

# Myocardial performance index after surgical correction of ventricular septal defects

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## Abstract

**Introduction:** The myocardial performance index (MPI) has been described as a non-invasive Doppler measurement of ventricular function. The aim of this study was to assess MPI following surgical correction of ventricular septal defect (VSD) and to evaluate its impact on postoperative recovery.

**Material and methods:** This is a prospective study involving 30 children (16 girls and 14 boys) operated on for VSD (group I). The control group (group II) consisted of 30 healthy children (age and sex matched).

**Results:** We found that both the right and left ventricular (RV and LV) MPI correlated significantly with the ejection fraction (EF) ( $r = -0.49$ ,  $p = 0.006$ ,  $r = -0.51$ ,  $p = 0.004$ , respectively). The LV EF and the LV FS were negatively correlated, while the left and right ventricular MPI was positively correlated with the: LVEDD ( $p = 0.000$ ), the VSD size ( $p = 0.000$ ), and the postoperative course of the patients in terms of the duration of ventilation ( $p = 0.000$ ), the duration of use of inotropics ( $p = 0.000$ ) and the duration of staying in the ICU ( $p = 0.000$ ). By linear regression, the factors that correlated with the postoperative course of VSD surgery were the RV MPI pre-surgery, MPI 2 days after surgery and the ejection fraction ( $p = 0.000$ ).

**Conclusions:** Myocardial performance index is a useful index for measurement of the left and right ventricular function. It correlates significantly with the ejection fraction, fractional shortening, VSD size, and the left ventricular size. It also significantly predicts the outcome of VSD surgery.

**Key words:** myocardial performance index, ventricular septal defect.

## Introduction

Numerous studies have shown that systolic and diastolic time intervals are closely linked to systolic and diastolic left ventricular performance. Although individual time intervals of the cardiac cycle can be easily obtained from Doppler velocity profiles as measurements of cardiac function, heart rate and load dependency have limited their clinical use [1-3]. Tei *et al.* [4] proposed a Doppler-derived index that is known as the myocardial performance index (MPI) for assessment of overall left ventricular function that combines systolic and diastolic time intervals. This index is defined as the sum of the isovolumetric contraction time and the isovolumetric relaxation time divided by the ejection time [5-8]. In previous studies, the index has been found to be reproducible, easily obtainable and to correlate closely with invasive measures of both systolic and diastolic function, being independent of heart rate and left ventricular

geometry. The myocardial performance index is potentially applicable not only to the evaluation of global left ventricular function but also to the evaluation of right ventricular function [9]. Quantitative assessment of ventricular function in patients with congenital heart disease is often challenging due to distorted ventricular geometry. The myocardial performance index has been reported in adults and children as a Doppler-derived non-geometric measure of ventricular function.

Precise assessment and monitoring of myocardial performance are necessary to make appropriate therapeutic decisions in the postoperative period. An evaluation of both systolic and diastolic performance of either right or left ventricle is mandatory. The majority of children treated surgically present more or less pronounced symptoms of heart failure [10]. The form and severity of cardiac defect, injury caused by surgical trauma itself and by employment of cardiopulmonary bypass as well as dynamic changes of the haemodynamic conditions following surgical repair contribute to the postoperative changes of myocardial function [11].

The use of an extra-corporeal circulation system results in a systemic as well as local inflammatory response [12]. It has been suggested that the severity of the inflammatory processes and associated risk of heart failure development in the postoperative period correlate with previous myocardial remodelling [13]. Haemodynamic changes related to the cardiac defect induce mechanisms that enable sufficient cardiac performance under the circumstances of the pathological loading [14]. Subsequently, the myocardium undergoes remodelling [15]. In the remodelled myocardium, in addition to changes detected at either organ or tissue level, there are molecular changes that lead to increased cellular vulnerability to oxidative stress [16]. Such stress is produced by ischaemia, followed by reperfusion during the cardiopulmonary bypass [17].

The aim of the work was assessing the myocardial performance index following surgical correction of congenital ventricular septal defects and to evaluate its impact on postoperative recovery.

## Material and methods

### Studied groups

This prospective study involved 30 children (16 girls and 14 boys) operated on for simple ventricular septal defect (VSD) (group I). The mean age of the studied children was 24.5 ( $\pm 2.29$ ) months and they were recruited from the Paediatric and Cardiology Departments of the Faculty of Medicine, Cairo University. Oral consent was obtained from the parents of the children.

The control group (group II) consisted of 30 healthy children, referred for echocardiographic examination due to the presence of any cardiac murmur, history of chest pain or an abnormal ECG, who had normal echocardiographic findings. Oral consent was obtained from the parents of the children for the use of their echocardiographic data.

### Echocardiographic examination

Complete transthoracic echocardiography including M-mode, 2-dimensional and Doppler (pulsed-wave, continuous-wave and colour) measurements was performed on all enrolled patients at rest using the Sonos 5500 ultrasound system (HP Hewlett Packard), with a 5 MHz transducer for children.

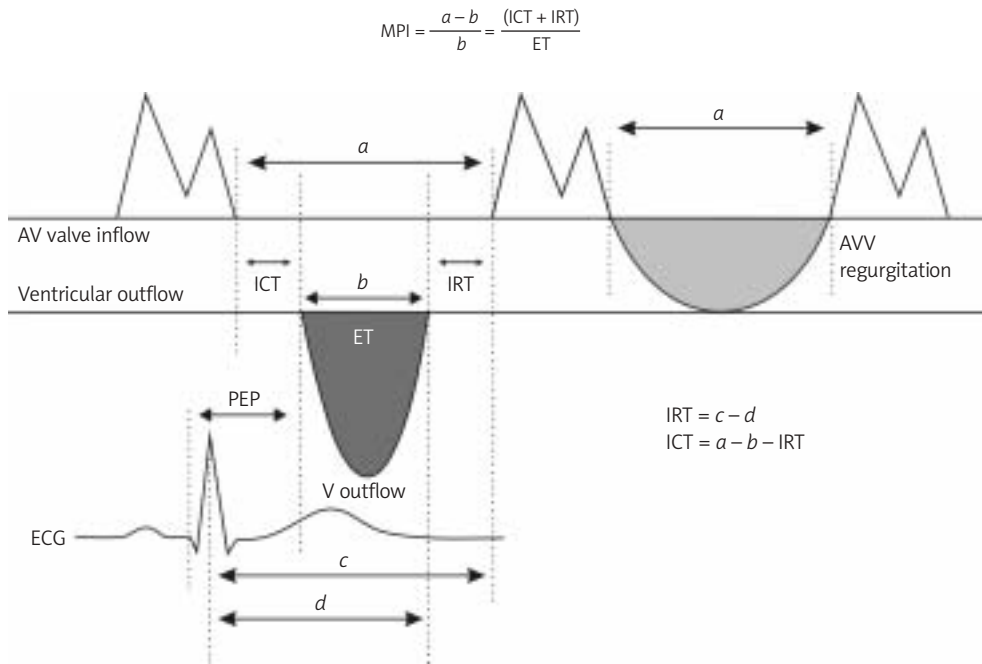
Left ventricular (LV) end-systolic, end-diastolic and left atrial dimensions were measured in the parasternal long axis and short axis views. Ejection fraction and fractional shortening of the left ventricle were estimated according to the guidelines of the American Society of Echocardiography. Global systolic function was considered abnormal if the ejection fraction was less than 55% and the fractional shortening was below 30% [18, 19].

Ventricular septal defects were identified in different windows, parasternal, subcostal and 4-chamber views where their location and size were identified. Shunt volume (restrictive or unrestricted) was detected indirectly by measuring the dimension of the left atrium and left ventricular end diastolic dimension [20].

The mitral and tricuspid inflow velocities were recorded from the apical 4-chamber view with the pulsed-wave Doppler sample volume positioned at the tips of the mitral or tricuspid leaflets, respectively, during diastole. The left ventricular outflow velocity pattern was recorded from the apical long-axis view with the Doppler sample volume positioned just below the aortic valve, and the right ventricular outflow velocity pattern was recorded from the parasternal short axis view with the Doppler sample volume positioned just below the pulmonary valve. An electrocardiogram was simultaneously recorded with a Doppler echocardiogram in all subjects.

The interval 'a' from cessation to onset of atrioventricular valve inflow is equal to the sum of isovolumetric contraction time (ICT), ejection time, and isovolumetric relaxation time (IRT). Ejection time 'b' is derived from the duration of ventricular outflow Doppler velocity profile. The sum of ICT and IRT was obtained by subtracting 'b' from 'a'. The MPI was calculated as:  $(a - b)/b$  (Figure 1) [21, 22].

The MPI was evaluated on the 2<sup>nd</sup> day, the 7<sup>th</sup> day after surgery and at the follow-up visit one month after surgery. The MPI was calculated as previously described separately for LV and RV.



**Figure 1.** The MPI is calculated from the following Doppler intervals: interval “a” represents the interval from cessation to onset of tricuspid valve inflow; interval “b” is RV ejection time (ejection time). The MPI is the ratio of the sum of ICT and IRT divided by ejection time. The ICT and IRT can be derived as shown in equations at bottom right. Duration of tricuspid valve regurgitation can be substituted for interval “a”  
 AV – atrioventricular, AVV – atrioventricular valve, ECG – electrocardiogram, V – ventricular

### Postoperative course

We also analysed the potential association between the size and severity of VSD defect, myocardial performance and postoperative course. Ventricular septal defect severity was defined based on the pressure gradient between RV and LV across the ventricular septum calculated prior to surgery.

The postoperative course was defined based on assisted ventilation time, inotropic support time and intensive care unit stay time. These parameters were correlated with the MPI value evaluated on the 2<sup>nd</sup> day after surgery.

### Results

#### Healthy children

The LV and RV dimensions, shortening fraction, PAP, LVMPI and RVMPI values in the healthy

children are outlined in Table I and their results were found to be within the normal ranges.

As regards the contractile indices we found that the ejection and fractional shortening were significantly correlated ( $r = 0.98, p = 0.000$ ); also there was a significant negative correlation between the ejection fraction and fractional shortening and the RV MPI ( $r = -0.49, p = 0.006$ ) and the LV MPI ( $r = -0.51, p = 0.004$ ).

#### Children with ventricular septal defect

The LV and RV dimensions, shortening fraction, PAP and VSD size in mm in group II are outlined in Table II.

As regards the contractile indices there was a significant negative correlation between the ejection fraction and fractional shortening in the preoperative echocardiogram and the preoperative

**Table I.** General characteristics of the control group (showing the age in months, the right and left ventricular MPI, the left ventricular end-diastolic dimensions, the fractional shortening, the size of the right ventricle and the pulmonary artery pressure)

Number 30	Age	RV MPI	LV MPI	LVEDD	FS [%]	RV [mm]	PAP
Range	20-40	31-32	32-34	2.9-3.1	28-38	1.15-1.3	21-29
Mean	32.16	0.315	0.332	3.013	32.16	1.220	25.66
Standard deviation	5.31	0.005	0.005	0.007	2.001	0.237	1.935

**Table II.** General characteristics of the patient group (showing the age in months, the left ventricular diastolic dimensions, the fractional shortening, the right ventricular size in mm, the pulmonary artery pressure and the size of the ventricular septal defect)

Number 30	Age	LVEDD	FS [%]	RV [mm]	PAP	VSD [mm]
Range	22-28	3.1-3.7	25-31	1.3-1.8	40-56	6-10
Mean	24.56	3.346	27.26	1.513	49.03	8.13
Standard deviation	2.299	0.1547	1.760	0.1357	5.027	0.937

**Table III.** The MPI values (both RV and LV) over the 1-month postoperative follow-up (days 2, 7 and after 1 month)

Number 30	RV MPI d2	RV MPI d7	RV MPI 1m	LV MPI d2	LV MPI d7	LV MPI 1m
Range	0.42-0.51	0.37-0.40	0.31-0.32	0.45-0.58	0.36-0.41	0.32-0.34
Mean	0.467	0.388	0.316	0.491	0.374	0.332
Standard deviation	0.020	0.009	0.004	0.0364	0.138	0.005

left and right ventricular MPI ( $p = 0.004$  and  $0.006$ , respectively) and the postoperative ejection fraction and fractional shortening and the postoperative right and left MPI, at 1 month follow-up ( $p = 0.004$  and  $0.005$ , respectively).

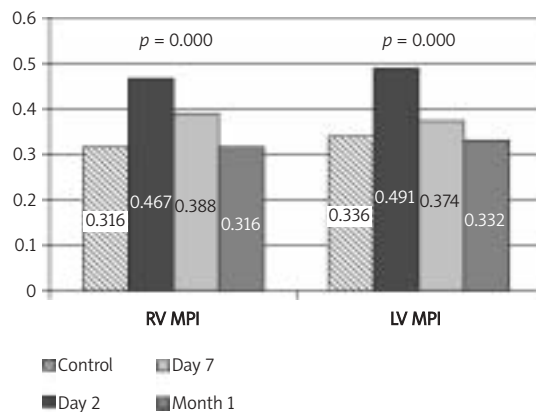
The results of sequential LV and RV MPI measurements in children operated on for VSD are listed in Table III. In children operated on for VSD, on the 2<sup>nd</sup> day after surgery a significant elevation of both RV MPI and LV MPI was observed.

Values of RV MPI and LV MPI were significantly higher in the patient group than in the control group, especially on the 2<sup>nd</sup> and 7<sup>th</sup> postoperative days ( $p = 0.000$ ). This difference disappeared at 1 month ( $p = 0.3$ ) [NS] between controls and patients 1 month post-operation, for both LV and RV MPI.

The regression of LV and RV MPI showed a significant decrease over the 1-month period (ANOVA  $p = 0.000$ ) (Figure 2).

**Correlations**

The LV EF and the LV FS were negatively correlated, while the left and right ventricular MPI



**Figure 2.** RV and LV MPI in the control group and patients' postoperative MPI over the 1-month period

was positively correlated with the: LVEDD ( $p = 0.000$ ), the VSD size ( $p = 0.000$ ), and the postoperative course of the patients in terms of the duration of ventilation ( $p = 0.000$ ), the duration of use of inotropics ( $p = 0.000$ ) and the duration of staying in the ICU ( $p = 0.000$ ) (Table IV, Figures 3-6).

By linear regression, the factors that correlated with the postoperative course of VSD, in terms of ICU admission, the duration of inotropics and the duration of ventilation, were the RV MPI pre-surgery, MPI 2 days after surgery and the ejection fraction (Figure 7).

**Discussion**

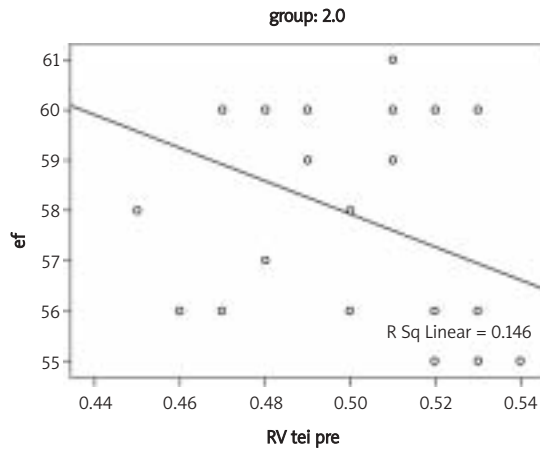
The myocardial performance index (MPI) has been described as a non-invasive Doppler measurement of ventricular function [4, 6, 8, 23, 24, 34, 35].

The MPI is a ratio between the sum of isovolumic time intervals, namely, isovolumic contraction time (ICT) and isovolumic relaxation time (IRT), and ejection time. These intervals can be easily obtained by routine Doppler techniques during a standard echocardiographic examination with excellent inter- and intra-observer reproducibility [25-28, 36].

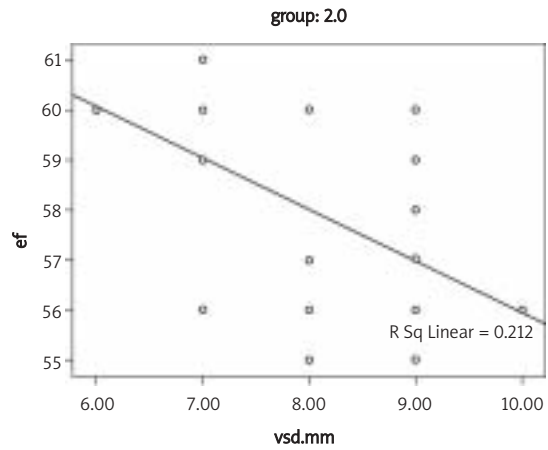
Because this index is a ratio of time intervals, it is not limited by the geometric shape of the ventricle and has been shown to be independent of heart rate [2, 8, 37]. The MPI has been shown to

**Table IV.** Postoperative course of the patient population, showing the ICU duration of stay of the patients, the duration the patients were ventilated in the ICU and the duration of inotropic infusion

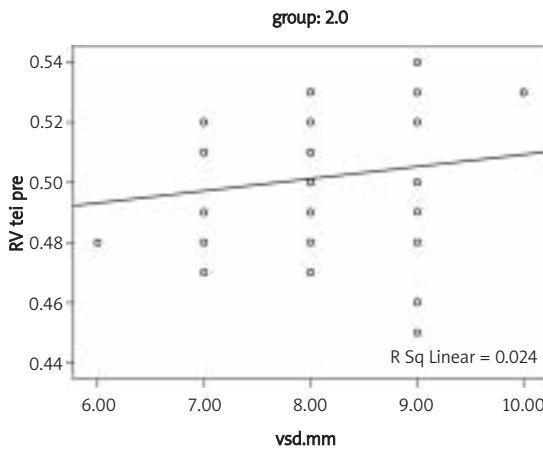
ICU stay	2.6 ±0.5 days
Duration of ventilation	5.5 ±1.1 h
Duration of inotropic infusion	2.6 ±0.5 days



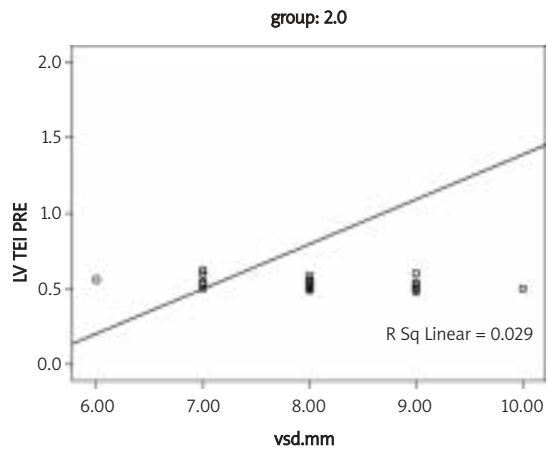
**Figure 3.** Shows the significant negative correlation between the ejection fraction and RV MPI ( $r = -0.382$ ,  $p = 0.037$ )



**Figure 4.** Significant negative correlation between the ejection fraction and VSD size ( $r = -0.776$ ,  $p = 0.000$ )



**Figure 5.** Significant positive correlation between the VSD size and RV MPI ( $r = 0.3$ ,  $p = 0.05$ )



**Figure 6.** The highly significant correlation between LV MPI and the VSD size ( $r = 0.37$ ,  $p = 0.04$ )

correlate well with other invasive and non-invasive measures of left ventricular function in adults [10, 38, 39].

In addition, studies in paediatric and adult patients have demonstrated that this index can quantitatively assess right ventricular (RV) dysfunction [27, 28, 40, 41].

In this study we found that all contractile indices, ejection fraction, fractional shortening, and both the right and left ventricular MPI are significantly correlated with the severity of the ventricular septal defect, in terms of size of the VSD and the left ventricular dimensions, and can give a good indication of the postoperative recovery of the patients after surgical closure. Thus, these indices give us a good indication about the dysfunction, in the right and left ventricles, that results from the VSD shunt.

By linear regression we also found that the RV MPI (preoperative and immediately after surgery) and the ejection fraction are the factors that most

significantly affect the postoperative course of surgery for VSD. This is an important finding, since estimation of RV function by traditional methods is hampered by its geometric shape. Thus, using this method, early identification of RV dysfunction can be made.

The duration of postoperative ICU stays places a considerable burden on the resources of the institution. Nonetheless, despite the magnitude of the problem of the long stay in children after cardiac surgery, a detailed assessment of the specific factors that predict and necessitate prolonged intensive care stay after surgery for heart disease in children is lacking.

This study indicates that RV and LV MPI following closure of ventricular septal defects impacts upon recovery time. It follows, therefore, that perioperative assessment of MPI correlates with recovery time and that consideration of this measurement in conjunction with the intended

operative procedure before scheduling operations may facilitate bed turnover. When ICU bed availability is an issue, children with complex chronic medical conditions including those with abnormal MPI should be electively scheduled for surgery in a series rather than parallel.

Cardiac output is a commonly used parameter in the postoperative period. However, preload, afterload, myocardial contractility and heart rate all affect this index; thus its value in the assessment of functional status of the myocardium is very limited. Theoretically MPI meets the criteria of a method capable of adequately evaluating myocardial performance.

In the examined group of healthy children, the small deviation of the results and particularly the narrow range of the MPI value confidence interval and the high level of consistency with data found in the literature confirm that the control group adequately reflected population data [32].

In the case of almost equal pressures in both cardiac ventricles, the RV is exposed to a significant pressure overload that induces hypertrophy and remodelling of the myocardium [33, 42].

Such a ventricle becomes particularly vulnerable to injuries related to the cardiopulmonary bypass. It leads to RV dysfunction disclosed by increased RV MPI. Postoperative course (catecholamine administration time, intubation time as well as ICU stay) correlated significantly with the index value calculated on the 2<sup>nd</sup> day following surgery. The standard parameters of cardiac output were poor predictors of the postoperative course in our study.

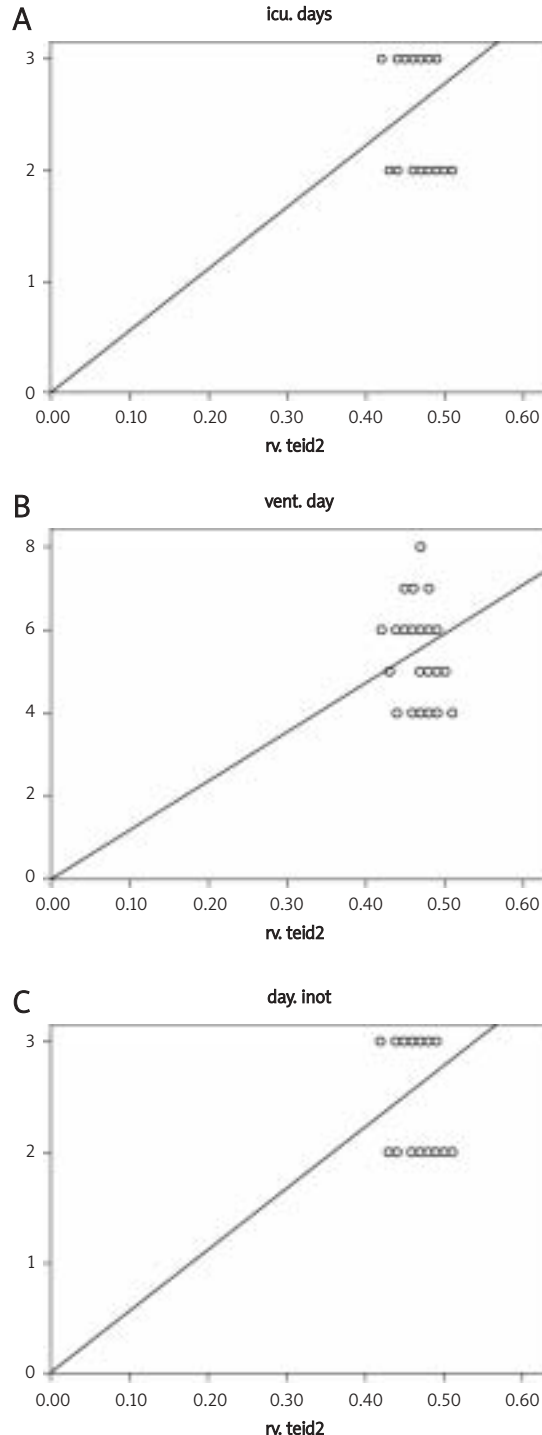
This study documented the high usefulness of MPI measurements for the assessment of ventricular function, especially that of RV, which, if decreased, often leads to serious clinical problems in the postoperative period.

In conclusion, MPI is a useful index for measurement of the left and right ventricular function. It correlates significantly with the ejection fraction, fractional shortening, VSD size, and the left ventricular size. The right and left ventricular MPI values are significantly elevated immediately post-closure of the VSD, and over a 1-month period they normalize to be comparable with the values of the control group. The RV preoperative MPI and the immediate postoperative MPI also significantly correlate with the postoperative course of the surgery and are strongly correlated with the duration of ICU stay, the duration of ventilation and the duration of inotropic use.

### Limitations

The lack of surgical data, intraoperatively, was a limitation of the study and in itself could have affected the postoperative recovery. Larger scale

trials with a larger number of patients will be needed to fully validate our trial.



**Figure 7.** Linear regression analysis showing a significant correlation ( $p = 0.000$ ) between RV MPI 2 days after surgery and the postoperative course of VSD surgery in terms of days of ICU admission, duration of ventilation and duration of inotropic administration (A, B and C, respectively)

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