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Morphological and Functional Characteristics of Right Heart in Children

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Abstract

Introduction: In previous echocardiographic studies less importance is given to the right heart chambers due to the dominant opinion that the right heart plays a minor role in the global cardiac function. Recent studies emphasized the undoubted importance of the right heart and indicated the study of right heart cavities as priority.

Aim: The aim of this study was to performe echocardiographic measurements of morphological and functional parameters of the right atrium and right ventricle in healthy children and present the results as a possible reference values.

Materials and Methods: The study included a group of 93 healthy children (48 boys and 45 girls), aged 1 month to 18 years. Dimensions and function of the right atrium and ventricle were examined by standard and new echocardiographic techniques.

Results: The values of the parameters were as follows : VCI / BSA: 11.25 ± 2.67 mm/m2 , RAVI: 23 ± 6.2 ml/m2 , TAPSE: 22.4 ± 3.7 mm , diameter of the RVOT: 16 2 ± 4.5 mm. PW of hepatic veins: S: 0.58 ± 0.16 m/s, D: 0.43 ± 0.15 m/s, AR: 0.26 ± 0.06 m/s. PW of tricuspid flow E: 0.67 ± 0.15 m/s, A: 0.44 ± 0.14 m/s, E/A ratio 1.63 ± 0.5 . TDI values of speed of tricuspid annulus movements: Sm: 0.14 ± 0.02 m/s, Em: 0.16 ± 0.03 m/s, Am: 0.11 ± 0.03 m/s, Em/Am ratio of 1.58 ± 0. 47, E/Em ratio 4.4 ± 1.3 , Tei index 0.32 ± 0.07.

Conclusion: Transthoracic echocardiography is applicable and reliable method for measuring the parameters of the morphology and function of the right heart cavities in children. The values obtained in our study with the supposed limits of mean ± SD could be used as reference values.

Keywords: Echocardiography, Right heart, Reference values, Healthy children

Abbreviations: BSA: Body Surface Area; SD: Standard Deviation; SE: Standard Error; RAVI: Right Atrial Volume Index; TAPSE: Tricuspid Annular Plane Systolic Excursion; IVRT: Iso Volumic Relaxation Time; Sm: Systolic tricuspid annular Motion, RVOT: Right Ventricular Outflow Tract; RVEDVi: Right Ventricular End-Diastolic Volume of the Right Ventricle

Introduction

Although considered the odd organ, in terms of morphological and hemodynamic sense, the heart may be seen as an even organ, that is, the left and the right heart. The left heart, which consists of the left atrium and the left ventricle, is a part of the systemic arterial bloodstream. It receives oxygenated blood from the lungs, through pulmonary veins, which is then pumped through the aorta and systemic arterial network. Deoxygenated blood from the body comes into the right heart made of the right atrium and ventricle, via the systemic venous sink and hollow veins, which is then directed into the lungs for re-oxygenation, via the pulmonary artery and its branches. Systemic and pulmonary circulation are connected to each other (circulation in the series) and therefore the normal function of both, the left and right heart is necessary for the proper functioning of the cardiovascular system. In addition to equally important role in proper functioning of the cardiovascular system, less importance is often given to the right "pulmonary" heart compared to the left 'systemic' heart. The first one, who stressed the true significance and the role of right heart, was Sir William Harvey. In his work "De Motu Cordis" in 1616, he wrote: "It can be said that the right ventricle was created to carry the blood through the lungs, not to nourish it ".

Monitoring of the patients with Fontan circulation, showed that the absence of contribution of the right ventricle, significantly

changes hemodynamics and the function of the cardiovascular system. The assessment of the right heart preservation proved to be significant in the evaluation and prognosis of conditions such as pulmonary hypertension, heart failure, right ventricular infarction and congenital heart defects. In 2006, the US National Institute of Cardiac, Pulmonary, and Hematological Diseases described as priority the study of the right heart cavities physiology, their role in various heart diseases, as well as opportunities for preservation of their adequate function in these conditions.

The aims of the study

Echocardiographic measurements of morphological and functional characteristics of the right atrium and right ventricle in healthy children and tests results presentation, as possible reference value.

Materials and Methods

The study included a group of 93 healthy children, pre-clinically examined, with no signs and symptoms of the cardiovascular system diseases. The children were aged 1 month to 18 years (9.3 ± 5 yr.), and the children of both sexes were included almost equally (48 boys and 45 girls). The study was conducted at the Department of Cardiology at the University Children's Hospital in Belgrade in 2005 and 2013. Body surface area in children (BSA body surface area) was calculated using the Haycock formula (BSA [m2] = 0,024265x weight [kg] 0.5378 x height [cm] 0.3964), and BMI using the formula: weight [kg]/ height[m]2. Echocardiographic measurements were performed using a high-quality echocardiographic device Phillips iE33. During the measurements, the children were lying on their back or on the left decubital position with electrodes attached to record the ECG simultaneously. ECG recording served us primarily for assessing sinus rhythm, frequency and the phases of the cardiac cycle.

The dimensions and function of the right vestibule were examined by standard (M-mode, 2D echocardiography, Pulsed Doppler) and new (Tissue Doppler) echocardiography techniques. All measurements were carried out in three consecutive cardiac cycles and the mean was taken as valid one. The most convenient moment of the measurement was the normal expirium of a child, with shallow breathing, without strain and thus, the respiration influence on the obtained values was reduced to a minimum. The checks were recorded on the appropriate media and subsequently analyzed "offline" by the child cardiologist.

The obtained values of all listed parameters were statistically processed and presented in the form of tables and charts [Table 1] [Figures 1-9]. The study protocol met the ethical criteria of the Helsinki Declaration, and before the examination, the parents of children were informed about its nature and the use of the results in our study. The children were subjected to these examinations only after the written consent of their parents.

Table 1: Echocardiographic parameters.

Echocardiographic Parameters	Mean	±SD
VCI max (mm)	13	9 – 17
Index of IVC collapsing (%)	62	52 – 72
VCI/m^2 (mm)	11,25	8,58 – 13,92
S, hepatic vain PW (m/s)	0,58	0,42 – 0,74
D, hepatic vain PW (m/s)	0,43	0,28 – 0,58
AR, hepatic vein PW (m/s)	0,26	0,20 – 0,36
RAVI (ml/m^2)	23	16,8 – 29,2
TAPSE (mm)	22,4	18,7 – 26,1
E, tricuspid valve PW (m/s)	0,67	0,52 – 0,82
A,tricuspid valve PW (m/s)	0,44	0,30 – 0, 58
A dur-AR dur (ms)	63,3	28,2 – 98,4
E/A	1,63	1.13 – 2,13
Em, TDI PW of tricuspid annulus (cm/s)	0,16	0,13 – 0,19
Am, TDI PW of tricuspid annulus (cm/s)	0,11	0,08 – 0,14
Em/Am	1,58	1,11 – 2,05
Sm TDI PW of tricuspid annulus (cm/s)	0,14	0,12 – 0,16
E/Em	4,4	3,1 – 5,7
Tei index	0,32	0,25 – 0,39
RVOT (mm)	16,2	11,7 – 20,7

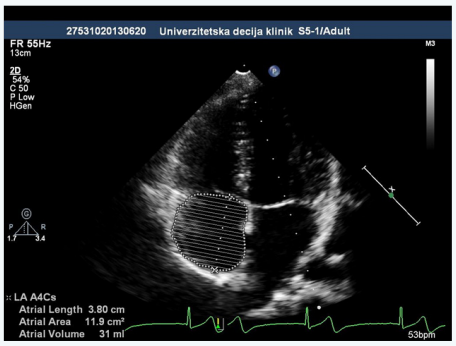

Figure 1: Calculation of right atrium volume, disk method.

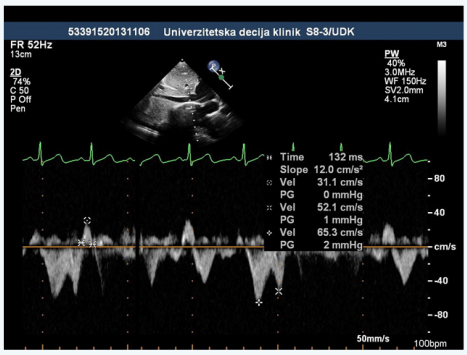

Figure 2: PW of hepatic veins.

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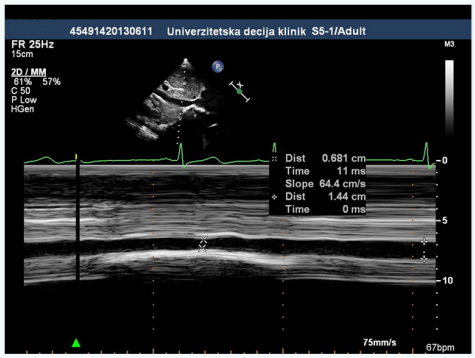

Figure 3: Respiratory collapse of the inferior vena cava.

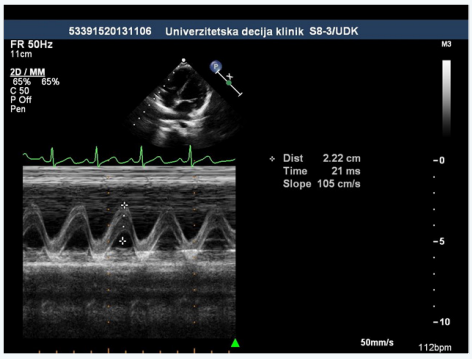

Figure 4: TAPSE: Tricuspid Annular Plane Systolic Excursion.

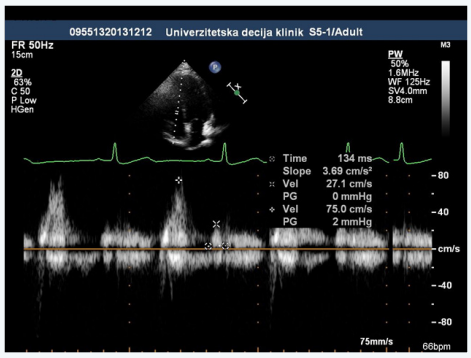

Figure 5: PW of tricuspid valve flow.

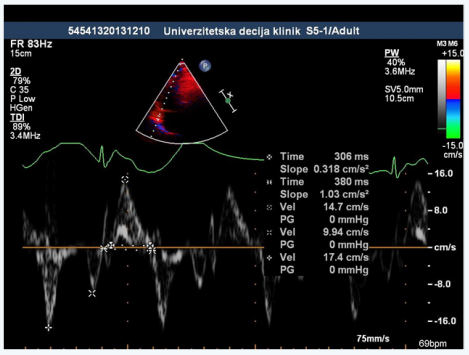

Figure 6: TDI and PW of tricuspid annulus velocity method pulsed wave.

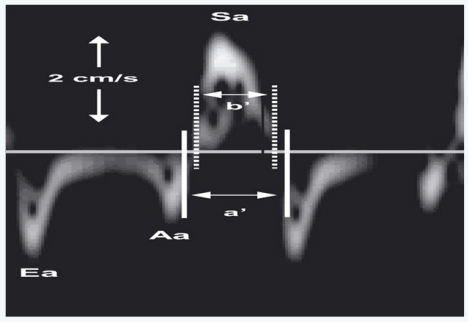

Figure 7: Scheme 1: Tei index index = (ab) / b.

Evaluation of Tissue Doppler Tei index , A. Schaefer

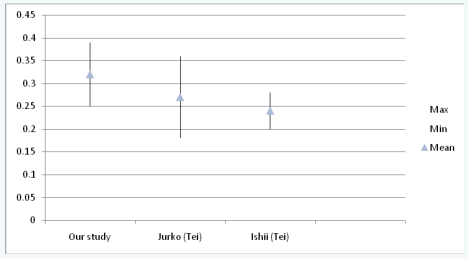

Figure 8: Chart of Tei index.

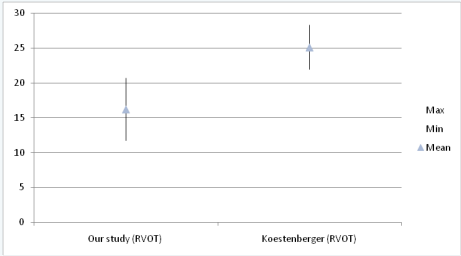

Figure 9: Chart of RVOT (mm).

In the statistical analysis, the data were expressed as mean, minimum and maximum values, and standard deviation (SD) and standard error (SE) were calculated. The nature of the echocardiographic variables distribution was assessed by Kolmogorov-Smirnov test. In the case of the normal distribution, T test was used for comparison of mean values. The differences in proportions were calculated by Chi-square test. Correlation analysis was performed by Spearman and Pearson methods in accordance with the type of data distribution. The value p <0.05 was considered statistically significant. All analysis was performed in SPSS version 14.0 for Windows operating system. Echocardiographic study included measurements of the following parameters: RAVI (Right Atrial Volume Index), PW Doppler of the flow in the hepatic veins, the maximum diameter of the inferior vena cava and the index of respiratory collapse, TAPSE - tricuspid annular plane systolic excursion, tricuspid flow PW Doppler, Tissue Doppler of tricuspid annulus, Tei index.

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Results

Having done the echocardiographic examination of healthy children, we got certain values of measured parameters that we presented in the form of table and text as well as minimum and maximum values, and the mean ± SD too. We assessed the associations, that is, the correlation level of values of various measured parameters, by statistical analysis, and it showed that, in most cases, there was a slight connection. The assessment was carried out on the basis of the values of obtained correlation coefficient (r).

Slight correlation (r=of ± 0.20 ± 0.40) was present in the case of the relationship of the following parameters: E ↔Tei, A↔Tei, E↔RVOT, TAPSE↔RVOT, Sm↔RAVI, Sm↔TAPSE, Sm ↔RVOT, Em↔RAVI, Em↔RVOT and Am↔RAVI. Significant correlation (r = from ± 0.40 to ± 0.70) was present between the values of parameters RAVI↔TAPSE RAVI↔RVOT. Using Student's T test we were determining the significance of differences in the results of our study in relation to the results of similar studies carried out earlier. The only significant difference was shown between the value of Tei index and RVOT diameter obtained in our study compared to other studies. ($P<0.05$)

Discussion

Options of echocardiographic analysis of right heart in children

Apart from the view that the right heart chambers are relatively unsuitable for the ultrasound, it is interesting that the recent studies carried out in children do not emphasize the problem of echocardiographic unavailability of the right vestibule and ventricle. Quality records, which are relatively independent of the position of the right ventricle, the heart rate and frequency, are characteristics of new non-dimensional echocardiographic techniques such as tissue Doppler, speckle tracking echocardiography etc.

The analysis of the right heart cavities morphology is, professionally, the most demanding and the most time consuming, due to the specific geometry and trabecular structure of the walls of the right ventricle and harder obtaining of quality section of retrosternally placed right ventricle. A large number of analysis are carried out from the corresponding sections, primarily from the apical four-chamber one, that provide a good enough idea of the morphology and function of the right heart cavities. In the childhood, chest wall is thinner the percentage of cartilage is higher in the bone structures, which, as such, in the absence of deformity, do not hinder echocardiography greatly. On the other hand, an aggravating circumstance is an increased heart rate, which complicates the analysis of specific echocardiographic parameters and frequent lack of cooperation of the child during the examination.

In our study, during the examination of healthy children and the measurement of previously mentioned parameters, there were not any difficulties in obtaining adequate echocardiography sections and a quality 2D image. All the necessary measurements were successfully carried out for each child included in the study.

Diameter VCI

It was found out by echocardiographic studies that the inferior vena cava diameter varies significantly during respiration. Also, during the breathing, there are significant changes of VCI in both, cranio-caudal, and medio-lateral direction which reduces the accuracy of measurement. To increase the applicability of the results obtained, the diameter of inferior vena cava should be indexed by body surface, and the phase of respiration, in which the measurement was performed, should be defined. Significant changes in diameter VCI in dehydrated children were proven in several studies, thus, its value can be considered as an indicator of the child hydration degree. The lack of reference values for children of certain age makes it difficult to objectively evaluate the hydration.

In our study, the maximum diameter of the VCI had similar values as well as in other studies that dealt with echocardiographic examination of healthy children. Average maximum diameter of the inferior vena cava was 11.3 ± 2.7 mm / m^2 body surface area, while the average index of collapsing of VCI was 62 ± 10%. The results indicate that these values could indicate a normal hydration and central venous pressure in children, which could be used as reference values in everyday routine practice.

Krause [1] measured the diameter of the VCI in children with terminal kidney disease before and 1 hour after dialysis. The average diameter of the VCI in the phase of inspiration and expiratory flow, indexed by body surface, was significantly different in children before and after dialysis (1.12 ± 0.38 vs 0.75 ± 0.26 cm) and was significantly correlated to the change in body weight before and after dialysis. There was no significant correlation in regard to different weight in children before dialysis.

Dehydration is a very common condition in pediatric practice. Sometimes, an unrecognized dehydration or the degree of dehydration, that was incorrectly assessed, can complicate the treatment of the patient. Also, an excessive rehydration can often negatively affect the morbidity and mortality of a sick child. It is, therefore, very important to find an adequate method of rapid and reasonably accurate assessment of a child hydration degree. Clinical signs of dehydration in children are not always reliable, and invasive measurement of central venous pressure is usually not justified. Therefore, the difference in diameter of the inferior vena and abdominal aorta (IVC/Ao Index) stands out as a quick and easy non-invasive method of evaluating child hydration.

Lei Chen [2] found a significant difference between the values of IVC / Ao Index of dehydrated and healthy children (0.75 vs

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1.01), as well as the difference in dehydrated children before and after rehydration (0.75 vs 1.09). Index IVC / Ao was significantly higher in healthy and rehydrated children in regard to dehydrated children. Examining healthy young people by echocardiographic examination, Kosiak [3] came to the reference values for IVC / BSA from 8 to 11.5 mm / m^2 and IVC / Ao of 1.2 ± 0.17. In his study, Natori [4] demonstrated a significant positive correlation between the diameter of VCI and pressure in the right atrium, which confirms that the measurement of this echocardiographic parameter can be used as a non-invasive method of pressure assessement in the right atrium.

The flow in the hepatic veins

Spectrogram of PW Doppler of the hepatic veins flow consists of antegrade systolic and diastolic confluence into the inferior vena cava and retrograde flow in the phase of contraction of the atria. Three-phase spectrogram is not present in all healthy children and its absence should not be interpreted as a mandatory sign of impaired right heart hemodynamics.

With all the children involved in our study during the echocardiographic examination, we found a clear three-phase flow in the hepatic veins. Systolic flow rates were higher than diastolic flow rates (0.58 ± 0.16 m / s vs 0.43 ± 0.15 m / s), and the rates of retrograde flow were significantly less during atrial contraction (0.26 ± 0.06 m / s). The rates that were found fit into the normal spectrogram of the venous confluence into the right atrium. The results were not significantly different from those obtained by Amoozgar [5] in his study, in children with normal pressure in the right atrium.

Examining spectrograms of hepatic venous flow in healthy children, Jequier [6] found a distinctive three-phase flow in all three hepatic veins in only 42% of children. According to the author, the thing that could indicate a disturbed flow in the hepatic veins is a change in pre-existing three-phase flow into two-phase or single-phase flow. The middle and the left hepatic veins had the most consistent three-phase flow, while the right hepatic vein, in addition to being less accessible for the examination, had the largest percentage of two-phase and single-phase flow. Single-phase flow in the hepatic veins is most often found in the neonatal age. The complete lack of retrograde flow could indicate an increased vascular resistance in the hepatic veins that could be seen in a variety of liver diseases with reduced hepatic compliance.

Flow rates in the hepatic veins proved to be a good indicator of pressure in the right atrium. In his study, Amoozgar [5] compared the hepatic venous confluence in children with congenital heart disease, who had the pressure in the right atrium previously measured by the direct manometry during cardiac catheterization. It showed that the change in speed of S waves, during the respiration for more than 38%, indicates the pressure in the DA higher than 8 mmHg, with a sensitivity of 90% and a specificity of 51.3%. The maximum speed of the systolic confluence, lower than 0,7m / s, indicated a pressure in the DA higher than 8 mmHg, with a sensitivity and specificity of 70% and 82.1%. Maximum expiratory diastolic confluence faster than 0.63 m/s was an indicator of the pressure in the DA higher than 8 mmHg, with a sensitivity of 60% and a specificity of 92.3%. The speeds of hepatic venous confluence showed some changes in different phases of respiration. In the group of children with the measured pressure in the DA less than 8 mmHg of the mean flow rate of the inspiration and expiratory flow, were significantly different (Si 0.92 m / s vs 0.56 m / s; Di 0.73 m / s vs De 0.46 m / s; ARi vs 0.43 m / s ARe 0.32 m / s) while the AR wave lasted for 84.3 msec in average.

The rates of hepatic venous flow are also affected by changes in intra abdominal and intra thoracic pressure, as well as changes in cardiac function. Increased pressure in the right cardiac cavities will increase the hepatic vein pulsatility, while the increased intra thoracic pressure (Valsalva maneuver) will reduce venous inflow and pulsatility of the hepatic veins.

The volume of the right atrium

The best indicator of morphological changes in the right atrium in a variety of hemodynamic disorders is its volume, that is, volume value indexed in relation to the surface of the body - RAVI (Right Atrial Volume Index). In the states of hypovolemia or volume overload as is the case in the presence of an atrial septal defect, there are significant changes in the dimensions of the right atrium and ventricle. However, studies have shown a very rapid and significant reversibility of these changes after transcatheter closure of ASD. In our study in healthy children, we found the average value of RAVI from 23.06 ± 6.2 ml / m^2, which is not significantly different from the reference values obtained in the other studies.

In the study Kucinska [7], the changes in children with ASD after transcatheter closure of defect Amplatzer septal occluder, were examined. Within 24 hours after the closure, there was a significant normalization of dimension DA and DV, while in the next three months, most of the dimensions of the right cardiac cavities, returned to normal values. A period a bit over two years, after the removal of the volume load, was needed to normalize the transverse diameter of the right atrium and the diameter of the right ventricular outflow tract. Nevertheless, it has been found that in children with transcatheter closed ASD, significantly faster hemodynamic recovery occurs, in relation to children in whom ASD was closed surgically. In new echocardiography recommendations in the assessment of morphological characteristics of the right atrium, RAVI of normal value of 21ml / m^2 is increasingly stated as a good indicator.

In his study, Sallach [8] examined the possibility of the use of RAVI value in assessing the degree of systolic and diastolic dysfunction of the right ventricle, as well as the clinical prognosis of patients with chronic heart failure. The results showed that the RAVI is a good determinant of right ventricle function and independent risk factor for long-term morbidity and mortality.

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Mean values of obtained RAVI were 31 ± 15 ml / m^2 for men and 21 ± 12 ml / m^2 for women (p = 0.0001). RAVI ≥ 41.6 ml / m^2, with a sensitivity of 68% and a specificity of 92% indicated a NYHA III or higher functional class of heart failure. RAVI ≥ 30.6 ml / m^2 i indicated, with a sensitivity and specificity of 78% and 77% in the RV, systolic dysfunction of RV grade ≥ 3. RV diastolic dysfunction greater than grade 3, was related to RAVI ≥ 37.8 ml / m^2 with a sensitivity and specificity of 80%.

Increased value RAVI does not always have to represent pathological findings. By examining active athletes, Ascenzi [9] found higher values RAVI (26.96 ± 7.28 ml / m^2) compared to the control group of people who do not do any sport actively (19.89 ± 4.99 ml / m^2). In this case, the increased values RAVI along with increased right ventricular diameters and specific functional changes of right heart are explained as a physiological adaptation to intensive trainings and are placed in the context of the "athlete's heart".

Doppler echocardiography tricuspid flow

The speed and the duration of individual phases of tricuspid inflow are a good indicator of right ventricular diastolic function, that is, its relaxation and diastolic pressures. Two speeds are analyzed on the spectrogram (early –E, and late - A diastolic inflow) and two intervals (isovolumic relaxation time - IVRT and diastasis). The spectrogram of tricuspid inflow shows certain changes during respiration which are considered normal. From inspiration to expiratory flow, the speeds of tricuspid inflow increase, the early E inflow for about 25%, and late A inflow for about 20%, and E / A ratio remains unchanged. Because of these changes, tricuspid inflow measurements by Doppler methods, must be defined and interpreted in relation to the phase of respiration in which they are made. The age of a child has no significant impact on the values of the tricuspid inflow parameters, except in the neonatal age, when the normal result is of higher speed of A waves compared to the E wave.

Normal functioning of the right atrium, tricuspid valve, as well as adequate compliance of the right ventricle is necessary for the adequate diastolic function of the right heart. With diastolic dysfunction, the first changes include the increase of function of the right atrium tank and pumps, while at later stage, conduit function dominates. At the same time, depending on the cause of diastolic dysfunction, there is a reduction of compliance and an increase in the right ventricle diastolic pressure. These changes are reflected in the spectrogram PW of Doppler tricuspid inflow. The state of hydration can also change the appearance of the tricuspid inflow spectral curve.

Our study showed tricuspid inflow speed values that fit into existing spectrogram models of a heart with normal function. Early diastolic tricuspid inflow was significantly of a higher speed compared to the late diastolic inflow during the atrial contraction (0.67 ± 0.15 m / s vs 0.44 ± 0.14 m / s) so that the average ratio of the early and the late diastolic inflow was 1.63 ± 0.5. In atrial contractions, the right ventricle was filling with blood on average 63.3 ± 35.1 ms longer than the inferior vena cava and hepatic veins, which corresponds to normal hemodynamic conditions.

By measuring in children with congenital heart defects, Amoozgar [5] analyzed obtained values in relation to invasively obtained pressure in the right atrium. In children with the pressure in DA lower than 8 mmHg, the values obtained are: E wave in inspiration 1.05 ± 0.25 m / s, E wave in expirium 0.82 ± 0.24 m / s, A wave in inspiration 0 77 ± 0.21 m / s, A wave in expirium 0.62 ± 0.15, the length of wave A (AD) 118.13 ± 34.19 msec. Children with pressure in DA, higher than 8 mmHg, had the following values: E wave in inspiration 1.18 ± 0.29 m / s, E wave in expirium 0.90 ± 0.19 m / s, A wave of inspiration 0 72 ± 0.30 m / s, A wave in expirium 0.69 ± 0.17,the length of A waves (AD) 123.67 ± 40.32 msec. It has been found that the calculated Ei / Ai is higher than 1.88 the pressure indicator in DA higher than 8 mmHg, with a sensitivity of 60% and specificity of 82.5% .

In a study, which Vermilion [10] carried out in children with pulmonary stenosis parameter values before and after balloon valvuloplasty were compared, as well as the values before valvuloplasty with values in healthy children. In children with pulmonary stenosis parameter values were significantly different compared to values in healthy children in terms of a larger A wave (0.64 ± 0.28 vs 0.39 ± 0.08 m / s) and a lower E / A ratio (1.11 ± 0.52 vs 1.76 ± 0.45). In patients before and after balloon valvuloplasty, significant changes had not been found in the measured parameters of tricuspid inflow. There was a significant difference in the pressure gradient in the right ventricular outflow tract before and after the intervention. The results showed decreased early diastolic filling and increased right atrium pump function in children with pulmonary stenosis. After balloon valvuloplasty there were no significant changes in the spectrum of diastolic filling of the right ventricle, which could indicate that the residual decreased compliance is a result of right ventricular hypertrophy caused by the obstruction of its outflow tract. The mean values of tricuspid inflow parameters in healthy children were as follows: E wave of 0.66 ± 0.1 m / s, A wave of 0.39 ± 0.08 m / s, E / A ratio of 1.76 ± 0.45.

In the study Jie Liu [11], the impact of reducing preload was analyzed, simulated by applying negative pressure to the lower part of the body of 60 mmHg, to the speeds of tricuspid inflow. Reducing the preload has led to a significant reduction in the speed of early E diastolic inflow (0.712 ± 0.081 m / s vs 0.556 ± 0.102 m / s), while it has not significantly increased the rate of late A tricuspid inflow (0.41 ± 0.078 m / s vs 0.453 ± 0.076 m / s). There had been a significant decrease in E / A ratio (1.79 ± 0.38 vs 1.26 ± 0.32). Three minutes after the termination of high pressure effects on the lower part of the body, the values of examined parameters were normalized. These results suggest the possible use of PW Doppler of tricuspid inflow in the detection of decreased preload with the decentralization of bloodstream in conditions such as acute dehydration, bleeding, and peripheral vasodilatation with capillary leakage in various states of shock.

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TAPSE (Tricuspid Annular Pulse Systolic Excursion)

The moving of the tricuspid valve annulus, between the end of diastole to the end of systole chamber, is a very good indicator of right ventricular systolic function and it correlates well with the parameters of systolic function obtained by right diagnostic cardiac catheterization and using magnetic resonance imaging. TAPSE however, represents only the impact of the right ventricular entrance on systolic function, while the contribution of outflow tract is assessed on the basis of the shortening fraction of that part of the right ventricle. The assessment of right ventricular systolic function of the standard methods used in the left ventricle such as ejection fraction and shortening fraction, is harder to do, because of its irregular geometry, trabecular walls and retrosternal position. This problem is particularly seen in children with congenital heart disease where, a wide range of abnormalities in the structure, shape and position of the right ventricle, is present.

In healthy children included in our study, TAPSE average value was 22.4 ± 3.7 mm, which, due to the most common age of the children in our study, fits in with the reference values that Nunez Gil [12] got in his study. In our study, lower limit value of TAPSE that you get when you subtract the mean value of 2 SD, would come to 15 mm. By examining the healthy children, Nunez Gil [12] come to the value of TAPSE which he characterized as a reference for certain ages. The mean value in all age groups was 17.09 ± 5.09 mm. TAPSE values ranged from 10.56 ± 3.96 mm in newborns, to 20.95 ± 6.54 mm in children aged 13-18 years. There were no significant differences between the sexes. Body surface area showed a strong positive correlation with the values TAPSE, while heart rate showed a negative correlation with TAPSE. TAPSE values, in relation to the body surface area (BSA), differed at different average values BSA in certain age groups and it was to 13.17 mm / m^2 at an average BSA of 1.59 m^2. In the neonatal age 5th percentile TAPSE was 7.8 mm, while in the age of children older than 5 years, 5th percentile TAPSE was 15 mm. All of these values obtained in healthy children contribute to proper interpretation and clinical applicability of the values TAPSE in children with various heart diseases.

Perhaps the most important use of TAPSE is in children with pulmonary arterial hypertension. Koestenberger [13] cites a number of studies that have shown a significant reduction in the value of TAPSE in patients with pulmonary hypertension compared to healthy children. As a determinant of progressive damage to the right ventricle systolic function, TAPSE value 2 SD below the normal value for age, was defined. With the speed of systolic tricuspid annular motion (Sm), TAPSE becomes the method of choice for routine assessment of right ventricular systolic function in the monitoring of patients with pulmonary arterial hypertension.

The diameter of right ventricular outflow tract (RVOT) changes in the states of loading the chamber with pressure or volume. Increased diameter indicates a reduced load carrying capacity by the right ventricle and the possible existence of its function impairment. Healthy children who participated in our study had an average diameter of RVOT 16.2 ± 4.5 mm. Our values were significantly lower than those that Koestenberger [14] got (25.1 ± 3.2 mm), also examining healthy children. The only difference was that, in our study, RVOT measurements were performed in the longitudinal parasternal section, while Koestenberger took the measurements of the transverse parasternal cross-section, which may be the reason for the different values of the diameter of right ventricular outflow tract. We should not ignore the differences in the subjective assessment of endocardial borders RVOT by the examiner during the measurement of the diameter, or the impact of the quality of the echocardiographic device measurement on the measuring results. In summary, this parameter is subject to subjective variability which is why it should be treated with caution in the functional analysis of the right ventricle.

Tissue velocity of tricuspid annulus

Tissue Doppler method can directly measure the speed of the part of right ventricular myocardium. Using pulsed TDI echocardiography with volume sample on the lateral attachment of tricuspid annulus, we measure systolic and diastolic motion velocities of that part of the right ventricle. Speed systolic tricuspid annular motion (Sm) proved to be a good quantitative parameter of right ventricular systolic function in children.

Right ventricular systolic function is an important indicator of the global heart function in a variety of congenital and acquired heart disease. Due to the unfavorable geometry and position of the right ventricle, an adequate and accurate assessment of its systolic function by conventional methods used for the assessment of left ventricular function such as ejection fraction and shortening fraction, was difficult to do. Ejection fraction of the right ventricle can be most accurately obtained using magnetic resonance, but this method is not yet available for routine use in patients with heart disease. Echocardiographic methods would be beneficial for assessing right ventricular systolic function that are feasible in daily practice, and yet, on the other hand, in good correlation with the indicators obtained by magnetic resonance imaging.

Measuring movement of the lateral attachment of tricuspid annulus in healthy children, we got that the maximum speed of early diastolic movement (0.16 ± 0.03 m / s), which are slightly higher than the speed of systolic motion (0.14 ± 0.02 m / s). The speeds of late diastolic movements (0.11 ± 0.03) are significantly lower than both systolic and early diastolic speeds of movement of that part of the right ventricle. This ratio of myocardium movement speed has given the average values Em / Am ratio of 1.58 ± 0.47 and E / Em ratio of 4.4 ± 1.3, which are, judging by the results of the studies previously carried out on healthy children, considered normal.

The values E / Em obtained in our study in healthy children, changed by more than ± SD, and particularly changed by more than ± 2SD may indicate changes in pressure in the hollow veins, that is, in central venous pressure. It is noteworthy that none of the above parameters itself is not a sufficient indicator of the right

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heart function. By joint analysis and perceiving the changes in the values of several parameters, from the index of collapsing VCI, the volume of DA, the speed of tricuspid flow to the movement speed values of tricuspid annulus, obtained by TDI method, we gain a more complete picture of possible hemodynamic changes.

So far, relatively little is known about the right ventricular systolic function in children with congenital heart defects. The nature and degree of changes in these children and mechanism of functional recovery following surgical treatment are insufficiently explained. Koestenberger [15] examined changes in speed Sm in children with congenital heart disease and pulmonary hypertension as well as in children with tetralogy Fallot, after operative correction of the fault. He assessed the value of Sm as an indicator of right ventricular systolic function compared to EF, and end-diastolic volume of the right ventricle (RVEDVi) obtained by MRI. The results of this study showed that the rate of Sm has been significantly reducing 10.4 years after the development of PAH in children with congenital heart defect, that is, in the state of load pressure of the right ventricle. In children, after tetralogy Fallot surgery, where volume overload is present, a significant reduction in Sm speed comes 13.6 years after surgery.

It could be concluded that it takes a longer time period of the right ventricle volume load to reach significant damage of its systolic function, and that the right ventricle is less sensitive to the state of volume overload compared to the load pressure. It is assumed that in the period of an infant and a small child, "adaptive hypertrophy" of the right ventricle occurs, but the chamber cannot tolerate the load or volume pressure for a long time, and over the time, the mandatory dysfunction occurs. A significant positive correlation was recorded between the Sm speed and EF right ventricular, while significant negative correlation was present between Sm speed and end-diastolic volume of the right ventricle. Based on these correlations, Sm speed can be characterized as a reliable and easily measurable indicator of right ventricular systolic function.

Tüller [16] also found good correlation between the speed of systolic movement of lateral part of tricuspid annulus with EF obtained by magnetic resonance imaging. The threshold value Sm of 0.12 m / s was used to identify the right ventricular systolic dysfunction with sensitivity of 86% and a specificity of 83%. There was a direct correlation between the values of Sm and EF of right ventricular. The speed Sm higher than 0,12 m / s indicated the normal EF> 55%, the speed Sm between 0.12 and 0.08 m / s the EF middle weakened 30-55%, while the EF lower than 30 % was indicated by the Sm speed lower than 0.08 m / s and all that with a sensitivity and specificity of about 80%. In other, similar studies, the Sm value of <0.10 m / s as an indicator of a significant impairment of o the right ventricle systolic function, is emphasized.

Rafeiyian [17] showed the measurement results of PW tissue Doppler of the lateral tricuspid annulus in healthy children of different ages and presented them as possible reference values. Slower speed of early diastolic movement and lower ratio of early and late diastolic movements in newborns was perceived. The biggest changes of parameter values have occurred during the first year of life, which indicates the most important changes in the growth of the structure and function of the right ventricle during this period. In his study in healthy children, Ascenzi [9] got the following values of TDI parameters: Em 0.17 ± 0.04, Sm 0.14 ± 0.03, 0.11 ± 0.04 Am, Em / Am 1.70 ± 0, 49, E / Em 4.11 ± 1.05. Our values of the same parameters did not differ significantly.

Tei index

Tei index or myocardial performance index is another method that attempts to overcome the problem of assessment of the right ventricle global function due to improper geometry and unsuitable retrosternal position. This problem is particularly seen in children with congenital heart disease where the shape and position of the right ventricle is additionally disrupted. Tei index proved to be simple, reliable, reproducible method of examining the right ventricle function. It is calculated by combining indicators of diastolic (IVRT) and systolic (IVCT, ET) component of the right ventricle function. The parameters for calculating the Tei index are obtained by using PW Doppler alone or in a combination with tissue Doppler.

In our study, we obtained slightly higher average value of Tei index (0.32 ± 0.07) compared to other studies. The difference in the value of Tei index probably arises from individual differences of examiners while assessing and marking the boundaries of time intervals on the spectrogram of Doppler techniques that are needed to calculate the Tei index. This depends on both the quality of thespectogram recording, that is, the quality of echocardiography devices, as well as from the experience and subjective assessment of the examiner. In all these studies, we can see that the values of Tei index have to significantly vary from the reference values, in order for it to be interpreted in terms of right ventricular dysfunction.

Ishii [18] calculated Tei index in children with ASD after Senning operation, and compared the results with the value of Tei index in healthy children. It turned out that, the value of the right ventricle Tei index in children is independent of age, heart rate, blood pressure, degree of tricuspid regurgitation and the degree of pulmonary hypertension. The mean value of Tei index was significantly different in children after Senning operation compared to healthy children (0.58 ± 0.09 vs 0.24 ± 0.04), while there was no significant difference between children with ASD and healthy children (0.25 ± 0.13 vs 0.24 ± 0.04). It could be said that cardiac function is significantly more resistant and longer preserved in the states of volume overload in ASD. After Senning operation right ventricle remains systemic and works opposite high systemic pressure and in this case there is a significant and early hypertrophic remodeling and the damaging of its function. Similar conditions are present in the existence of pulmonary arterial hypertension, in which Tei started the implementation of the index and registered significantly higher values of 0.93 ± 0.34

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compared to the healthy population.

By testing healthy children, Jurko [19] got an average value of Tei index for DV 0.27 ± 0.09, and for LV 0.32 ± 0.07. The value of Tei index of LV, unlike DV, differs in relation to the age of the child and in children under 3 years, it is significantly higher compared to older children (0.40 ± 0.09 vs 0.33 ± 0.22). In the case of the right ventricle dysfunction, there is a gradual lengthening of IVRT and IVCT while ET shortens, it leads to an increased value of Tei index, so that we can say that the higher Tei index value, the worse the heart function is .

The analysis of correlation between the values of echocardiographic parameters

When assessing the existence of correlation between the values of different echocardiographic parameters, we realized that significant correlation coefficients, with respect to other parameters, are more often shown by tissue Doppler parameters with values RAVI, TAPSE and RVOT diameter. According to that, it could be said that for faster, and yet reliable assessment of right heart cavities function, measuring of previously mentioned parameters can be used, and on the basis of their values changes , the changes in the value of other important parameters can be assumed. The volume of the right atrium is very sensitive to hemodynamic changes and it significantly changes in the states of right heart load, either by pressure or volume. These changes are usually reversible, but their level is a reliable indicator of introducing, correcting and monitoring the success of heart disease treatments. The values TAPSE and RVOT diameter reflect the functional state of the right ventricle, except that TAPSE represents a share of inflow part of DV, and diameter RVOT a share of RV outflow tract in its overall function. Some tissue Doppler parameters clearly represent the systolic (IVCT, Sm) and diastolic (IVRT, Em, Am) function of the right ventricle, while the global cardiac function is estimated from Tei index as a function of the above parameters [20-33].

Conclusion

In our study, as in other recent studies that dealt with echocardiographic right heart analysis in children of different ages, significant difficulties in obtaining adequate echocardiographic images and values of certain parameters, did not occur. It tells us about transthoracic echocardiography as a reliable method for measuring morphology indicators and function of the right heart cavities in children. By examining the interconnections of certain parameter values, in certain cases we got easy to significant positive correlation, that is, the cases in which, changed values of certain parameters indicate possible changes to the values of other parameters in the same direction. A significant correlation was found between the parameters: RAVI↔TAPSE and RAVI↔RVOT.

By reviewing and analyzing the existing literature, we found possible reference values, as well as the threshold values of echocardiographic parameters that can indicate a disorder of cardiac function. The values obtained in healthy children included in our study, in almost all cases, did not significantly differ from the reference values obtained in other studies (excluding the value of Tei index and diameter RVOT), so that our value, with the assumed limits of mean ± SD, could be used for the same purpose [33-40].

Recent works in this area show the new echocardiographic methods such as strain rate and speckle tracking echocardiography to enable easier, more objective and more accurate analysis of the minimum, initial changes in the function of the right heart, which will greatly contribute to an easier and more precise diagnosis and improved treatment of heart diseases in children.

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