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Regional oxygen saturation change rate for detection of leg ischemia in minimally invasive cardiac surgery

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Abstract

Introduction: The criteria for placement of distal perfusion cannulas vary among reports. This cohort study aimed to establish a reproducible method to monitor critical leg ischemia during minimally invasive cardiac surgery.

Methods: We included 121 patients who underwent minimally invasive cardiac surgery via right thoracotomy with right femoral arterial cannulation from 2015 to 2018. The change rate of regional oxygen saturation (ΔrSO_2) was calculated as follows: rSO_2 (baseline) − rSO_2 (actual number)/rSO_2 (baseline). Patients were divided into Group N ($\Delta rSO_2 < 40\%$): 100/121 (83%) and Group H ($\Delta rSO_2 > 40\%$, <10 minutes if $>40\%$): 21/121 (17%). A distal perfusion cannula was placed when ΔrSO_2 was $>40\%$ over 10 minutes.

Results: No patients experienced significant leg ischemia. Significantly longer cardiopulmonary bypass and aortic cross-clamp times were observed in Group H than in Group N (cardiopulmonary bypass time, 129 ± 36 minutes (Group N) vs. 151 ± 34 minutes (Group H), $p = 0.01$). ΔrSO_2 correlated positively with plasma creatine phosphokinase elevation ($R = 0.40$, $p < 0.001$) on postoperative day 1. Serum lactate on intensive care unit admission showed a significant positive correlation ($R = 0.40$, $p < 0.001$) with ΔrSO_2.

Conclusion: ΔrSO_2 measurement by near-infrared spectroscopy can facilitate distal leg perfusion monitoring and assist surgeons in preventing critical leg ischemia during minimally invasive cardiac surgery.

Keywords

leg ischemia; near-infrared spectroscopy; oxygen saturation; minimally invasive cardiac surgery

Introduction

Minimally invasive cardiac surgery (MICS) provides cosmetic benefits in addition to other points such as shorter hospital stays.[1] In the meta-analysis comparing conventional sternotomy and MICS for mitral valve surgery, the advantages of MICS were shorter intensive care unit (ICU) stay, shorter duration of respirator dependence, and less use of blood products, while longer cardiopulmonary bypass (CPB) and higher aortic dissection rate in MICS were observed than in standard sternotomy approach.[2] Therefore, MICS approach is safely achieved in appropriately selected patients with good surgical outcomes by expert surgeons, although surgical field is limited because of a small window in mini-thoracotomy.[3,4]

One of the approaches for MICS is right mini-thoracotomy with cannulation of arterial and venous cannulas from the groins. Large-sized arterial cannulas are required to achieve efficient blood flow in CPB. However, one of the surgical concerns is leg ischemia caused by femoral artery (FA) cannulas,[5] which is critical but preventable if a reliable monitoring system for leg ischemia is provided and the insertion of distal perfusion cannula to the cannulated FA is properly established. Direct assessment of the leg appearance and thermal monitoring of distal legs during MICS are not practical for surgeons.[6] Moreover, pulse assessment of the tibial arteries by Doppler is not quantitative and reliable enough for surgeons to decide whether alternative cannulas on the

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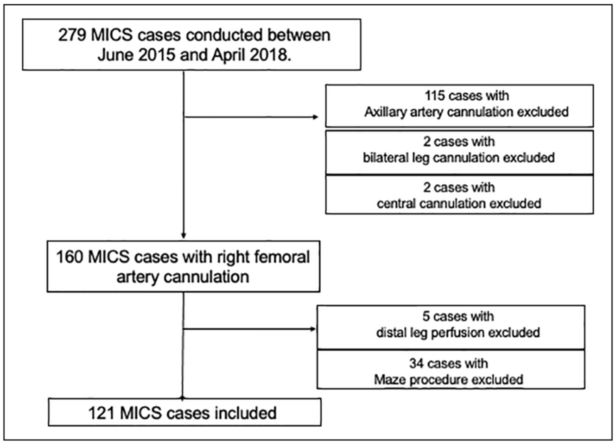

Figure 1. Study flowchart. One hundred twenty-one minimally invasive cardiac surgery cases with right femoral artery cannulation were included in this study.

FA are necessary, especially when patients are on CPB without pulsatile flow.[7] The criteria for significant leg ischemia during MICS are still uncertain in the literature. Therefore, a continuous and steady monitoring system is required for surgeons. In fact, near-infrared spectroscopy (NIRS) provides surgeons with information of distal leg ischemia related to spasms and temporary obstruction of peripheral arteries caused by kinking or large-sized cannulas and distal embolism during extracorporeal membrane oxygenation support.[6,8] To our knowledge, there are only three English articles about the clinical use of NIRS to monitor leg ischemia during MICS.[9–11] We had introduced the NIRS monitoring system for distal leg ischemia during MICS in 2013 and established the criteria for initiation of distal perfusion cannulas to distal legs.

Although direct assessment of the leg is a dependable method, the criteria for placement of distal perfusion cannulas vary among reports. Thus, this study aimed to establish a reliable monitoring approach to prevent critical leg ischemia during MICS and assess the reliability of the criteria for insertion of distal perfusion cannulas.

Patients and methods

Ethical approval for this research was obtained from the institutional ethical committee at Chibanishi General Hospital, Chiba, Japan. Informed consents were waived for this study. From June 2015 to April 2018, 121 MICS cases via right mini-thoracotomy with right FA cannulation were included in this study (Figure 1). MICS cases, which required central cannulation or peripheral arterial cannulation to both legs and/or upper limbs were excluded. Cases with peripheral arterial diseases were not indicated for MICS with peripheral cannulation. Thirty-four cases with Maze procedure were excluded since this procedure increases plasma creatine phosphokinase (CPK) level postoperatively.[12] Five patients who required additional distal perfusion to the lower leg were excluded from this analysis (n = 5, no leg ischemia after MICS) since the regional oxygen saturation (rSO_2) values in these cases were back to normal after distal perfusion, which complicates analysis of this study for risk factors with elevated CPK and association between CPK and rSO_2.[6] The criteria for placement of distal perfusion leg cannula was set as $\Delta rSO_2 > 40\%$ over 10 minutes in our institution as no rigid criteria for distal leg perfusion was found during MICS.

MICS procedures for valve repair/replacement were performed under general anesthesia; an arterial line was placed in the radial artery and central venous catheter. An NIRS monitoring system was attached to both legs.[6] A right mini-thoracotomy was made with a 5- to 7-cm-long skin incision at the fourth right intercostal space. CPB was established via right FA cannulation (PCKC-A, MERA, Tokyo, Japan), and femoral vein and internal jugular cannulations (HLS Cannula, Maquet, Rastatt, Germany) were added if necessary. Systemic perfusion was controlled between 2.2 and 2.6 L/m^2. Antegrade cardioplegia was delivered through an aortic root needle. The lowest blood temperature during CPB was 32°C. After CPB was terminated, the arterial and venous cannulas were removed surgically, and peripheral pulsatility and normalization of rSO_2 value (back to baseline values of rSO_2) was confirmed.[6] After surgical procedures, the patients were sent to the ICU, and clinical parameters including CPK, CPK-myocardial band (CPK-MB), serum lactate, and base excess were measured at ICU admission and every 6 hour. Clinical symptoms of leg ischemia were recorded if noticed. Leg ischemia was defined with the report by Rutherford et al.[13] Rehabilitation data such as the distance of the first walk was recorded to assess the effect of leg perfusion on clinical data by physiotherapists who were blinded to the clinical operative data, such as rSO_2. Clinical events such as leg pain and numbness associated with leg ischemia after MICS were also recorded.

The rSO_2 was measured in both legs using NIRS in each time frame. The rSO_2 at baseline was measured before initiation of MICS procedure in the operating room. The change rate in rSO_2 (ΔrSO_2) was calculated as follows: rSO_2 (baseline) – rSO_2 (actual number)/rSO_2 (baseline). Based on the lowest ΔrSO_2, the patients were divided into two groups as Group N (normal ΔrSO_2 Group) ($\Delta rSO_2 < 40\%$): 100/121 (83%) and Group H (High ΔrSO_2 Group) ($\Delta rSO_2 > 40\%$, <10 minutes if >40%): 21/121 (17%).

Preoperatively, the size of the short and long axis of the FA (superficial and deep FAs), and the number of branches arising from FA were measured using ultrasonography by trained sonographers. The occlusion rate

Table 1. Patient demographics.

Patient demographics	Total (n = 121)	Group N (n = 100)	Group H (n = 21)	p value
Age (years)	67 ± 14	68 ± 13	63 ± 16	0.2
Female/male	64/57	50/50	14/7	0.2
Body surface area (m^2)	1.56 ± 0.21	1.59 ± 0.29	1.55 ± 0.20	0.5
Diabetes mellitus (n, %)	9 (7.4%)	6 (6.0%)	3 (14.2%)	0.2
Hypertension (n, %)	59 (48.8%)	50 (50.0%)	9 (42.9%)	0.6
Chronic kidney disease (n, %)	7 (5.8%)	7 (7.0%)	0	1
COPD (n, %)	6 (5.0%)	6 (6.0%)	0	0.6
NYHA III or IV (n, %)	20 (16.5%)	3 (3.0%)	0	0.4
Preoperative beta blockers (n, %)	22 (18.2%)	20 (20.0%)	2 (9.5%)	0.4
Ejection fraction (%)	66.5 ± 9.7	66.6 ± 9.2	65.9 ± 12.3	0.8
EuroSCORE2	1.9 ± 2.8	2.0 ± 3.0	1.6 ± 1.4	0.5
Right ankle brachial index	1.3 ± 0.2	1.3 ± 0.2	1.2 ± 0.2	0.1
Long diameter of the right CFA (mm)	9.9 ± 1.8	10.0 ± 1.9	9.6 ± 1.4	0.4
Short diameter of the right CFA (mm)	9.2 ± 1.7	9.2 ± 1.7	8.9 ± 1.3	0.5
Diameter of the right SFA (mm)	7.1 ± 1.5	7.2 ± 1.5	6.7 ± 1.7	0.1
Diameter of the right DFA (mm)	6.2 ± 1.5	6.2 ± 1.5	5.7 ± 1.4	0.08
Sectional area of right CFA (mm^2)	73.5 ± 28.0	74.5 ± 29.6	68.7 ± 18.7	0.4

CFA: common femoral artery; COPD: chronic obstructive pulmonary disease; DFA: deep femoral artery; NYHA: New York Heart Association; SFA: superficial femoral artery.
Data are presented as mean ± standard deviations.

of the right FA by an arterial cannula was calculated as follows: cross-sectional area of the cannula × 100/cross-sectional area of the FA.

Statistical analysis

Continuous data are shown as mean ± standard deviation (SD), and they were analyzed by paired t-test or Wilcoxon signed rank test, if appropriate. Categorical variables were analyzed with chi-square test or Fisher's exact test. Pearson's correlation coefficients were calculated between ΔrSO_2 and continuous variables. Statistical exams were conducted with SPSS version 25.0 (IBM Corp., Armonk, NY, USA). $p < 0.05$ was considered significant in statistical analysis.

Results

We analyzed 121 cases (female/male, 64/57) who underwent MICS. Mean age and body surface area of the patients were 67 ± 14 years and 1.56 ± 0.21 m^2, respectively. Patient demographics are shown in Table 1. The patients with peripheral disease were not included in this study as we usually choose standard sternotomy approach if the patients have that disease. Ankle brachial index, contrasted computed tomography, and ultrasonographies are routinely conducted to assess the quality and size of peripheral arteries. The rates of comorbidities including diabetes mellitus, hypertension, chronic kidney diseases, and chronic obstructive pulmonary disease were similar between the smaller ΔrSO_2 group (Group N) and larger ΔrSO_2 group (Group H). Preoperative cardiac status including medication, related symptoms, cardiac function, and predictive mortality score (EuroSCORE2) did not show significant difference between the two groups.

Operative data with a comparison between the high and low ΔrSO_2 group

The types of cardiac surgery were similar between the two groups with more than half of patients undergoing mitral valve surgery ± tricuspid annuloplasty. The operation time showed no significant difference between the smaller ΔrSO_2 group (Group N) and larger ΔrSO_2 group (Group H), (208 ± 51 minutes vs. 226 ± 40 minutes, $p = 0.1$), while CPB time and aortic cross-clamp time were significantly shorter in Group N (CPB time, 129 ± 36 minutes; aortic cross-clamp time, 99 ± 37 minutes) than in Group H (CPB time, 151 ± 34 minutes; aortic cross-clamp time, 120 ± 29 minutes) (Table 2). In terms of the size of the right FA and the occlusion rate of the cannulated right FA, no significant differences were found between the two groups (Table 1). No patients required distal perfusion cannula insertion (Table 2). The choice of size of arterial cannula did not differ between the two groups. The requirement of blood products and hemoglobin levels (data are not shown), which could affect rSO_2 levels, in pre and post procedures were similar in both groups. The lowest temperature during MICS had similar numbers in the two groups. Early surgical outcomes had no significant difference in intubation time, ICU stay, timing of oxygen weaning, and hospital stay (Table 2).

Table 2. Operative data.

Operative data	Total (n = 121)	Group N (n = 100)	Group H (n = 21)	p value
Arterial cannula size				0.4
15 Fr	14	12	2	
16 Fr	57	50	7	
17 Fr	3	3	0	
18 Fr	46	34	12	
20 Fr	1	0	1	
Distal perfusion cannula insertion	0	0	0	–
Occlusion rate (%)	36.5 ± 10.2	36.0 ± 8.6	39.0 ± 8.6	0.2
Operation time (min)	211 ± 50	208 ± 51	226 ± 40	0.1
Cardiopulmonary bypass time (min)	133 ± 37	129 ± 36	151 ± 34	0.01
Aortic cross-clamp time (min)	102 ± 37	99 ± 37	120 ± 29	0.02
Blood transfusion (n, %)	21 (17%)	18 (18%)	3 (14%)	1
Lower body temperature (°C)	31.9 ± 0.7	31.9 ± 0.8	32.0 ± 0.3	0.7
Types of surgery				
AVR ± TAP	49	42 (42%)	7 (33%)	
MVP ± TAP	51	39 (39%)	12 (57%)	
MVR ± TAP	7	6 (6%)	1 (5%)	
AVR + MVP ± TAP	2	2 (2%)	0	
DVR ± TAP	4	3 (3%)	1 (5%)	
ASD closure ± TAP	6	5 (5%)	1 (5%)	
Cardiac tumor resection	3	3 (3%)	0	
Intubation time post-surgery (hours)	9.5 ± 5.7	9.6 ± 6.1	9.2 ± 3.7	0.8
ICU stay (days)	3.0 ± 4.6	3.0 ± 5.1	2.7 ± 1.1	0.7
Oxygen weaned off after surgery (days)	3.3 ± 2.1	3.3 ± 7.5	3.1 ± 2.2	0.9
Distance of first walk after surgery (m)	38.3 ± 34.1	40.4 ± 34.7	26.2 ± 29.7	0.08
Date of first 150-m walk after surgery (days)	4.5 ± 7.3	4.4 ± 7.6	5.3 ± 6.0	0.6
Hospital stay (days)	10.8 ± 11.5	10.4 ± 10.5	12.8 ± 15.5	0.4

ASD: atrial septal defect; AVR: aortic valve replacement; DVR: double valve replacement; MVP: mitral valve plasty; MVR: mitral valve replacement; TAP: tricuspid annuloplasty.
The occlusion rate of the right FA by an arterial cannula was calculated as follows: cross-sectional area of the cannula × 100/cross-sectional area of the FA.

Significant linear correlation between ΔrSO_2 and postoperative lactate and CPK

The mean level of plasma CPK in all patients at ICU admission was 535 ± 478 IU/L. The mean CPK levels in all patients showed an increasing trend in the postoperative period and reached a peak at the average of 19 ± 11 hour after ICU admission, with the mean maximum CPK level of 1,048 ± 583 IU/L. The mean CPK-MB level in all patients showed a slight increase from 29 ± 13 IU/L at ICU admission to 32 ± 15 IU/L at 4.8 ± 6.8 hour after surgery. The average serum lactate level in all patients at ICU admission was 2.1 ± 1.1 mmol/L, and this showed a gradual increase to the peak of 4.7 ± 2.3 mmol/L at 5.3 ± 3.7 hour after MICS. Table 3 shows a comparison of the clinical values related to leg perfusion between Group N and H, showing that significantly higher CPK level at admission and maximum CPK were found in Group H than in Group N. Significantly larger elevation of serum lactate at ICU admission was observed in Group H than in Group N, while no significant difference was observed in CPK-MB values at all time frames. Baseline rSO_2 values had no difference between Group H and Group N, while a significantly smaller minimum rSO_2 was found in Group H with higher ΔrSO_2.

ΔrSO_2 showed a significant positive correlation with elevation of plasma CPK level ($R = 0.40$, $p < 0.001$) one day after surgery. The serum lactate level at ICU admission also showed a significant positive correlation ($R = 0.40$, $p < 0.001$) with ΔrSO_2 (Figure 2). However, after ICU admission, lactate levels were not correlated with ΔrSO_2 (data were not shown).

Rehabilitation data and clinical symptoms of leg ischemia in two groups

No symptoms related to leg ischemia after MICS developed in both groups. No intervention for leg ischemia was needed during hospitalizations after MICS in all patients studied. During the rehabilitation period, the date of the first 150-m walk and the distance of the first walk were routinely recorded by physiotherapists who were not informed about any of the ΔrSO_2 data. The dates of first 150-m walk after MICS did not show significant difference between the two groups (Group N vs. H: 5.3 ± 6.0 vs.

Table 3. Perioperative factors.

Perioperative factors	Group N (n = 100)	Group H (n = 21)	p value
CPK at ICU admission (IU/L)	489 ± 459	750 ± 517	0.02
Maximum CPK (IU/L)	971 ± 530	1,415 ± 690	0.01
Time to peak CPK (hours)	19.9 ± 11.4	16.9 ± 8.9	0.3
CPK-MB at ICU admission (IU/L)	28 ± 14	31 ± 9	0.5
Maximum CPK-MB (IU/L)	31 ± 15	36 ± 17	0.2
Time to peak CPK-MB (hours)	4.9 ± 7.2	4.2 ± 5.1	0.7
Lactate at ICU admission (mmol/L)	2.0 ± 0.9	3.0 ± 1.6	0.01
Maximum lactate (mmol/L)	4.6 ± 2.4	5.1 ± 1.8	0.3
Time to peak lactate (hours)	5.6 ± 3.8	4.3 ± 3.0	0.1
Postoperative clinical symptoms	0	0	–
Baseline rSO_2	68.6 ± 13.8	68.8 ± 12.0	0.9
minimum rSO_2	55.5 ± 11.9	31.5 ± 8.6	<0.001
Change rate of rSO_2 (%)	18.7 ± 10.0	53.8 ± 10.8	<0.001

CPK-MB: creatine phosphokinase-myocardial band; rSO_2: regional oxygen saturation.

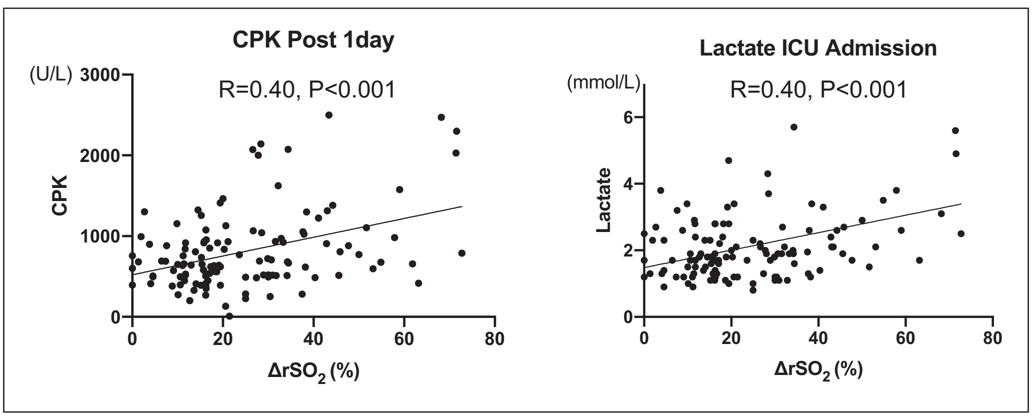

Figure 2. Linear curves showing significantly positive correlation between ΔrSO_2 and plasma creatine kinase (CPK) at postoperative day 1 and serum lactate soon after ICU admission.

4.4 ± 7.6 days, p = 0.6). The distance of the first walk after surgery was longer in Group N (40.4 ± 34.7 m) than in Group H (26.2 ± 29.7 m) (p = 0.08).

Discussion

In this study, we applied NIRS monitoring to monitor leg perfusion during MICS. However, practical cut-off numbers of leg ischemia in NIRS were uncertain for clinical use, so we setup the criteria for the placement of distal perfusion cannulas at the arterial cannulation sites ($\Delta rSO_2 > 40\%$ for 10 minutes). This level was reasonable enough to use as a standard criterion, as no patients experienced clinical ischemic leg events and no patients required interventions for leg ischemia after surgeries in this study. In addition, after this study, we had completed more than 100 MICS cases without leg ischemia according to our criteria of cannulation to the distal legs, which supports the validity of our policy in preventing leg complications. In contrast, significant differences in clinical symptoms associated with low leg perfusion such as compromised walk capacity in Groups N and H might have been seen in this study, if distal perfusion cannulas had not been placed for patients with $\Delta rSO_2 > 40\%$ for more than 10 minutes. However, this would not have been ethically appropriate to avoid evitable leg complications that affect the quality of life after surgeries.

MICS with right thoracotomy approach needs peripheral cannulation with preferably large arterial cannulas to perfuse the whole body sufficiently. In contrast, large arterial cannulas can obstruct the distal part of cannulated arteries, especially in old Asian female patients with small FA. This can lead to ongoing leg ischemia and subsequent progression to leg injury.[11] Thus, a sensitive and reliable continuous monitoring system to help surgeons recognize ongoing leg ischemia during arterial cannulation to the groins is required. The NIRS provides continuous data of rSO_2 and tissue oxygenation index, which are mainly used for monitoring cerebral perfusion during conventional cardiac surgery. This system can be used to monitor peripheral circulation of the legs as well.[14]

In this study, the change rate of rSO_2 had a significantly positive correlation with postoperative CPK and lactate levels. CPK is one of the simple biomarkers for muscular ischemia and injury. Tarui et al. reported no correlation between minimum rSO_2 and CPK levels.[9] This is possibly because they analyzed correlation with minimum rSO_2 rather than ΔrSO_2, which we believe is more sensitive to monitor leg perfusion than minimum rSO_2. High serum lactate level indicates a low cardiac output and compromised peripheral circulation.[15] We experienced elevation of plasma CPK and lactate levels in Group H in the early postoperative period when some patients might have silent leg ischemia or muscular injury. We also found a clinical tendency in decreased walk capacity in Group H, which could indicate that some of the patients might have silent leg ischemia. These data suggest that patients with >40% of ΔrSO_2 even under 10 minutes need backflow cannulas to perfuse the distal legs if longer CPB time and aortic cross-clamp time are expected for complex valve repairs.[9]

This study has few limitations. This is a retrospective cohort study, and its single-center design indicates bias. Other factors contributing to leg ischemia, that is, leg temperature, might need to be considered in this study.

Conclusion

The measurement of rSO_2 with NIRS can help in monitoring leg perfusion continuously and prevent critical leg ischemia during MICS. The $\Delta rSO_2 > 40\%$ could suggest silent leg ischemia with increased plasma CPK and serum lactate level after MICS.

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Author Contributions

F.S. contributed to data analysis, writing, and editing; Y.N. contributed to supervision, editing, project administration, and investigation; Y.O. contributed to data curation and investigation; Y.U. contributed to data curation; and N.Y. contributed to data curation.

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