

Does Myocardial Oxygen Extraction Depend on Preoperative Functional Class in Beating Heart Atrial Septal Defect Repair

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ABSTRACT

BACKGROUND: To determine the effect of preoperative functional class on myocardial oxygen extraction in patients undergoing Beating Heart repair of Atrial Septal Defect (ASD).

METHODS: 140 consecutive patients with secundum Atrial Septal Defect were operated on beating heart with normothermic normokalemic (37°C, 4.5 mmol/L) bypass without cross-clamping the aorta between January 2016 to December 2018. Patients above 15 years of age and having high school as minimum qualification were enrolled. All patients with ASD size of smaller than 2 cm, those with associated cardiac anomalies, with accompanying co-morbidities, and age more than 65 years were excluded. Patients were classified as per New York Heart Association (NYHA) criteria. We sought to determine whether the preoperative NYHA functional class has any effect on myocardial oxygen extraction.

RESULTS: There were 84 females (60%) and 56 males (40%) with a female: male ratio of 1.5. The age of patients ranged between 18–65 years with a mean age of 42 ± 4.2 . Elderly patients were found to have a higher functional class as per NYHA classification. Functional class improvement was 37% from NYHA class IV to III, 18.5% from IV to II, 7.4% from IV to I, 51.6% from III to II, 30.2% from III to I, and 71.1% from II to I after one year of follow up. Overall myocardial oxygen extraction in Volume%, (12.4 ± 3.1) was comparable to that seen in a normal healthy beating heart at rest. Our study determined that there was no difference in myocardial oxygen extraction in different NYHA classes.

CONCLUSION: Preoperative NYHA functional class does not affect myocardial oxygen extraction in patients operated on beating heart.

KEYWORDS: Atrial septal defects, Beating heart, Functional Class, Myocardial oxygen extraction

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INTRODUCTION

Beating heart surgery with normothermic cardiopulmonary bypass has gained popularity as this technique eliminates myocardial ischemia, is simple, and shortens the cardiopulmonary bypass and total operation times without increasing the risk of central nervous system injury^[1]. Postoperative blood loss, inotropic drug requirements, and ventilation times are significantly reduced, possibly resulting in better recovery and fewer complications in the postoperative period^[2]. Besides arresting the heart may cause a decrease in cognitive ability increasing morbidity, low quality of life, prolonged hospital stay, and increased

costs^[3,4]. Reperfusion injury is also well recognized^[5]. The interplay between factors like cerebral embolization, hypoperfusion, and local or systemic inflammatory response is cumulative^[6]. Patients with complex congenital cardiac anomalies and valvular operations associated with prolonged CPB and cross-clamp time are particularly vulnerable. Various attempts at alleviating these drawbacks have been studied^[7,8,9].

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The heart has the highest oxygen consumption per tissue mass of all human organs and receives 250ml/min of coronary blood flow amounting to up to 5% of all cardiac output^[10]. Under resting conditions, the coronary blood flow remains constant between mean arterial pressures of 60–140 mm Hg^[11]. Myocardial oxygen requirement is determined by Coronary blood flow and oxygen extraction. The myocardial oxygen extraction coefficient expresses the fraction of available oxygen in arterial blood removed by the myocardium. Myocardial oxygen extraction during rest is approximately 60% to 70% of total coronary oxygen content and remains stable over a wide range of work loads^[10]. Measured in volume percent (vol% = ml O₂/100ml of blood)), theoretically, maximal myocardial oxygen extraction is about 20 vol%, a value, however never achieved in reality, as it remains around 15-16 vol%. Typically O₂ extraction is 10–12 (vol%) in a normal beating heart at rest. In reality, therefore the heart extracts about one-half to two-thirds of physiologically available oxygen under normal conditions^[12].

Right ventricular dysfunction is predominantly responsible for symptoms in patients with an atrial septal defect. Besides the development of pulmonary hypertension and arrhythmias also contributes. Because of being asymptomatic for decades with isolated secundum ASD, many patients are unmindful of reduction in exercise capacity and many cases realize relief of symptom once the repair is done^[13] after ASD is picked up incidentally.

This study was to determine whether preoperative NYHA functional class has any effect on myocardial oxygen extraction in patients who had ASD repair done on beating heart without cross-clamping the aorta.

MATERIAL AND METHODS

140 patients with ASD were prospectively enrolled in the study between January 2016 to December 2018 and had beating heart repair with normothermic-normokalemic (37°C, 4.5mmol/L) cardiopulmonary bypass (CPB) without aortic cross-clamp. Patients above 18 years of age were enrolled. All patients with ASD size of smaller than 2 cm, those with associated cardiac anomalies, with accompanying co-morbidities, and age more than 65 years were excluded. Patients were classified as per New York Heart Association (NYHA) criteria.

Under general anesthesia, patients were operated on

through median sternotomy and aortic and bicaval cannulation for cardiopulmonary bypass (CPB). A high-pressure aortic root suction vent through a 16 Fr cardioplegic cannula with suction pressure of around 75 mmHg together with Trendelenburg position was maintained throughout the procedure to prevent any air embolism. A hematocrit of around 30%, a Pump flow rate at 2.5 L/min/m², and a mean arterial pressure above 80 mmHg were maintained throughout the procedure. The right atrium was opened and a septal defect was identified and delineated. Repair of ASD in all was done using a pericardial patch. The suture material used for patch repair was 4-0 prolene. Lateral atriotomy was repaired using 3-0 prolene. Myocardial oxygen extraction was calculated by taking blood samples from the aortic root and simultaneously from the coronary sinus ten minutes (10 min) after the commencement of cardiopulmonary bypass. The oxygen content of the arterial and coronary sinus blood samples was calculated by using equation:^[12]

$$\text{Oxygen content} = (1.36 \times \text{Hb}) \times (\text{SaO}_2) (0.0031 \times \text{Pao}_2).$$

$$[\text{CaO}_2 / \text{CvO}_2] \quad 100$$

Where

1.36 = is the amount of oxygen (ml at 1 atmosphere) bound per gram of hemoglobin.

0.0031 = represents the amount of oxygen dissolved in plasma

SaO₂ = Oxygen saturation of blood sample

Pao₂ = Partial pressure of oxygen in the blood sample

CaO₂ = oxygen content of aortic root blood and

CvO₂ = oxygen content of coronary sinus blood

Once Oxygen content was determined, myocardial oxygen extraction was calculated using the formula.^[12]

$$\frac{\text{CaO}_2 - \text{CvO}_2}{\text{CaO}_2} \times 100$$

$$\text{CaO}_2$$

Patients were shifted to the intensive care unit and electively ventilated. The time to extubation of all patients was recorded. All Patients were put on low dose aspirin (75mg) for six months post-operatively starting from day two of surgery. Echocardiography was done in all patients at 3 monthly intervals and echocardiographic parameters at one

year postoperatively were studied to determine cardiac performance. A standard written informed consent and Institutional Ethical Committee clearance were taken at the conception of the study.

Statistical analysis

Statistical analysis was performed to detect significant differences between measured variables. Continuous variables were expressed as mean $\pm$ standard deviation. Categorical variables expressed as percentages were rounded off to the nearest whole number and analyzed using Fisher's exact test. A p-value less than 0.05 was considered statistically significant.

RESULTS

There were 84 females (60%) and 56 males (40%) with a female: male ratio of 1.5. The mean age of patients was 42 ± 4.2 with a range of 18–65 years.

Preoperatively 40 (29%) patients were in class I, 42 (30%) in class II, 31 (32%) in Class III and 27 (19%) patients in class IV NYHA group. The mean age of each functional class is shown in **Table 1**. Closure of the defect led to most of the patients being classified in a lower NYHA functional class owing to relief in symptoms. Postoperatively, there were 82 (58%) in class I, 33 (24%) in class II, 15 (11%) in Class III, and 10 (7%) patients in the class IV NYHA group. The mean age of each functional class is shown in **Table 1**. Since the class I patients was classified as having only ASD but no clinical symptoms or disability, migration to NYHA class I was considered the endpoint of the study. Thus 100 patients from NYHA class II, III, and IV were considered to have migrated from higher class to lower NYHA class. The overall functional class improvement was thus 73% **Table 2**. Of all patients who reported functional class improvement, 56% improved by one functional class, 15% by two functional classes, and 2% by three functional classes. **Table 2**. Functional class improvement was 37% from NYHA class IV to III, 18.5% from IV to II, 7.4% from IV to I, 51.6% from III to II, 30.2% from III to I, and 71.1% from II to I after one year of follow up of each patient. **Table 3**

Overall myocardial oxygen extraction ranged from 9 vol% to 14 vol% with a mean of 12.4 ± 3.1 vol% in the study group. Taking 12 vol% as the normal myocardial oxygen extraction in a resting beating heart, we compared it with the

overall mean myocardial extraction in the study group using statistical analysis and did not observe any significant difference ($p=0.432$). The same was true when myocardial oxygen extraction of patients in each NYHA functional class was compared with one another. **Table 4**.

DISCUSSION

The preservation of the myocardium during cardiac operations has undergone a sea change. Despite this, some degree of myocardial ischemia still occurs leading to perioperative adverse effects. Though the use of continuous warm blood cardioplegia helps maintain the heart in an aerobic state, cardioplegic techniques may still cause postoperative myocardial stunning and edema intrinsic to the diastolic state of the arrested heart^[14,15] thus inevitably producing some degree of reperfusion injury. In contrast, keeping the heart beating results in less myocardial edema and better cardiac function^[14]. Cardiac surgery on the beating heart offers a safe alternative in comparison to cardioplegic arrest for noncomplex cardiac anomalies. Cardiopulmonary bypass time and its duration and aortic cross-clamp time account for most of the postoperative adverse effects. Beating heart surgery significantly lowers the cardiopulmonary bypass and aortic cross-clamp time^[16]. Though many studies have shown that closure of ASD significantly improves functional class especially in symptomatic patients and those with right ventricular failure^[17,18,19], a review study however reported that with isolated secundum ASD, the NYHA class was unchanged in 75% of patients, while others are improved or worsened^[20] over a long period of followup. Our study however reported a far greater percentage of patients who showed acceptable functional class improvement, amounting to 73%. 27% of patients in our study continued in their functional class after one year of follow-up. **Table 2 & 3**.

The amount of oxygen consumed by the myocardium is less than the amount delivered by the coronary flow. Oxygen extraction of the heart is relatively high when compared with the rest of the organ systems of the body. Myocardial oxygen extraction during rest is approximately 60% to 70% of total coronary oxygen content and remains stable over a wide range of work loads^[10]. Measured in volume percent (vol% = ml O₂ /100ml of blood), theoretically, maximal

myocardial oxygen that can be extracted is about 20 vol% a value never achieved in reality as it remains around 15-16 vol% because of the kinetics of oxygen dissociation from hemoglobin^[12]. Typically however myocardial O₂ extraction is 10–12 (vol%) in a normal beating heart at rest. In our study, the mean myocardial oxygen extraction during beating heart repair of ASD in all patients taken together was 12.4 ± 3.1 , which was comparable to the value we set as normal for our subjects. e 12vol% conforming to a value of

p=0.432 which was not significant.

We conclude preoperative NYHA functional class does not have any effect on myocardial oxygen extraction and patients who have high NYHA functional can safely be operated on a beating heart in selected circumstances. The procedure does not put any additional strain on the cardiac muscle and helps in better functional recovery in the postoperative period.

Table 1: Preoperative and Postoperative Functional Characteristics.

S.No	Preoperative functional class	N=140	
		n (%)	Mean Age
1	I	40 (29%)	38.3± 0.2
2	II	42 (30%)	36.2± 3.5
3	III	31 (22%)	40.6± 2.2
4	IV	27 (19%)	50.1± 0.4
Postoperative functional class			
1	I	82 (58%)	45.3 ± 1.2
2	II	33 (24%)	39.2 ± 2.5
3	III	15 (11%)	45.6 ± 2.2
4	IV	10 (7%)	55.1 ± 1.4

Table 2: Overall Class Migration Of Patients From Higher NYHA To Lower Class.

		N=100	
1. No. of class migrations		n	(%)
a.	One class	56	56%
b.	Two class	15	15%
c.	Three class	2	2%
2. Overall class improvement		73	73%

Table 3: Class wise improvement in functional class

Class wise improvement	No. of patients in the higher group who migrated to the lower group	Total No. of patients in higher group	Percentage of the patient who migrated
a. IV to III	10	27	37%
b. IV to II	5	27	8.5%
c. IV to I	2	27	7.4%
d. III to II	16	31	51.6%
e. III to I	10	31	30.2%
f. II to I	30	40	71.1%

Table 4: NYHA Class Wise Myocardial O₂ Extraction compared to Normal Beating Heart At Rest (12vol%)

S.No	Preoperative functional class	No.of patients in each class	Age in years mean± SD	Myocardial O ₂ Extraction in volume% mean± SD	p-value
1	I	40	38.3 ± 0.2	13.2 ± 3.5	<0.225
2	II	42	36.2 ± 3.5	12.6 ± 3.2	< 0.242
3	III	31	40.6 ± 2.2	10.2± 1.7	< 0.112
4	IV	27	50.1 ± 0.4	9.8± 1.1	< 0.313
Over all in study group N=140		140	42 ± 4.2	12.4 ± 3.1	< 0.432

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