The myocardial performance index in children after surgical correction of congenital malformations with intracardiac shunt

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Abstract

Background: The lack of a simple and clinically useful method of myocardial function assessment makes it difficult to monitor patients after repair of congenital cardiac malformations. The myocardial performance index (MPI) introduced in 1995 by Chuwa Tei may help to precisely follow the course of postoperative myocardial function disturbances.

Aim: To assess the usefulness of MPI for cardiac function evaluation following surgical correction of congenital defects performed in cardiopulmonary bypass and to evaluate it's prognostic value.

Methods: This prospective study involved 73 children who underwent surgery for simple defects with intracardiac shunt – 34 children with atrial septal defect (ASD) and 39 with ventricular septal defect (VSD). In the examined patient group, MPI and the parameters of cardiac index were measured in the early postoperative period. Then the results were correlated with congenital defect severity and postoperative course. The control group consisted of 77 healthy children.

Results: In the control group of healthy children, mean values of the right (RVMPI) and the left ventricular MPI (LVMPI) were 0.32±0.06 and 0.33±0.05, respectively. In children after ASD correction, MPI was elevated only for the right ventricle (mean value of 0.41±0.07). Meanwhile in children operated on for VSD, both the RVMPI and LVMPI values increased postoperatively. RVMPI reached a peak value on the 2nd postoperative day (0.48±0.20) while LVMPI reached a peak value between the 3rd and 5th day after surgery (0.49±0.10). A significant and strong correlation between severity of VSD and MPI values was observed. A marked correlation between MPI calculated on the 1st postoperative day and the course after surgery was also noted.

Conclusions: The MPI is a precise tool assessing both systolic and diastolic ventricular performance in the early postoperative period following surgical correction of a congenital defect with intracardiac shunt and is also a useful predictive factor of the postoperative course.

Key words: congenital malformations with intracardiac shunt, evaluation of myocardial performance, postoperative course, MPI, Tei Index

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Introduction

Despite significant developments in paediatric cardiac surgery in recent years, the search for methods of outcome improvement after surgical correction of congenital cardiac malformations continues. Progress in this area depends mainly on the quality of postoperative care. The problems of key importance are associated with changes of myocardial function [1, 2]. The majority of children treated surgically present less or more pronounced symptoms of heart failure [3]. 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 [4].

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The use of an extracorporeal circulation system results in a systemic as well as local inflammatory response [5]. 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 [6]. Haemodynamic changes related to the cardiac defect induce mechanisms that enable sufficient cardiac performance under the circumstances of the pathologic loading [7]. Subsequently, the myocardium undergoes remodelling [8]. 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 [9]. Such stress is produced by ischaemia, followed by reperfusion during the cardiopulmonary bypass [10].

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 (RV) or left ventricle (LV) is mandatory. A clinically useful index should be as much as possible independent of *preload, afterload* and heart rate variability [11]. Echocardiographic methods used previously have numerous limitations concerning particularly the assessment of myocardial diastolic function [12]. Moreover, the change of ventricular shape often observed in hearts with congenital malformations and lack of methods that enable qualitative evaluation of RV performance additionally make the detailed assessment of myocardial function difficult [13, 14].

Introduced by Chuwa Tei in 1995, the myocardial performance index (MPI) may add additional, valuable information to that obtained by standard echocardiographic measurements [15, 16]. The MPI is defined as the sum of contraction and relaxation isovolumetric times divided by ejection time. This easily measurable, sensitive, repetitive and heart rate-independent index allows a comprehensive evaluation of both systolic and diastolic function of either RV or LV [17]. In the literature, the advantage of cardiac function assessment with the MPI over conventional examinations and its significant predictive value are emphasised [18-20]. However, no reports have been published on postoperative myocardial monitoring using this index in patients with congenital cardiac malformations.

The purpose of this study was to evaluate myocardial performance in the early postoperative period using the MPI index, then to compare this method with conventional echocardiographic measurements of cardiac function. Moreover, we also examined whether the absolute values of this index calculated on the 1st day after surgery have any predictive value for postoperative outcome.

Methods

Studied group

This prospective study involved 73 children operated on for simple, congenital defects with intracardiac shunt. The control group consisted of 77 healthy children, referred for echocardiographic examination due to the presence of any cardiac murmour, history of chest pain or an incomplete right bundle branch block in ECG who had normal echocardiographic examination.

Atrial septal defect – (ASD). Thirty-four children with ASD were operated on (19 girls and 15 boys), including 24 cases of ASD II, 2 children with sinus venosus superior ASD form, 5 children with intermediate atrioventricular septal defect and 3 children with partial atrioventricular septal defect. Mean age of the children was 36.0±43.3 months, median 12.5 months, and ranged from 5 to 146 months.

Ventricular septal defect – (VSD). Thirty-nine operated children had VSD (18 girls and 21 boys). Mean age of the studied children was 24.6 (±46.4) months, median 5 months, and ranged from 0.5 to 168 months.

Echocardiographic examination

MPI index. The MPI was evaluated on the 1st day after surgery, followed by several once daily measurements during next week. The measurements on the 2nd and 7th days were performed in almost all cases. Finally children were examined at 1-month follow-up visit.

The MPI was calculated separately for LV and RV as the sum of isovolumetric contraction (ICT) and relaxation (IRT) times divided by ejection time (ET) (Figure 1). Each time the measurements were taken from 5 heart cycles, then their results were averaged. Time intervals necessary for index calculation were measured based on Doppler flow both through atrioventricular valves and in LV and RV outflow tracts.

Other echocardiographic parameters. Besides MPI, systolic volume, cardiac output, and their derivates such as stroke volume index and cardiac index, were calculated.

Other measurements

We also analysed the potential association between the type of cardiac malformation (in the case of VSD also its severity) as well as intraoperative factors, such as aortic cross-clamping time and aortic cross-clamping time to reperfusion time ratio, and myocardial performance.

In children with VSD, severity of cardiac defect was defined based on the pressure gradient between RV and LV across the ventricular septum calculated prior to surgery. Additionally, the size of the defect as assessed by the cardiac surgeon during the operation, was taken into account.

The postoperative course was defined based on assisted ventilation time, inotropic support time and intensive care unit stay time. These parameters were correlated with MPI value evaluated on the 1st day after surgery.

Statistical analysis

The results are presented as mean ± standard deviation or median. The 95% confidence intervals (CI) are also presented.

To assess the significance of the differences between variables, non-parametric tests were used because they did not follow a normal distribution pattern, as assessed by the Kolmogorov-Smirnov Z test with Lilliefor's correction and by Shapiro-Wilk test. To compare two sets of variables, the Mann-Whitney U test was employed while if more than two series were analysed, ANOVA Kruskal-Wallis test was used. Wilcoxon rank pair and Kolmogorov-Smirnov tests were used to compare two variables. Correlations between variables were tested using the correlation Spearman's rank test. A p value <0.05 was considered significant.

Results

Healthy children

The LVMPI and RVMPI values and their confidence intervals in the healthy children are outlined in Table I. Additionally, the shortening fraction and ejection fraction were evaluated in the control group and their results were found to be within the normal ranges.

Children with ASD

The values of LVMPI and RVMPI in children operated on for ASD are presented in Table II. In the group of children operated on for ASD, RVMPI was significantly higher on the 1st postoperative day versus the control group (p <0.0001). In the following days, the index gradually decreased to reach normal values and at the final follow-up examination it did not differ significantly from that in healthy children (Figure 2).

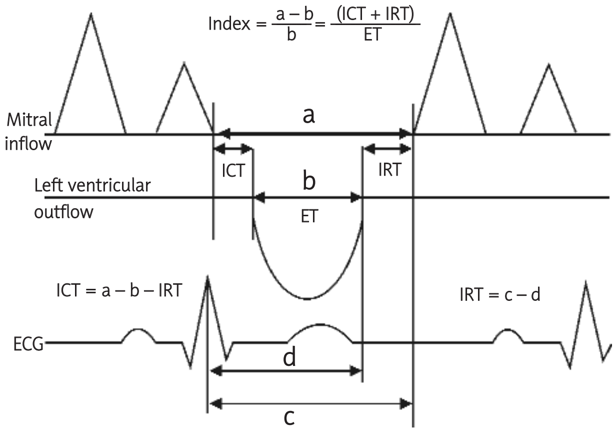

Figure 1. MPI calculation according to the Tei method

Abbreviations: ICT – isovolumetric contraction time, IRT – isovolumetric relaxation time, ET – ejection time. Segment a – period between closure and opening of either mitral or tricuspid valve. Segment b – period from onset to completion of either left or right ventricle systolic ejection

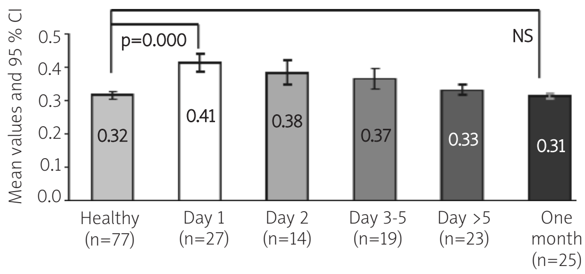

Figure 2. Children operated on for ASD – mean values and 95% CI of RVMPI on consecutive days after the surgical correction are given

Table I. Right ventricular MPI (RVMPI) and left ventricular MPI (RVMPI) in the group of healthy children

N=77	RVMPI	LVMPI
Mean	0.32	0.33
±2 SD	0.11	0.10
Median	0.31	0.33
95% CI	0.30-0.33	0.32-0.34

Table II. Mean values of MPI in children operated on for ASD

	Day 1, n=27	Day 2, n=14	Day 3-5, n=19	> Day 5, n=23	One month, n=25
RVMPI	0.41±0.07	0.38±0.06	0.37±0.07	0.33±0.03	0.31±0.02
LVMPI	0.33±0.05	0.32±0.05	0.35±0.05	0.36±0.16	0.33±0.03

Table III. Mean values of MPI index in children operated on for VSD

	Day 1, n=27	Day 2, n=14	Day 3-5, n=19	> Day 5, n=23	One month, n=25
RVMPI	0.45±0.14	0.48±0.20	0.44±0.10	0.40±0.10	0.33±0.04
LVMPI	0.46±0.10	0.46±0.13	0.49±0.10	0.41±0.10	0.34±0.04

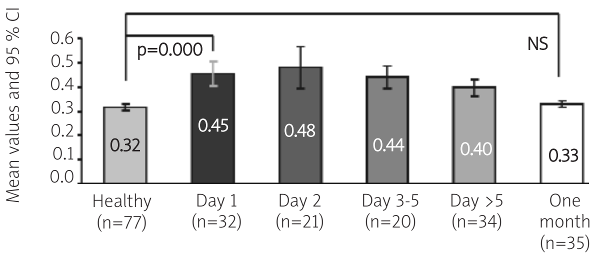

Figure 3. Children operated on for VSD – mean values and 95% CI of RVMPI on consecutive days after the surgical repair are given

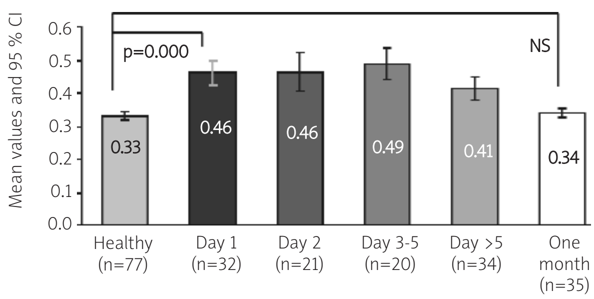

Figure 4. Children operated on for VSD – mean values and 95% CI of LVMPI on consecutive days after the surgical correction are given

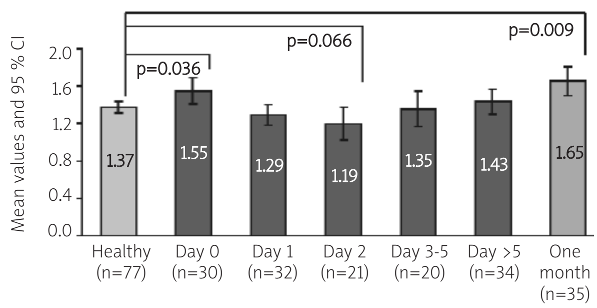

Figure 5. Changes of stroke volume index in the postoperative period in children with VSD. Mean values and 95% CI are given

In the follow-up, both in the early postoperative period and at the final examination, LVMPI did not differ significantly from the control group.

The stroke volume index and cardiac index did not change in the postoperative period and did not differ significantly from healthy children. These parameters did not correlate with RVMPI values evaluated at the same time points (p=0.2914, r=0.186 and p=0.2378, r=0.208, respectively, NS). No significant correlation between MPI and the postoperative course parameters was also observed.

Children with VSD

The results of MPI measurements in children operated on for VSD are listed in Table III. In children operated on for VSD, on the 1st day after surgical correction of congenital malformation a significant elevation of both RVMPI and LVMPI was observed (p=0.0000) (Figures 3 and 4).

Values of RVMPI were significantly higher than in the control group and reached their peak on the 2nd postoperative day and gradually decreased thereafter. On the day of the final follow-up examination they did not differ significantly from the values in healthy children (Figure 3).

Similar course was shown for LVMPI in children after VSD surgical repair, although the peak was reached slightly later, i.e. on the 3rd to 5th day after the operation (Figure 4).

Stroke volume index reached minimum values on the 2nd postoperative day and gradually decreased thereafter. On the final follow-up examination day, it was significantly higher than in the group of healthy children (p=0.0009) (Figure 5).

Cardiac index in children after surgical correction did not differ from the healthy subjects at any time of the follow-up.

A significant correlation between both RVMPI and LVMPI values, measured on the 1st postoperative day and the size of the defect, was observed (Figure 6). A similar strong and significant negative correlation between LV/RV preoperative gradient and either LVMPI or particularly RVMPI was shown (p=0.0122, r= –0.398 and p=0.0000, r= –0.642, respectively).

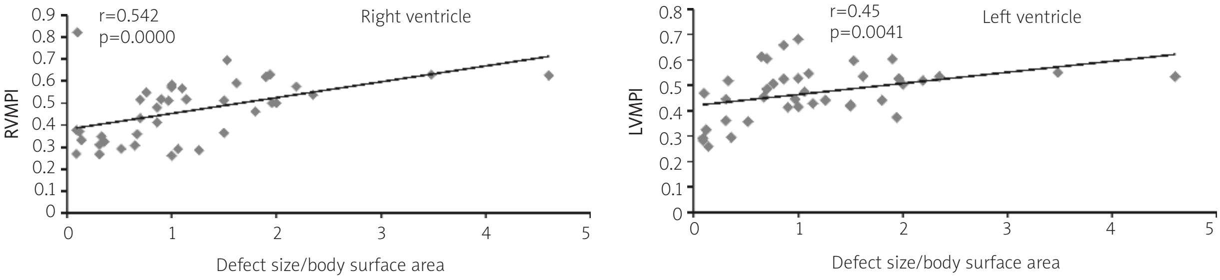

Figure 6. Children operated on for VSD – correlation between severity of congenital malformation (defined as defect size corrected for body surface area) and RVMPI and LVMPI calculated on the 1st day after the surgery are presented

The intraoperative parameters (such as cross-clamping and reperfusion times) did not show any correlations with LVMPI or RVMPI.

The RVMPI and LVMPI values measured on the 1st postoperative day significantly and strongly correlated with the parameters of postoperative course. The strongest relationship was shown between RVMPI and catecholamine infusion time (Figure 7). Also, a significant correlation was shown between RVMPI and intubation time (p=0.0003, r=0.545) as well as between LVMPI and either intubation or ICU stay (p=0.0011, r=0.503 or p=0.0064, r=0.429, respectively).

Referring mean values of echocardiographic parameters calculated on the subsequent days of the follow-up to the values obtained in the group of healthy children allowed their dynamics in the postoperative period to be followed (Figure 8).

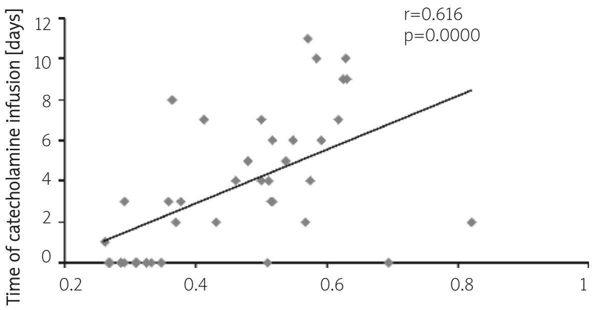

Figure 7. Children operated on for VSD – relationship of the RVMPI to the time of catecholamine infusion

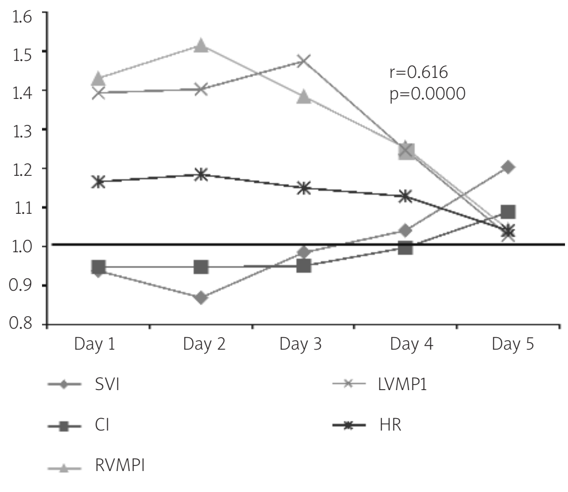

Figure 8. Changes of the relative values of the echocardiographic parameters and heart rate in the postoperative period in children operated on for VSD. Value 1 – control group of healthy children for a given parameter

Abbreviations: SVI – stroke volume index, CI – cardiac index, RVMPI – right ventricular MPI, LVMPI – left ventricular MPI, HR – heart rate

Discussion

Examinations evaluating myocardial performance directly after operation, evolution of its function during the recovery period and the time necessary to reach complete recovery are of limited value. 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 to adequately evaluate myocardial performance. However, no population-based normal ranges have been identified nor its distribution in the course of a variety of diseases studied.

In the examined group of healthy children, the small deviation of the results and particularly narrow range of 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 [14].

In the children operated on for ASD, postoperative dysfunction involved only RV. Left ventricular performance (evaluated by LVMPI) exposed to the same degree of surgical stress remained unchanged. The comparison of RVMPI and LVMPI values changes justifies the conclusion that ASD surgery itself does not alters previously normal LV myocardium. Postoperative myocardial dysfunction involved only the areas that underwent remodelling before as a result of the primary haemodynamic changes. In spite of increased RVMPI, postoperative patient course was usually uneventful. No significant correlations between elevated RVMPI values and the normal parameters of cardiac output were observed. This could mean that MPI provides another form of information and reveals subclinical injury to the RV myocardium that does not have a significant impact on cardiac output.

In the children operated on for VSD, measurement of MPI is an indicator of RV and LV dysfunction. The MPI values, particularly RVMPI, were shown to be strongly correlated with congenital defect severity defined as the magnitude of interventricular gradient and size of the defect. Larger defects (i.e. lower gradient across the septum) produced more pronounced impairment of the RV myocardial function.

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 [10]. Such a ventricle becomes particularly vulnerable to injuries related to the cardiopulmonary bypass. It leads to RV dysfunction disclosed by increased RVMPI.

The examined parameters did not show any relationship with intraoperative parameters. Postoperative course (catecholamine administration time, intubation time as well as ICU stay) correlated significantly with the index value calculated on the 1st day following surgery. The strongest association was found between RVMPI values and catecholamine infusion time. Decreased diastolic compliance of RV affected by previous remodelling leads to a drop in venous return and may become the predominant cause of decreased cardiac output. Inotropic drugs administered in this condition do not cause the desired haemodynamic effect and often are used too long. The standard parameters of cardiac output were poor predictors of the postoperative course in our study.

A typical sequence of MPI changes was observed in the postoperative period in children operated on for VSD, including heart failure, recovery and hyperkinetic phase (Figure 8). In the heart failure phase, elevated MPI values were accompanied by decreased stroke volume. At the same time, the cardiac index remained normal, which was likely a result of a compensatory increase in heart rate. In the hyperkinetic phase, stroke volume reached values significantly higher than in the healthy children, together with normalisation of MPI. The most likely explanation of the observed phenomenon was fast healing of the inflammatory postoperative foci in LV, which, in the presence of persistent LV hypertrophy, leads to the development of hyperkinesia.

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. It is of importance if we realise the very limited value of conventional echocardiographic methods to quantify RV performance [21].

It should be emphasised that in the two largest medical databases worldwide (MEDLINE and EMBASE; March 2006) no reports on use of MPI as a tool of early postoperative clinical assessment in children with congenital cardiac malformations were found.

Conclusions

1. The MPI index in children with selected congenital defects with intracardiac shunt is useful for the assessment of myocardial performance in the early postoperative period following surgical correction using cardiopulmonary bypass. It enables precise assessment of both right and left ventricular systolic and diastolic function.
2. In children operated on for ASD, postoperative dysfunction involves only the right ventricle.
3. Right ventricular MPI in children with ASD is a sensitive parameter of functional assessment that may disclose even subclinical injury not compromising cardiac index.
4. In children operated on for VSD, the calculations of MPI revealed both right and left ventricular dysfunction.
5. Impaired myocardial function noted after the surgery involves particularly those areas of cardiac muscle parts that underwent previous remodelling induced by primary haemodynamic changes.
6. Cardiopulmonary bypass and surgical procedures only slightly affected normal myocardium.
7. Measurement of MPI provides more useful postoperative information than that derived from standard echocardiographic methods of cardiac function assessment.
8. Right and left ventricular MPI indices calculated on the first day after surgery in children with VSD

showed strong correlation with the postoperative course.

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Wskaźnik sprawności mięśnia serca u dzieci po korekcjach przeciekowych wad serca

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Streszczenie

Wstęp: Brak prostej i klinicznie użytecznej metody oceny stanu mięśnia serca w znacznym stopniu utrudnia monitorowanie chorych po korekcjach wad wrodzonych. Nadzieję na precyzyjne śledzenie zaburzeń czynności mięśnia serca wniosło wprowadzenie przez Chuwa Tei w 1995 r. wskaźnika sprawności mięśnia serca – MPI.

Cel: Zbadanie przydatności wskaźnika MPI do oceny stanu serca po korekcjach wad wrodzonych z użyciem krążenia pozaustrojowego.

Metodyka: Badaniem prospektywnym objęto 73 dzieci leczonych operacyjnie z powodu prostych, przeciekowych wad serca (34 dzieci z ubytkiem w przegrodzie międzyprzedsionkowej – ASD i 39 z ubytkiem w przegrodzie międzykomorowej – VSD). W badanych grupach dokonano pomiarów wskaźnika MPI i parametrów rzutu serca we wczesnym okresie pooperacyjnym. Wyniki skorelowano z ciężkością wady i przebiegiem pooperacyjnym. Grupę odniesienia stanowiło 77 zdrowych dzieci.

Wyniki: Średnie wartości (SD) MPI dla prawej komory (RVMPI) i MPI dla lewej komory (LVMPI) w grupie odniesienia wynosiły odpowiednio 0,32±0,06 i 0,33±0,05. U dzieci po korekcji ASD wskaźnik MPI był istotnie podwyższony tylko dla komory prawej (wartość średnia 0,41±0,07). U dzieci po zabiegu z powodu VSD wskaźnik MPI był istotnie podwyższony zarówno dla prawej, jak i lewej komory. Najwyższe wartości wskaźnik RVMPI osiągał w 2. dobie po operacji (0,48±0,20), a wskaźnik LVMPI między 3. a 5. dobą (0,49±0,10). Zaobserwowano istotny i silny związek pomiędzy ciężkością VSD a wartościami MPI. Stwierdzono istotną korelację pomiędzy wartościami MPI mierzonymi w 1. dobie po zabiegu a przebiegiem pooperacyjnym.

Wnioski: Wskaźnik MPI jest precyzyjnym narzędziem oceny funkcji skurczowej i rozkurczowej komór serca we wczesnym okresie po korekcji wady przeciekowej oraz jest dobrym prognostykiem przebiegu pooperacyjnego.

Słowa kluczowe: przeciekowe, wrodzone wady serca, ocena stanu miokardium, przebieg pooperacyjny, wskaźnik MPI

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