produced varied results. For instance, Ruf et al demonstrated the utility of renal NIRS in predicting ARF in pediatric cardiac surgery patients, highlighting its potential for early detection and intervention [4]. In contrast, De Keijzer et al observed a limited correlation between renal NIRS values and postoperative ARF in adults, emphasizing the need for further research to validate its predictive capabilities [3].

Given the importance of early detection and prevention, the present study was designed to evaluate the association between intraoperative renal NIRS findings and the occurrence of postoperative ARF. The study population comprised 357 patients who underwent cardiac surgery with CPB. By identifying critical thresholds and durations of renal oxygen desaturation during surgery, we sought to establish the utility of NIRS as a reliable predictor of ARF and to contribute to the optimization of perioperative management strategies aimed at improving patient outcomes.

Material and Methods

Ethics Approval

The study was conducted prospectively in our clinic, in accordance with the principles outlined in the Declaration of Helsinki. It included patients who underwent open-heart surgery with CPB between December 1, 2022, and December 31, 2023. Prior to the initiation of the study, ethics approval was obtained from the institutional review board (approval number: 2011-KAEK-25 2022 10-12). All participants provided their informed consent before enrollment.

Study Design and Patient Selection

This prospective study included patients who underwent elective open-heart surgery with CPB. Inclusion criteria were having a left ventricular ejection fraction >30%, normal preoperative serum creatinine levels (sCr) <1.2 mg/dL, and a skin-to-kidney distance ≤4 cm. Exclusion criteria were patient refusal, age <18 years, emergency or redo surgery, preoperative acute or chronic renal failure, history of renal transplantation, a body mass index (BMI) >32 kg/m^2, and a skin-to-kidney distance >4 cm.

Patients were divided into 2 groups according to whether ARF developed in the first 48 hours postoperatively. Group 1 consisted of 313 patients who did not develop ARF in the postoperative period, and Group 2 consisted of 44 patients who developed ARF in the postoperative period. The diagnosis of ARF was defined according to KDIGO criteria. The KDIGO criteria classify ARF into 3 stages based on serum creatinine levels and urine output [5,6]. Stage 1 is characterized by a 1.5- to 1.9-fold increase in serum creatinine from baseline or an absolute increase of ≥0.3 mg/dl. Urine output in this stage is reduced to less than 0.5 ml/kg/hour for a duration of 6-12 hours. Stage 2 involves a 2.0- to 2.9-fold increase in serum creatinine from baseline, accompanied by urine output below 0.5 ml/kg/hour for 12 hours or more. Stage 3, the most severe stage, includes a 3.0-fold or greater increase in serum creatinine from baseline, a serum creatinine level of ≥4.0 mg/dl, or the initiation of renal replacement therapy. Urine output in Stage 3 is less than 0.3 ml/kg/hour for a period of 24 hours or longer or complete anuria lasting for 12 hours or more.

Anesthesia Procedure

Patients were evaluated by preoperative examination before anesthesia. Demographic characteristics, comorbidities, and routine preoperative laboratory values were recorded. Peripheral oxygen saturation (SpO_2), electrocardiography, and invasive blood pressure monitoring with arterial cannulation placed in the nondominant arm were performed. Before induction of anesthesia, NIRS sensors (INVOS 5100C, Medtronic) were placed

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in both kidneys at T12/L2 under ultrasonography guidance, and baseline renal rSO2 values were recorded. After 2 vascular accesses were established with an intravenous cannula, general anesthesia was induced, and the patient was orotracheally intubated. Following the induction of anesthesia, central venous line catheterization was performed using the Seldinger technique, and central venous pressure was monitored. Fluid resuscitation therapy was performed according to central venous pressure and hemodynamic parameters. A Foley catheter was placed in the bladder for urine output monitoring.

Cardiopulmonary Bypass Procedure

Patients were anticoagulated before standard aorta and vein cannulation. Anticoagulation was performed with unfractionated heparin (Koparin vial, Koçak Farma, Türkiye) at a dose of 300 units/kg and evaluation was performed by measuring activated clotting time (ACT). Arterial blood gas was also analyzed simultaneously with ACT measurement. CPB was started when ACT was >450. Patients who achieved cardiac arrest with cardioplegia solution were monitored with a hypothermia level of 30-32ºC. Perfusion in CPB was maintained at 2.4 L/min/m^2. After the end of the surgical procedure, CPB was terminated by ensuring normothermia in the patients. The targeted criteria before the patient were weaned from CPB were hemodynamic stability, body temperature of 37°C, ventilation of both lungs with adequate tidal volume and normal arterial blood gas values. Heparin neutralization was achieved with protamine (Promin, Vem İlaç Sanayi, Türkiye). At the end of the operation, patients were intubated and transferred to the ICU.

We recorded intraoperative mean arterial pressures, heart rate, body temperature on CPB, arterial blood gas and renal rSO2 values, aortic cross-clamping (ACC), perfusion and operation durations, urine output, postoperative laboratory values, extubation duration, duration of ICU stay and hospitalization durations, complications, and mortality.

Calculation of Renal Tissue Oxygenation Values

Prior to the induction of anesthesia, NIRS sensors were placed in both kidney regions at the T12/L2 level under ultrasonography guidance. The mean rSO2 values obtained from the right and left sides [3] were recorded as data in the anesthesia follow-up form. The assessment of renal tissue oxygenation was conducted during specific intraoperative periods. These periods included the pre-induction phase (T0), where rSO2 values were measured before anesthesia induction; the post-induction phase (T1), immediately after anesthesia induction; and the pre-CPB phase (T2). Additionally, rSO2 measurements were taken during the hypothermic phase of CPB (T3), the warming phase of CPB (T4), and immediately after CPB was completed (T5).

The first NIRS value measured in the pre-induction period was accepted as the baseline value. The duration of time during which the NIRS baseline value fell below 80%, 70%, and 60% was calculated for all patients. Similarly, De Keijzer et al also included 80%, 70%, and 60% thresholds in their study on regional oxygenation [3]. These durations were then compared between the groups. Additionally, the sensitivity and specificity of the cut-off points for rSO2 values below these thresholds were determined.

Statistical Analysis

R 2024.04.2 software was used for statistical analysis. Descriptive statistics are given with frequency and percent for qualitative variables and mean, standard deviation, median, minimum and maximum values for quantitative variables. The Shapiro-Wilk test was used to test normality and the Mann-Whitney U test was used for 2 independent group comparisons for quantitative variables. Fisher's and Yates's chi-square tests were used to compare qualitative variables between groups. ROC analysis, utilizing the Youden index, was performed to identify optimal cut-off points for NIRS values at different desaturation thresholds, enabling the differentiation between patients with and without renal failure. $P<0.05$ was considered the statistical significance level.

Results

Patient Demographics and Preoperative Characteristics

A total of 407 patients were initially analyzed in the study. Based on the inclusion criteria, 26 patients were excluded, leaving 381 patients for analysis. During the follow-up phase, 24 additional patients were excluded due to insufficient data, resulting in 357 patients included in the final analysis. Among these, 313 patients (87.7%) did not develop ARF postoperatively (Group 1), while 44 patients (12.3%) were diagnosed with ARF (Group 2). A comparison of demographic and preoperative characteristics between the groups is summarized in **Table 1**. Group 2 patients were significantly older than in Group 1 (P=0.024). No statistically significant differences were observed in sex, body mass index, or comorbidities such as hypertension, diabetes mellitus, and hyperlipidemia between the groups.

Intraoperative Data of the Patients

The comparison of intraoperative data between the groups is presented in **Table 2**. Group 2 had significantly longer operation times, CPB durations, and aortic cross-clamping (ACC) durations compared to Group 1 (P<0.05). The use of intra-aortic balloon pump, erythrocyte suspension, fresh frozen plasma,

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Table 1. Comparison of demographic and preoperative characteristics between patients with and without acute renal failure.

	Without ARF=Group 1 (n=313)	With ARF=Group 2 (n=44)	*P* value
Age (years), (mean±SD)	63.4±9.20	66.8±9.22	0.024[a]
Sex			
Female, n (%)	106 (33.9%)	15 (34.1%)	1.000[b]
Male, n (%)	207 (66.1%)	29 (65.9%)	
BMI (mean±SD)	26.8±3.05	26.4±2.61	0.503[c]
Hypertension, n (%)	297 (94.9%)	41 (93.2%)	0.716[d]
Diabetes mellitus, n (%)	89 (28.4%)	12 (27.3%)	1.000[b]
Hyperlipidemia, n (%)	162 (51.8%)	23 (52.3%)	1.000[b]
Cerebrovascular disease, n (%)	18 (5.8%)	3 (6.8%)	0.733[d]
Peripheral artery disease, n (%)	29 (9.3%)	4 (9.1%)	1.000[d]
Ejection fraction (%), (mean±SD)	52.0±7.5950 (40-65)	51.6±7.9455 (40-65)	0.766[a]
EuroScore, median (min-max)	3 (0-11)	3 (0-7)	0.317[a]

[a] Mann-Whitney U test; [b] Yates's chi-square test; [c] Independent sample t-test; [d] Fisher's chi-square test. SD – standard deviation; n – number, $P<0.05$=significance level; ARF – acute renal failure; BMI – body mass index.

Table 2. Comparison of intraoperative parameters between patients with and without acute renal failure.

	Without ARF=Group 1 (n= 313)	With ARF=Group 2 (n= 44)	*P* value
Operation duration (minutes), (mean±SD); median (min-max)	217.3±24.38 212 (180-360)	226.0±19.1 225 (190-270)	**<0.001[a]**
CPB duration (minutes), (mean±SD); median (min-max)	102.6±12.07 99 (84-165)	111.9±19.6 104.5 (91-175)	**0.004[a]**
ACC Duration (minutes), (mean±SD); median (min-max)	79.5±9.14 76 (70-125)	85.3±13.5 85 (70-125)	**0.013[a]**
IABP n (%)	3 (1.0%)	3 (6.8%)	**0.027[c]**
Erythrocyte suspension (units), median (min-max)	1 (0-6)	4 (0-8)	**<0.001[a]**
FFP (Units), median (min-max)	2 (1-8)	3.5 (2-5)	**<0.001[a]**
Inotropic agent therapy			
0 Inotrope infusion therapy n (%)	15 (4.8%)	2 (4.5%)	1.000[c]
1 Inotrope infusion therapy n (%)	220 (70.3%)	26 (59.1%)	0.184[b]
2 Inotrope infusion therapy n (%)	61 (19.5%)	7 (15.9%)	0.718[b]
3 Inotrope infusion therapy n (%)	12 (3.83%)	5 (11.36%)	**0.045[c]**
4 Inotrope infusion therapy n (%)	5 (1.6%)	4 (9.09%)	**0.016[c]**

[a] Mann-Whitney U test; [b] Yates's chi-square test; [c] Fisher's chi-square test. SD – standard deviation; n – number; $P<0.05$=significance level; ARF – acute renal failure; CPB – cardiopulmonary bypass; ACC – aortic cross-clamping; IABP – intra-aortic balloon pump; FFP – fresh frozen plasma.

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Table 3. Comparison of percent changes in NIRS values at intraoperative time points between patients with and without acute renal failure.

	Without ARF=Group 1 (n=313)	With ARF=Group 2 (n=44)	*P* value
T0-T1 percent change, (mean±SD)	0.005±0.04	-0.02±0.05	**0.009**[a]
T0-T2 percent change, (mean±SD)	-0.05±0.05	-0.10±0.06	**<0.001**[a]
T0-T3 percent change, (mean±SD)	-0.16±0.06	-0.27±0.05	**<0.001**[a]
T0-T4 percent change, (mean±SD)	-0.07±0.05	-0.18±0.06	**<0.001**[a]
T0-T5 percent change, (mean±SD)	-0.04±0.05	-0.14±0.06	**<0.001**[a]

[a] Mann-Whitney U test. SD – standard deviation; n – number; p<0.05=significance level; NIRS – near-infrared spectroscopy; ARF – acute renal failure.

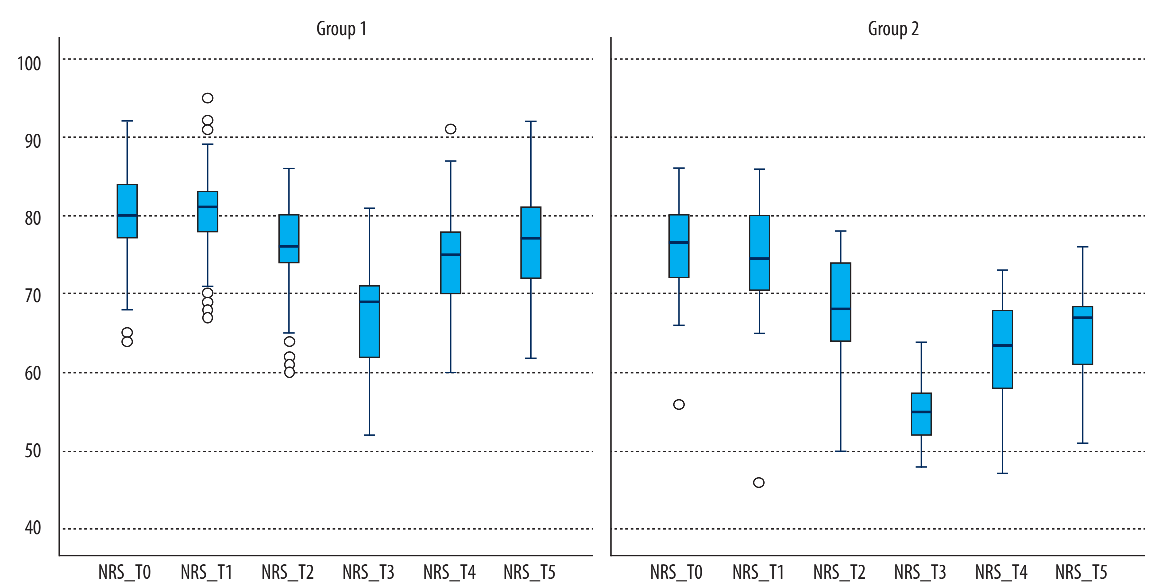

Figure 1. Changes in NIRS values at intraoperative time intervals between patients with and without acute renal failure.

and inotropic agent therapy was also significantly higher in Group 2 (*P*<0.05). Specifically, the need for triple and quadruple inotrope infusion therapies was more frequent in Group 2.

Changes in NIRS Values of the Patients

The percent changes in NIRS values at different intraoperative time intervals (T0, T1, T2, T3, T4, and T5) were compared between the groups. At T1, T2, T3, T4, and T5, Group 2 exhibited significantly greater decreases in NIRS values compared to Group 1 (*P*<0.05) (**Table 3, Figure 1**). Additionally, the duration of time spent with rSO2 values below 80%, 70%, and 60% of the baseline was significantly longer in Group 2 (*P*<0.05) (**Table 4**).

ROC Analysis of NIRS-Based Renal Desaturation Thresholds

ROC analysis was conducted to identify significant cut-off points for NIRS values at different desaturation thresholds using the Youden index.

For rSO2 values below 80%, the cut-off point was determined as >145 minutes, with a sensitivity of 97.7% and a specificity of 55.6%. The area under the curve (AUC) for this cut-off point was 0.783, which was statistically significant (*P*<0.001) (**Table 5, Figure 2**).

For rSO2 values below 70%, the cut-off point was identified as >75 minutes, with a sensitivity of 93.2% and a specificity

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Table 4. Comparison of the time spent below 80%, 70%, and 60% of baseline NIRS values between groups with and without acute renal failure.

	Without ARF=Group 1 (n=313)	With ARF=Group 2 (n=44)	P value
NIRS below 80% (minute) (mean±SD); median (min-max)	142.6±64.1 140 (0-320)	204.1±31.2 205 (125-255)	**<0.001[a]**
NIRS below 70% (minute) (mean±SD); median (min-max)	40.73±49.7 40 (0-320)	135.3±44.7 132.5 (65-255)	**<0.001[a]**
NIRS below 60% (minute) (mean±SD); median (min-max)	1.58±8.2 0 (0-65)	58.4±42.4 55 (0-255)	**<0.001[a]**

[a] Mann-Whitney U test. SD – standard deviation; n – number; *P*<0.05=significance level; NIRS – Near-infrared spectroscopy; ARF – acute renal failure.

Table 5. Analysis of NIRS-based renal oximetry at various desaturation thresholds.

	Cut-off	Sensitivity (95% CI)	Selectivity (95% CI)	AUC (95% CI)	P value
NIRS below 80%	>145	97.7 (88.0-99.9)	55.6 (49.9-61.2)	0.783 (0.737-0.825)	**<0.001[a]**
NIRS below 70%	>75	93.2 (81.3-98.6)	80.5 (75.7-84.8)	0.923 (0.890-0.948)	**<0.001[a]**
NIRS below 60%	>30	86.4 (72.6-94.8)	96.5 (93.8-98.2)	0.924 (0.892-0.949)	**<0.001[a]**

[a] Mann-Whitney U test. n – number; *P*<0.05=significance level; AUC – area under curve; NIRS – near-infrared spectroscopy.

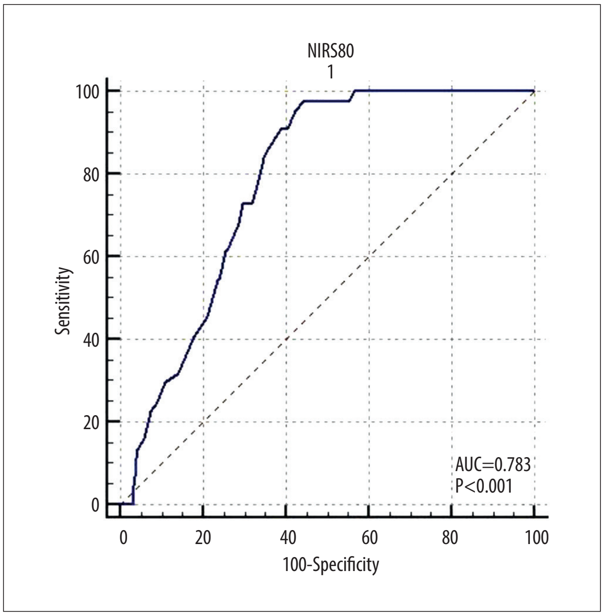

Figure 2. ROC curve analysis for rSO2 values below 80%: Sensitivity and specificity at the identified cut-off point.

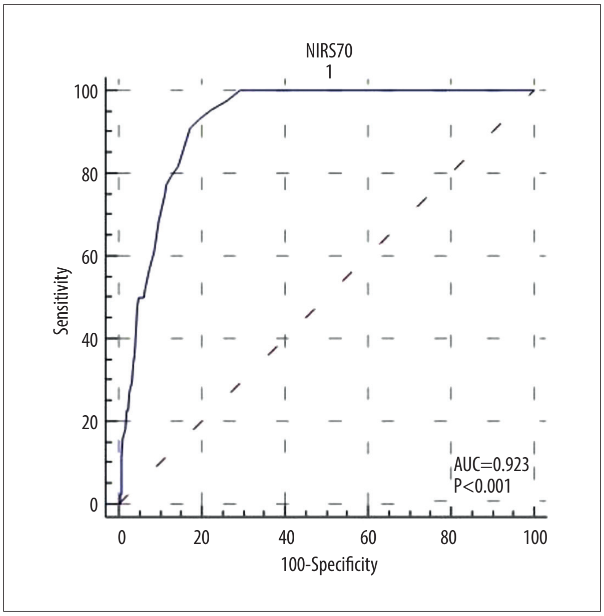

Figure 3. ROC curve analysis for rSO2 values below 70%: Sensitivity and specificity at the identified cut-off point.

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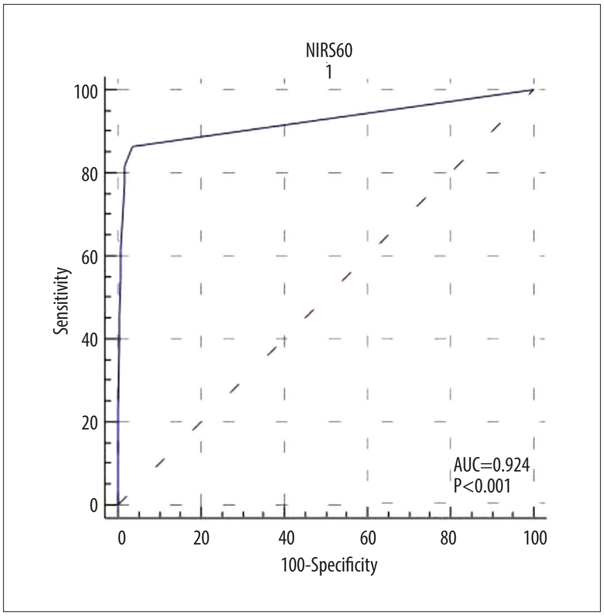

Figure 4. ROC curve analysis for rSO2 values below 60%: Sensitivity and specificity at the identified cut-off point.

of 80.5%. The AUC for this cut-off point was 0.923, which was statistically significant (*P*<0.001) (**Table 5, Figure 3**).

For rSO2 values below 60%, the cut-off point was determined as >30 minutes, with a sensitivity of 86.4% and a specificity of 96.5%. The AUC for this cut-off point was 0.923, which was statistically significant (*P*<0.001) (**Table 5, Figure 4**).

Postoperative Data of the Patients

The comparison of the postoperative data of the 2 groups is summarized in **Table 6**. Duration of ICU stay, hospitalization time, continuous positive airway pressure (CPAP) requirement, and wound infection rate were higher in Group 2. This result was statistically significant (*P*<0.05).

Discussion

There can be adverse effects on organ systems after CPB in open-heart surgery. One of these systems whose function is affected is the renal system. The kidneys may fulfill their functions at a lower level after CPB compared to the preoperative period as a result of reduced cardiac performance and inadequate perfusion. In open-heart surgery practice, renal function is traditionally monitored by urine output and serum creatinine levels. These parameters are also used in the KDIGO criteria. However, diagnosis with these parameters can delay renal replacement therapy. Therefore, it is important to determine different methods for early diagnosis of ARF during open-heart surgery. In the literature, there are studies conducted by measuring renal tissue oxygen saturation with renal NIRS for this purpose [3,7,8].

Table 6. Comparison of postoperative outcomes between patients with and without acute renal failure.

	Without ARF=Group 1 (n=313)	With ARF=Group 2 (n=44)	*P* value
Extubation duration (hours), (mean±SD); median (min-max)	8.47±3.28 8(4-38)	9.45±4.72 8(6-34)	0.112[a]
Intensive care duration (days), (mean±SD); median (min-max)	54.89±15.16 52(25-158)	66.09±41.04 57(40-250)	**0.036[a]**
Duration of hospitalization (days), (mean±SD); median (min-max)	7.63±1.44 7(5-17)	7.91±1.75 7(6-17)	**0.270[a]**
CPAP requirement/respiratory distress, n (%)	56 (17.9%)	15 (34.1%)	**0.020[b]**
Pneumonia, n (%)	23 (7.4)	7 (15.91)	0.076[c]
Reintubation, n (%)	7 (2.24)	3 (6.82)	0.113[c]
Arrhythmia, n (%)	35 (11.18)	10 (22.72)	0.055[b]
Neurological complications, n (%)	12 (3.83)	2 (4.5)	0.686[c]
Wound site infection, n (%)	10 (3.19%)	6 (%13.64)	**0.008[c]**
Hemorrhage revision, n (%)	11 (3.51)	4 (9.09)	0.099[c]
30-Day Mortality, n (%)	8 (2.55)	3 (6.82)	0.142[c]

[a] Mann-Whitney U test; [b] Yates's chi-square test; [c] Fisher's chi-square test. n – number; *P*<0.05=significance level; SD – standard deviation; ARF – acute renal failure; CPAP – continuous positive airway pressure.

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Among the studies in this area, the research by De Keijzer and colleagues stands out as a notable example. Their investigation focused on renal, cerebral, and peripheral tissue oxygenation to evaluate its predictive value for postoperative renal failure in patients undergoing coronary artery bypass surgery. Their study found no significant correlation between renal NIRS measurements and postoperative renal failure, while peripheral tissue oxygenation emerged as a more reliable indicator in this context. However, the authors highlighted 2 key limitations that could have influenced their results. Firstly, the study included only 41 patients, which limited the generalizability of the findings. Secondly, the skin-to-kidney distance in their study population was set at ≤5 cm, potentially affecting the accuracy of renal NIRS measurements [3]. In contrast, our study addressed these limitations by including a larger cohort of 357 patients and restricting the skin-to-kidney distance to ≤4 cm. This methodological refinement enhances the reliability of NIRS measurements and strengthens the applicability of our findings in predicting postoperative renal failure.

The rate of ARF was 12.3% in our study. Hu et al reported in a systematic review and meta-analysis that this rate can reach a composite incidence of 22.3% [9]. Many factors trigger ARF in open-heart surgery operations performed with CPB. Embolism, low perfusion, inflammatory mediator release, and hemodilution are among these factors [10]. Advanced age is also included among the risk factors after open-heart surgery [11,12]. In our study, the mean age of patients with ARF was higher, in accordance with the literature. There was no significant difference between the groups in terms of sex distribution (**Table 1**). According to the results of our study, sex is not a determining factor in the development of ARF.

Hypertension and diabetes mellitus are common comorbidities in patients undergoing open-heart surgery. Chronic hypertension impairs autoregulatory mechanisms by vasoconstriction in preglomerular vascular structures and renders the kidneys vulnerable to damage when perfusion pressure is insufficient. Therefore, hypertension as a comorbidity is an important disease in the development of renal failure [13]. Diabetes mellitus has also been reported to be associated with vasculopathy and nephropathy due to mechanisms including tissue hypoxia, inflammation, and endothelial damage [14]. In our study, when the rates of patients with hypertension and diabetes mellitus were compared, no difference was found between the patient group with renal failure and the patient group without renal failure (**Table 1**). Although hypertension and diabetes mellitus are predictive factors in the development of ARF, we think that the reason for the lack of difference between the groups is that hypertension and diabetes mellitus are common comorbidities in patients undergoing open-heart surgery. However, close follow-up in terms of renal failure is also important in patients who are not fully regulated in terms of these comorbidities.

Intraoperative factors such as operation duration and CPB and ACC duration were statistically significantly higher in the ARF group (**Table 2**). This reveals the negative effect of prolonged surgical procedures and CPB duration on renal function. A study in the literature reported that the risk of development of ARF increased when CPB duration exceeded 70 minutes and ACC duration exceeded 60 minutes [1]. The association of prolonged CPB and ACC durations with ARF is also compatible with our findings.

Our study found that patients with ARF received a higher rate of inotropic agent treatment, and more erythrocyte suspension and fresh frozen plasma were used intraoperatively (**Table 2**). Intra-aortic balloon pump (IABP) requirement was also higher in the patient group with ARF (**Table 2**). In open-heart surgery, it is important to maintain hematocrit (Hct) at a certain level for adequate perfusion of tissues. Therefore, routine hemodilution during CPB excessively increases the risk of ARF. A study by Karkouti et al reported in that moderate hemodilution (Hct ≥24%) is acceptable in CPB to ensure renal perfusion, and excessive hemodilution (Hct <21%) or erythrocyte transfusion can lead to ARF and increased need for dialysis. In our study, we performed replacement with erythrocyte suspension to keep the Hct level at 24% and above [15]. In the literature, adverse effects of inotropic agents, especially traditional beta mimetic agents, on renal function in open-heart surgery have been reported [16,17]. This situation is similar to our study. In addition, renal perfusion is impaired when hemodynamic instability develops. The need for more inotropic agents and IABP in the patient group with ARF indicates that we encountered more hemodynamic instability in these patients.

In this study, NIRS values were compared between groups in 2 ways. The first evaluation method was to compare the% change in NIRS values of the groups according to specific time intervals. In this comparison, a significant decrease in rSO_2 values was observed in Group 2 (patients with ARF) compared to Group 1 (patients without ARF) at all time points (T1-T5) (**Table 3, Figure 1**).

The second evaluation method was performed by comparing the time in minutes of the% change in NIRS values between the groups compared to baseline (decrease from baseline). In this comparison, a 20% decrease in NIRS value from baseline to less than 80% was considered an important threshold value. Similarly, Ortega-Loubon et al reported that a 20% decrease in NIRS from baseline in patients who developed acute renal failure after open-heart surgery may be a good criterion for the diagnosis of acute kidney injury associated with cardiac surgery [7]. In addition, as in the study by Ilonka et al, the times of decrease of NIRS value from baseline to below 70% and 60% were also compared between the groups [3]. It was found that patients in Group 2 remained at low oxygen

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saturation levels significantly longer than Group 1 in terms of the times below the 80%, 70% and 60% thresholds of NIRS. There is a dramatic difference, especially in the times below 60% (**Table 4**). This suggests that the risk of ARF development increases as time elapsed during periods of decreased tissue oxygenation increases.

The ROC analyses performed in our study show the sensitivity and selectivity of the NIRS threshold values determined to predict the development of ARF. The cut-off point >145 minutes for the 80% cut-off value is considered a strong indicator for predicting ARF development, with a sensitivity of 97.7% (**Table 5, Figure** 2). Similarly, high sensitivity and selectivity rates were also found for 70% (**Table 5, Figure 3**) and 60% (**Table 5, Figure 4**) cut-off values. In particular, when the cut-off point >30 minutes was chosen for the time below 60%, sensitivity and selectivity were 86.4% and 96.5%, respectively. These results indicate that both sensitivity and selectivity increase with increasing NIRS desaturation duration. Therefore, intraoperative NIRS values can be considered as a reliable indicator for predicting the risk of ARF.

When we evaluated the postoperative results in our study, we found that the duration of ICU stay, hospitalization duration, CPAP requirement, and wound infection rates were significantly higher in Group 2 ($P<0.05$) (**Table 6**). This finding suggests that the development of ARF increases postoperative morbidity and prolongs the postoperative recovery period. In particular, the increased rates of CPAP requirement and wound infection indicate that these patients are more vulnerable to postoperative complications, and the need for a stay in the ICU is increased.

One of the limitations of our study is that it was single-centered. In addition, the fact that the study was not performed with a single surgical team but with different surgical teams and that only short-term results were analyzed are other limitations.

Conclusions

These results suggest that NIRS values used to monitor tissue oxygenation in the intraoperative period play a critical role in preserving renal function, especially in high-risk surgical procedures such as open-heart surgery. Furthermore, the low NIRS levels and prolonged desaturation durations seen in Group 2 show a strong association with the development of ARF.

Continuous NIRS monitoring during the intraoperative period may help in the early detection and prevention of serious complications such as ARF. Taking measures to improve perfusion, especially when NIRS decreases by more than 20%, may reduce the risk of ARF. Careful monitoring of times below the critical thresholds of 80%, 70%, and 60% may help early detection of renal perfusion disorders. The surgical team can preserve renal function by providing more aggressive fluid therapy and hemodynamic support in patients exceeding these thresholds.

Patients who develop ARF should be monitored more closely in the postoperative period due to the risk of prolonged ICU stay and complications. This study shows that intraoperative monitoring of NIRS values and monitoring of critical thresholds may be an important tool in predicting the development of ARF and other postoperative complications.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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