Anatomical Variants of Transposition of the Main Vessels and Their Relationship with the Content of Chemical Elements in Heart Ventricles

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Translated from *Byulleten' Eksperimental'noi Biologii i Meditsiny*, Vol. 145, No. 5, pp. 578-581, May, 2008
Original article submitted March 11, 2008

Cardiometrical characteristics of anatomical variants of the main vessels transposition are determined by different functional load of heart compartments and are associated with metabolic processes of different intensity, which is confirmed by the content of chemical elements in the right- and left-ventricular myocardium. It was shown that the content of chemicals was virtually the same in both cardiac ventricles in case of main vessels transposition and isolated atrial septal defect. Positive correlations between the degree of left-ventricular hypertrophy and content of S, K, Fe, and Sr in it and a negative correlation between this hypertrophy and Cu content were revealed. Transposition of the main vessels and defects of atrial and ventricular septa were associated with different levels of chemical elements in both ventricles, particularly of Zn, Mn, Fe, and Ca.

Key Words: *main vessels transposition; cardiometric parameters; chemical elements*

Introduction of new medical technologies in practical cardiosurgery attracted attention to the studies of the myocardium in young children with complex congenital heart diseases, previously considered inoperable.

Transposition of the main vessels (TMV) is a group of congenital heart diseases with concordant atrioventricular and discordant ventriculo-arterial conjunctions [2,7]. Several anatomical forms of TMV are known, the most incident of which are two: simple (with intact ventricular septum, IVS) and with ventricular septum defect (VSD). The prevalence of these anatomical variants of TMV, their specific clinical course, hemodynamics, and morphology [3] form the basis for the development of other TMV forms, which necessitates their comprehensive studies.

It was hypothesized that the development of congenital heart diseases was associated with imbalance of chemical elements [5].

We evaluated the cardiometric characteristics of the heart in anatomical variants of TMV and analyzed the distribution of chemical elements in the right- and left-ventricular myocardium in the studied groups.

MATERIALS AND METHODS

The study was carried out on autopsy material from 34 patients with TMV aged under 1 year dead during the postoperative period: 17 with IVS (mean age 4 months±1 month 10 days) and 17 with VSD (mean age 3 months 6 days ± 1 month 13 days). The following cardiometric parameters were eva-

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luated: heart weight (measured after autopsy and purification of the organ from blood and clots), thickness of ventricular myocardium (on cross-sections), linear size of each ventricle (inflow and outflow tracts). In order to detect changes in heart weight caused by congenital heart disease, the due weight of the newborn heart was calculated from baby's body weight by the formula [4].

Right- and left-ventricular myocardium specimens for histological study were fixed in 4% formalin in phosphate buffer. The concentrations of S, K, Ca, Cr, Mn, Fe, Ni, Cu, Zn, Br, Rb, and Sr were measured in the same tissue fragments. The studies were carried out by the method of synchrotron radiation X-ray fluorescence (SRRF) at the Element Analysis Station, Siberian Center of Synchrotron Radiation, Institute of Nuclear Physics, Siberian Division of Russian Academy of Sciences (Novosibirsk). The spectra were processed using AXIL special international program. In contrast to other methods, this method is the most precise and highly reproducible [6,8]. The content of chemical elements (μg/g tissue) was evaluated.

Standardized concentrations of elements were used in order to bring the concentrations of trace and macroelements to the universal scale. Standardized coefficient for each element was calculated by the formula

$$K=\frac{Cij\times n}{\sum_{j=1}^{n} Cij},$$

where K is standardized coefficient, Cij is concentration of element i in sample j (in μg/g), and n is the number of samples. Standardized concentrations of elements were derived by multiplication of the true concentration by estimated coefficient.

Blood saturation values (rSO_2) were analyzed, which were measured by life-time pulse oximetry.

The results were processed using Microsoft Excel 2000 software. The significance of differences between the means and correlations was evaluated using Student's t test. The differences were considered significant at $p<0.05$.

RESULTS

All patients with TMV were divided into 2 groups depending on anatomical variants: 1) TMV patients with atrial septal defect (ASD; simple TMV form) and 2) TMV with ASD and VSD.

The condition in group 1 was characterized by two-directional dumping: when atrioventricular valves were closed, the blood from lesser circulation flowed into systemic circulation, while when the valves were open, it flew from systemic into lesser circulation. The volume of shunted blood was equal in both directions. The volume of bidirectional shunt depended on the size of atrial defect and difference in the resistance of lesser and systemic circulation. Since the greater and lesser circulations are separated in TMV, the main mechanism of compensation is the increase in the circulating blood volume, which leads to plethora of the lesser circulation [1]. Hence, isolated atrial shunting the volume of shunted blood depends on elasticity of the atria and pressure difference in them during different phases of the cardiac cycle. Functional

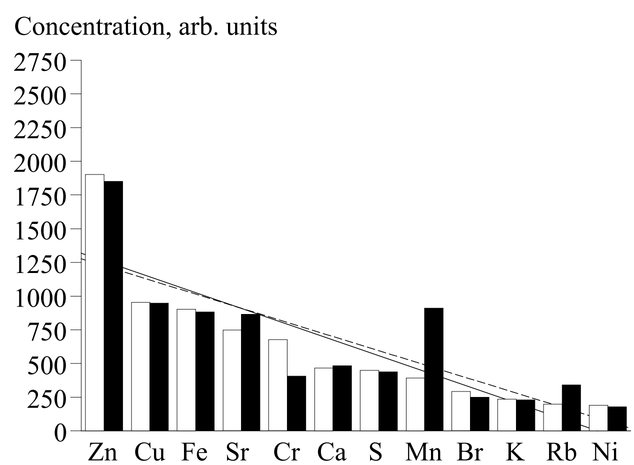

Fig. 1. Content of chemical elements in the right- (light bars) and left-ventricular myocardium (dark bars) in TMV patients with IVS.

TABLE 1. Correlations (r) between Thickness of Myocardium and Content of Chemical Elements in It

Heart compartment	Anatomic groups	S	K	Fe	Cu	Sr	Zn
Right ventricle	group 1	0.15	0.09	0.58*	-0.26	-0.19	0.12
	group 2	0.31	0.15	-0.29	-0.60*	0.13	0.08
Left ventricle	group 1	0.92**	0.75**	0.82**	-0.92**	0.67**	-0.18
	group 2	0.46	0.47	0.50	-0.33	0.30	-0.25

Note. *$p<0.05$, **$p<0.01$ compared to the other group.

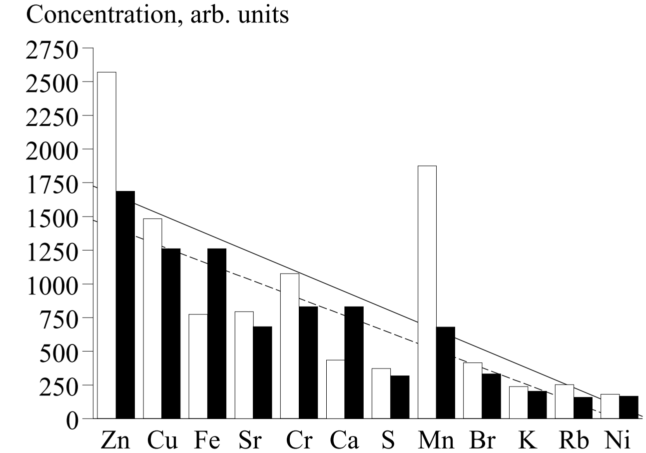

Fig. 2. Content of chemical elements in the right- (light bars) and left-ventricular myocardium (dark bars) in TMV patients with VSD.

load to the ventricles in this anatomical TMV form is virtually the same, which is confirmed by virtually the same content of macro- and trace elements indirectly determining the intensity of metabolic processes in the right- and left-ventricular myocardium (Fig. 1).

Group 2 TMV was characterized by the presence of two communications (at the levels of ASD and VSD), which improved blood mixing at the level of ventricles due to cross-shunting. If VSD was small, the pressure in the lesser circulation increased negligibly, in case of large VSD the pressure leveled in both circulation circles, which led to the development of high pulmonary hypertension and progressive hypoxemia [7,10]. Hence, the optimal hemodynamic variant for group 2 was large ASD and small VSD. Greater volume of blood in this anatomical variant of TMV results in greater functional load of both ventricles than in variant 1.

The content of chemical elements (standardized concentrations) in group 2 was higher than in group 1 by almost 250 arbitrary units. Since the right ventricle in TMV works for the greater circulation, its working load is higher than that of the left one, which modulated the content of chemical elements: a clear-cut trend to an increase in the right ventricle in comparison with the left one (Fig. 2).

In group 2, the content of Cu was 1.3-1.5 times higher than in group 1. It was experimentally shown that excessive content of Cu can cause improper position of the aorta, VSD, and pulmonary trunk hypoplasia [9].

The relationship between the content of chemical elements and cardiometric parameters of ventricles in different anatomical variants of TMV is confirmed by correlations between the content of chemical elements and thickness of the myocardium in the corresponding compartment of the heart

TABLE 2. Cardiometrical Parameters in Infants with TMV

Group	Heart weight, g*	Wall thickness, cm		Myofibril diameter, μ		Inflow, cm		Outflow, cm	
		RV	LV	RV	LV	RV	LV	RV	LV
1	52.60±8.31	0.60±0.15	0.61±0.17	11.65±2.12	11.85±1.95	2.50±0.41	2.60±0.24	3.60±0.61	3.70±0.47
2	48.70±9.33	0.60±0.12	0.55±0.14	11.90±3.11	11.60±2.55	2.5±0.21	2.80±0.36	3.60±0.52	4.00±0.54

Note. *Due heart weight 24.00±0.15 g. RV: right ventricle; LV: left ventricle.

(Table 1). The strength of correlations between ventricular wall thickness and content of chemical elements in it changed almost 2-fold under conditions of different volume load. The degree of ventricular hypertrophy in TMV patients (a leading mechanism of circulation compensation) was different in the groups (Table 2). In group 1, the wall thickness and muscle fiber diameter in the right and left ventricles were virtually the same, while in group 2 the right ventricle was more hypertrophic by these parameters in comparison with the left one. Heart weight in infants with TMV 2-2.5 times surpassed the due weight.

Hemodynamic disorders in TMV are determined by inverted position of the main vessels. Normally, the blood successively pass through the greater and lesser circulations, while in transposition they function in parallel, because of complete separation. Hence, patient's life depends solely on the presence of a communication between the greater and lesser circulation (ASD, VSD, patent arterial duct). The communication between the greater and lesser circulation is most fully realized in group 2.

Group 2 was characterized by a more pronounced right-to-left sunting. Under these conditions, saturation of the blood released into the systemic circulation was higher than in group 1 (67.4±6.7 and 59.5±12.5%, respectively). However, the pressure in the left and right ventricles leveled at the expense of progressive hypervolemia in the lesser circulation and development of high pulmonary hypertension, as a result of which shunting through VSD, which would have promoted release of a greater volume of venous blood into the lungs and its return into systemic circulation, decreased. Due to this, the percent of venous blood participating in gas exchange became minimum in high pulmonary hypertension, which led to aggravation of hypoxemia. For this reason, blood saturation in group 2 with high pulmonary hypertension was lower than in group 1 (49.1±8.9 and 60.2±12.8%, respectively).

Hence, cardiometric peculiarities of different anatomical variants of TMV are associated with different intensity of metabolic processes. The hypertrophic processes in the heart in TMV variant 1 are even and the concentrations of chemical elements in the right and left ventricles are the same. In TMV variant 2 the hypertrophic processes are more pronounced in comparison with variant 1, which correlates with higher content of chemical elements. In addition, the right ventricle works under conditions of greater load because of VSD in group 2, and hence, the concentration of chemical elements in it is higher than in the left one. However, despite intensive heart work in patients with TMV variant 2, oxygen supply in these patients is worse because of lower oxygen saturation of the blood.

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