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POSSIBILITIES OF ECHOCARDIOGRAPHY IN ASSESSING THE MASS OF THE RIGHT VENTRICULAR MYOCARDIUM AND VISUALIZATION OF THE PATENTES DUCTUS ARTERIOSUS USING 3D ECHOCARDIOGRAPHY

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Abstract. Assessing the structure of the right ventricle using two-dimensional echocardiography is a rather difficult and rare task in clinical practice. The mass of the right ventricular myocardium is more often determined using magnetic resonance imaging, computed tomography and three-dimensional echocardiography. Pathological conditions of the right ventricular myocardium are often observed in diseases of the circulatory system, including, but not limited to, congenital heart defects and major vessels, such as an patentus ductus arteriosus (extracardial shunt during fetal circulation). Estimating the mass of the right ventricular myocardium, taking into account its “irregular” geometric shape, is quite difficult. The 3D echocardiography method offers significant advantages by eliminating the need for geometric assumptions and providing a more accurate representation of the shape and structure of the right ventricle. Studies conducted by a number of authors have established that 3D echocardiography is 9 times more accurate in assessing the characteristics of the pancreas compared to 2D echocardiography and is comparable to angiography (catheterization of heart chambers). For visualization of the open ductus arteriosus, this method demonstrates high accuracy, which is confirmed by a number of studies. The use of 3D echocardiography provides new opportunities for a more detailed assessment of pancreatic myocardial mass and visualization of anatomical structures of the heart, including ectracardial ones, while being a non-invasive and less costly procedure.

Keywords: right ventricular myocardial mass, methods for estimating right ventricular myocardial mass, 2D echocardiography, 3D echocardiography, patentus ductus arteriosus, patentus ductus arteriosus imaging, angiography https://doi.org/10.56871/RBR.2025.25.67.007

ПРЕИМУЩЕСТВА 3D-ЭХОКАРДИОГРАФИИ В ОЦЕНКЕ МАССЫ МИОКАРДА ПРАВОГО ЖЕЛУДОЧКА И ВИЗУАЛИЗАЦИИ ОТКРЫТОГО АРТЕРИАЛЬНОГО ПРОТОКА

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Резюме. Оценка структуры правого желудочка при помощи двухмерной эхокардиографии достаточно трудная и редкая задача в клинической практике. Масса миокарда правого желудочка чаще определяется с помощью магнитно-резонансной томографии, компьютерной томографии и трехмерной эхокардиографии. Патологические состояния миокарда правого желудочка наблюдаются часто при заболеваниях системы кровообращения, включая в том числе врожденные пороки сердца и магистральных сосудов, такие как открытый артериальный проток (экстракардиальный шунт в период фетального кровообращения плода). Оценка массы миокарда правого желудочка с учетом его «неправильной» геометрической формы достаточно сложна. Метод 3D-эхокардиографии предлагает значительные преимущества, при этом исключается необходимость геометрических допущений и обеспечивается более точное представление о форме и структуре правого желудочка. Проведенные рядом авторов исследования установили, что 3D-эхокардиография в 9 раз более точно способна оценивать характеристики правого желудочка по сравнению с 2D-эхокардиографией и сопоставима с ангиографией (катетеризацией камер сердца). Для визуализации открытого артериального протока данный метод демонстрирует высокую точность, что подтверждает ряд исследований. Использование 3D-эхокардиографии предоставляет новые возможности для более детальной оценки массы миокарда правого желудочка и визуализации анатомических структур сердца, в том числе экстракардиальных, при этом являясь неивазивной и менее затратной процедурой.

Ключевые слова: масса миокарда правого желудочка, методы оценки массы миокарда правого желудочка, 2D-эхокардиография, 3D-эхокардиография, открытый артериальный проток, визуализация открытого артериального протока, ангиография

INTRODUCTION

An assessment of the structure of right ventricle (RV) using two-dimensional echocardiography (2D-Echo) still remains problematic and is rarely used in clinical practice. There are a large number of studies devoted to the assessment of RV function and volume, but the assessment of myocardial mass is somewhat ignored and practically not described [1–5]. Magnetic resonance imaging (MRI), computed tomography (CT) and three-dimensional echocardiography of the heart (3D-EchoCG) are most often used to determine the RV myocardial mass (RVMM) [6–8].

At the same time, RV myocardial hypertrophy can be observed in many diseases, such as pulmonary hypertension, congenital heart defects, pulmonary valve stenosis and some infiltrative diseases [6].

One of such nosological forms is patent ductus arteriosus (PDA), which, if persistent for a long time, causes severe pulmonary hypertension, leading to volume overload and hypertrophy of the right heart chambers. PDA accounts for 5–10% of all congenital heart defects (CHD), is observed more commonly in premature female infants compared to males, 3:1, respectively [9]. According to P.S. Rao, M.J. Kern:“The physiological impact and clinical significance of a PDA largely depend on its size and the patient's cardiovascular status” [10].

The ductus arteriosus can be classified as “silent”, small, medium or large, therefore there are several classifications — clinical and angiographic. However, until now, there are no data on echocardiographic changes in the right heart chambers depending on the size of the duct and the duration of its functioning.

This publication is devoted to the issues of assessing the RV myocardial mass in order to determine the most accurate methods, as well as the issues of three-dimensional echocardiography in visualizing the arterial duct.

ASSESSMENT OF RIGHT VENTRICULAR MYOCARDIAL MASS

When discussing methods for evaluating myocardial mass, it should be noted that an assessment of the left ventricle (LV) is more common in literature. This is due to significant differences in the structure of two ventricles. The LV has a bullet-shaped form, making it easier to assess transthoracically. The right ventricle, in turn, has a complex, irregular crescent or triangular pyramidal shape. Therefore, there is no geometric figure that could adequately depict the dimensions of this structure without simplifying its shape [11].

The right ventricle, from a practical and functional point of view, is U-shaped (horseshoe) curved loop [12]. The complex geometry of RV allows it to wrap around the LV cavity in a crescent-like manner [13]. Functionally, the RV has three segments, separated by two muscular nodes: the 1st in the area of the atrioventricular valve, the 2nd one is immediately below the atrioventricular valve (the widest), and the 3rd one located in the area of the RV outflow tract and/or in the area of visualization of the moderator bundle (slit-shaped).

The right ventricle has three walls: anterior, posterior (diaphragmatic), and left (internal or septal), but modern authors point to only two walls: the parietal wall, which forms its anterior and posterior surfaces, and the septal wall, which separates the cavities of the right and left ventricles [12]. It should be noted that the septal wall, formed by the interventricular septum (IVS), consists of the anterior and posterior IVS and the membranous part of the IVS.

During the examination, pronounced trabecularity is detected in the RV cavity, with the moderator bundle (guiding trabecula) visible in the right ventricular outflow tract. The anatomical features described above prevent, and sometimes make it impossible, to obtain high-quality acoustic windows for RV assessment from standard two-dimensional echocardiographic positions [8, 11, 14].

Moreover, there is no clear opinion how to assess the interventricular septum, which anatomically belongs to both ventricles, and functionally to the left [15–17]. Finally, two-dimensional echocardiography does not allow the inclusion of the right ventricular outflow tract (conus arteriosus) in observations [11]. However, there are methods of assessment. Several geometric models have been proposed to estimate the RV [8]. The first one assumes that the RV has an elliptical cross-sectional area [18], and for ease of application, a pyramidal shape was adopted [19]. The second method uses the area of the prismatic shape of the RV. It has proven itself in the study of congenital heart defects [20]. Further studies of static and dynamic changes in the RV led to the use of a crescent-shaped RV in cross-section, in which case the cavity volume was calculated by multiplying the area and length [21]. Further work in this direction formed a different opinion about the shape of the RV: along the short axis, the free wall has a circular shape, and along the long axis, it is parabolic [22].

Experimental studies have shown that isolated RV myocardial hypertrophy is limited by its free wall [23]. However, it cannot be ruled out that the interventricular septum (IVS) is not affected by isolated right ventricular (RV) changes; after all, its mass is excluded from calculations [7, 17, 23]. This is confirmed by the fact that during heart dissection, the RV free wall is easily separated from the IVS and the LV free wall, while it is difficult to separate the LV free wall from the IVS. In addition, the results demonstrate a more frequent IVS hypertrophy in isolated LV hypertrophy (LVH) than in RV hypertrophy (RVH). Although later studies indicate that the trabecular component of the IVS does belong to the RV [8].

The RVMM can be estimated from the product of the specific gravity of the myocardium and the volume of the free wall of the RV [7]. J.J. Joyce et al. (2001) confirmed the accuracy of this method using MRI, CT and three-dimensional echocardiography [7, 24, 25].

Let us consider the methods for calculating the RVMM [6–8].

RVMM is estimated by the following equation:

$$\text{RVMM} = \text{FSRV} \cdot \text{TW} \cdot \text{MD},$$

where RVMM is the myocardial mass of the right ventricular free wall; FSRV is the surface area of the right ventricular free wall; TW is the thickness of the right ventricular free wall; MD is the myocardial density, assumed to be 1.05 g/cm³ [6–8].

The anterior RV wall thickness is assessed instrumentally, while the FSRV requires calculation. To determine the FSRV, it is proposed to use the one-quarter prolate ellipsoid surface area (Fig. 1), as well as the formulas below.

Exact radius method

The authors used two mutually perpendicular radii R_1 and R_2, which were measured in the apical position (Fig. 1, *b*). The final version of the formula with correction factors looks like this [7]:

$$\text{RVMM} = 3{,}4\left(\frac{R_1^2}{2}\right)\cdot\left(1+\frac{R_2\sin^{-1}\varepsilon}{R_1\,\varepsilon}\right)\cdot(\text{TC}) + 2{,}2,$$

where RVMM is the myocardial mass of the right ventricular free wall; FSRV is the surface area of the right ventricular free wall; TW is the thickness of the right ventricular free wall; MD is the myocardial density, assumed to be 1.05 g/cm³, R_1 and R_2 are large and small radii, respectively (Fig. 1).

Simplified radius method [7]

The same radii are used, but the formula is simplified and more clinically applicable.

$$\text{RVMM} = 3{,}63\left(\frac{R_1^2}{2}\right)\cdot\left(1+\frac{R_2}{R_1}\right)\cdot(\text{TC}) + 2{,}1,$$

where RVMM is the myocardial mass of the right ventricular free wall; FSRV is the surface area of the right ventricular free wall; TW is the thickness of the right ventricular free wall; MD is the myocardial density, assumed to be 1.05 g/cm³, R_1 and R_2 are large and small radii, respectively (Fig. 1).

One-quarter prolate ellipsoid surface area method [7]

The authors suggested that the longitudinal cross-sectional area could be used to estimate the RVMM.

$$\text{FSRV} = \text{К};$$
$$\text{RVMM} = 5{,}84 \cdot \text{К} \cdot \text{TW} + 1,$$

where FSRV is the surface area of the right ventricular free wall, К is a longitudinal cross-sectional area measured at the apical position.

The “bullet” formula [6]

The transverse area of the right ventricle is calculated using two mutually perpendicular axes D_1 and D_2, located at equal

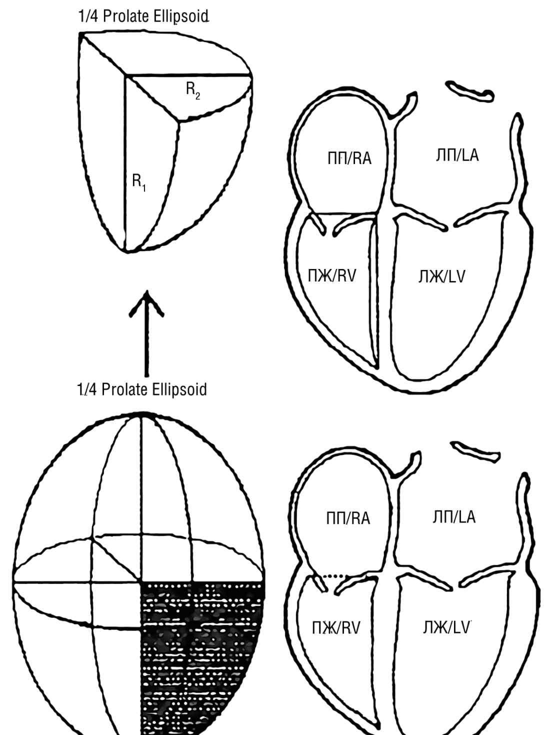

Fig. 1. The one-quarter model prolate ellipsoid surface area (1/4 of the surface area of the ellipsoid, which is taken as the right ventricle) (*a*): R_1 — large radius; R_2 — small radius. The shaded part represents the longitudinal plane. The four-chambered apical position of the heart (*b*): RA — right atrium; RV — right ventricle; LA — left atrium; LV — left ventricle; R_1 — measurement of the length of the pancreatic ventricle; R_2 — measurement of the diameter of the tricuspid valve; the dotted line indicates the measurement of the area of the right ventricle [7]

Рис. 1. Модель one-quarter prolate ellipsoid surface area (1/4 площади поверхности эллипсоида, за который принимается правый желудочек) (*а*): R_1 — большой радиус; R_2 — малый радиус. Заштрихованная часть представляет собой продольную плоскость. Четырехкамерная апикальная позиция сердца (*б*): ПП — правое предсердие; ПЖ — правый желудочек; ЛП — левое предсердие; ЛЖ — левый желудочек; R_1 — измерение длины межжелудочковой перегородки ПЖ; R_2 — измерение диаметра трикуспидального клапана; пунктиром указано измерение площади правого желудочка [7]

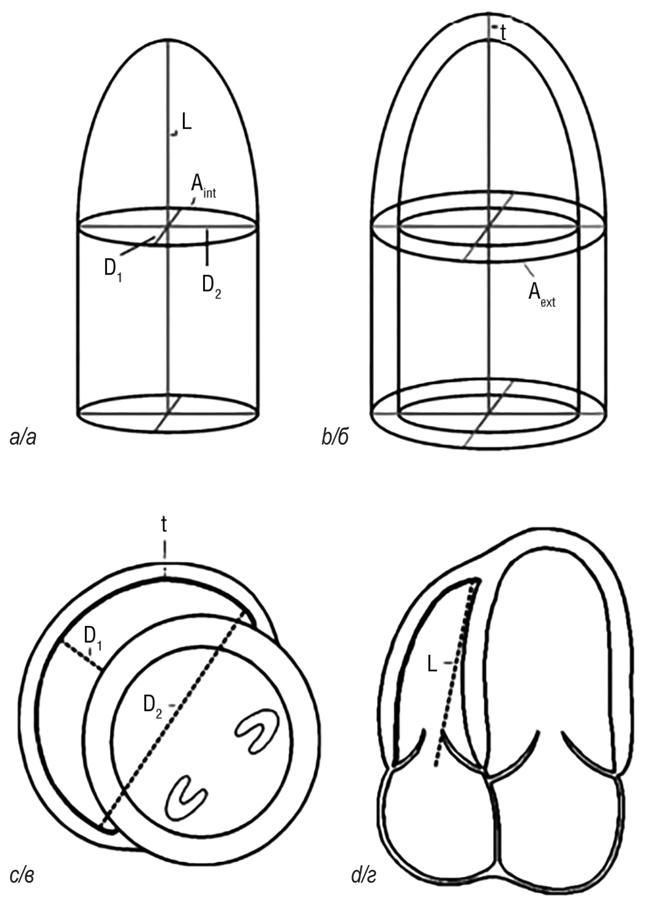

Fig. 2. **The "bullet" formula: *a* — geometric model of the LV; D_1, D_2 — mutually perpendicular axes along the short axis; L — long axis of the LV; *b* — position along the short axis; c — volume of the LV cavity plus the thickness of the myocardium (t); *d* — apical position [7]**

Рис. 2. **Формула «пули»: *а* — геометрическая модель ЛЖ; D_1, D_2 — взаимно перпендикулярные оси по короткой оси, L — длинная ось ЛЖ; *б* — позиция по короткой оси; *в* — объем полости ЛЖ плюс толщина миокарда (t); *г* — апикальная позиция [7]**

distances from the tricuspid ring and the apex of the right ventricle (Fig. 2):

$$\text{RVCCSA} = \frac{5}{24}\pi \cdot D_1 \cdot D_2 \cdot L,$$

where RVCCSA is the cross-sectional area of the RV; D_1 and D_2 are mutual perpendiculars; L is the long axis of the RV (tricuspid-apical axis), measured in the apical position.

Three segment method [6]

This method was developed based on the shape the right ventricle takes when dissected and unfolded (Fig. 3). It requires measuring three segments of the endocardium: *b* — the length of the endocardium in the short-axis position of the aortic valve (Fig. 4, *a*); B — the short-axis length between the tricuspid valve annulus and the apex (Fig. 4, *b*); *h* — the four-chamber position (Fig. 4, *b*).

These segments were measured in diastole and correspond to the two bases and the height of the trapezoid (Fig. 3). The area of the trapezoid was then calculated using the formula:

$$A = \left(\frac{b_1 + B}{2}\right) \cdot h$$

where A is the area of the trapezoid; b_1, B, and h are the endocardial lengths measured in diastole.

Myocardial mass was calculated by multiplying the area of the trapezoid by the RV wall thickness:

$$\text{RVMM} = A \cdot TW \cdot 1{,}055,$$

where RVMM is the myocardial mass of the right ventricular free wall; "A" is the calculated surface area of the trapezoid, TW is the thickness of the right ventricular free wall, 1.055 is the myocardial density (Fig. 3).

Using recent methods, RV myocardial mass can be quite satisfactorily estimated using two-dimensional echocardiography, as confirmed by S.C. Pontes Jr. et al., who compared the calculated mass with anatomical mass. To this end, they conducted tests first on animals and then on humans [6]. However, these methods cannot be considered standard, since RV mass was still underestimated. It should be noted here that RV mass measurement is generally associated with a large number of errors, even when using other methods, such as three-dimensional echocardiography or MRI.

A recent meta-analysis showed that both MRI and 3D echocardiography underestimate ventricular volumes [26]. Thus, there is no non-invasive method that would provide data similar to anatomical ones [6].

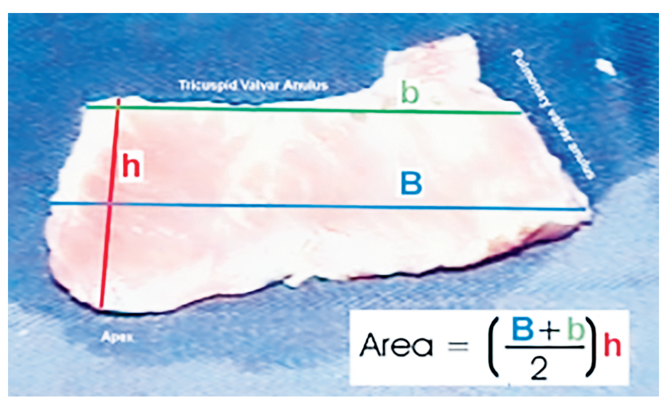

Fig. 3. **Free wall of the pancreas after preparation. Area — the area; B — large base; b — small base; h — height [6]**

Рис. 3. **Свободная стенка правого желудочка после препаровки: Area — площадь; B — большое основание; b — малое основание; h — высота [6]**

CAPABILITIES AND ADVANTAGES OF 3D ECHOCARDIOGRAPHY

Despite all of the above-mentioned difficulties, 3D echocardiography appears to be a highly accurate method for both qualitative and quantitative examination of the RV [11, 27]. Unlike 2D scanning, 3D echocardiography offers numerous advantages, as it does not require geometric assumptions about the true shape of the ventricle or standard images [27].

3D echocardiography combines multiple scanning planes, improving the consistency of boundary detection and allowing each image to be evaluated in three-dimensional relation to others. This technique can effectively reconstruct myocardial segments that cannot be sufficiently visualized due to the anatomical location of the RV. Special algorithms allow for changing the position and orientation to optimize the image; the 3D model can be rotated and viewed. This method allows for more accurate determination of the RV free wall thickness. According to a study by L. Jiang et al., the accuracy of 3D echocardiography was ninefold higher than that of 2D echocardiography [11].

Uneven RV hypertrophy is often described in the literature, depending on the cause of its overload. Thus, with pressure overload, the RV outflow tract wall and/or the myocardium surrounding the supraventricular crest hypertrophy primarily [11]. In this regard, isolated assessment of the RVMM using a two-dimensional method is not always correct, since it may increase due to RV dilation, rather than wall hypertrophy. With isolated RV pressure overload, the RVMM increase occurs due to an increase in wall thickness, while with isolated volume overload without concomitant pulmonary hypertension, the increase occurs due to RV chamber dilation [17].

VISUALIZATION OF PATENT DUCTUS ARTERIALIS USING 3D ECHOCARDIOGRAPHY

3D echocardiography and its unique capabilities for real-time volumetric visualization facilitate highly accurate cardiac chamber assessment. Recently, the method has been used to visualize extracardiac structures [28], such as the aorta, pulmonary trunk, and patent ductus arteriosus, which act as extracardiac shunts during fetal circulation.

A 2012 study by several authors from Ain Shams University Hospital (Cairo) demonstrated the accuracy of 3D echocardiography in determining the size and anatomical type of the patent ductus arteriosus compared to 2D echocardiography and angiography. All 42 consecutive patients

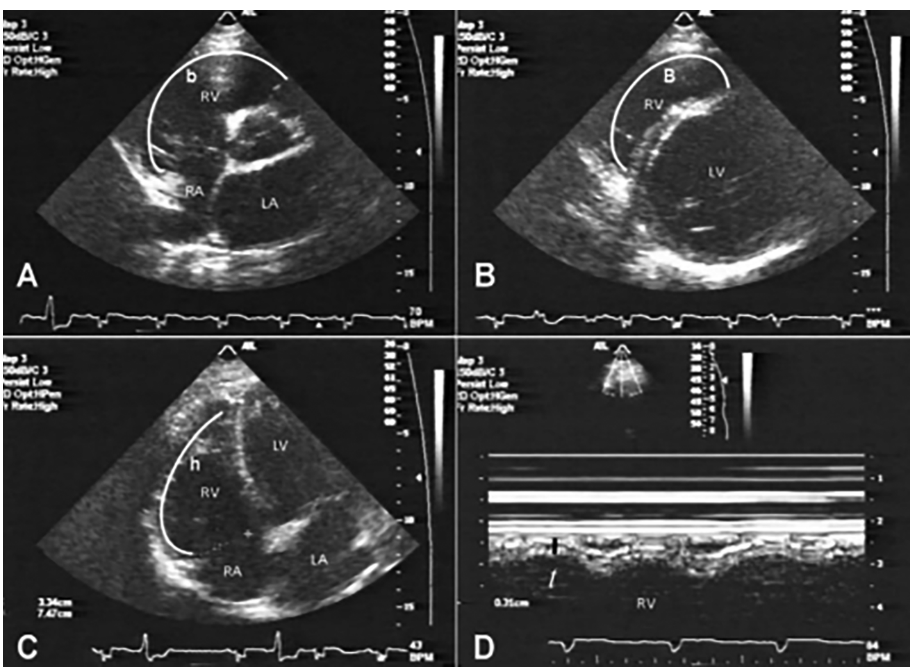

Fig. 4. Measurement of the endocardium using the three segments method: *a* — parasternal position along the short axis at the level of the aortic valve; *b* — parasternal position along the short axis at the papillary muscle level; *c* — apical four-chamber position; *d* — measurement of pancreatic thickness in M-mode. RA — right atrium; LA — left atrium; RV — right ventricle; LV — left ventricle [6]

Рис. 4. Измерение эндокарда по методу трех сегментов: *а* — парастернальная позиция по короткой оси на уровне аортального клапана; *б* — парастернальная позиция по короткой оси на уровне сосочковых мышц; *в* — апикальная четырехкамерная позиция; *г* — измерение толщины ПЖ в М-режиме. RA — правое предсердие (right atrium); LA — левое предсердие (left atrium); RV — правый желудочек (right ventricle); LV — левый желудочек (left ventricle) [6]

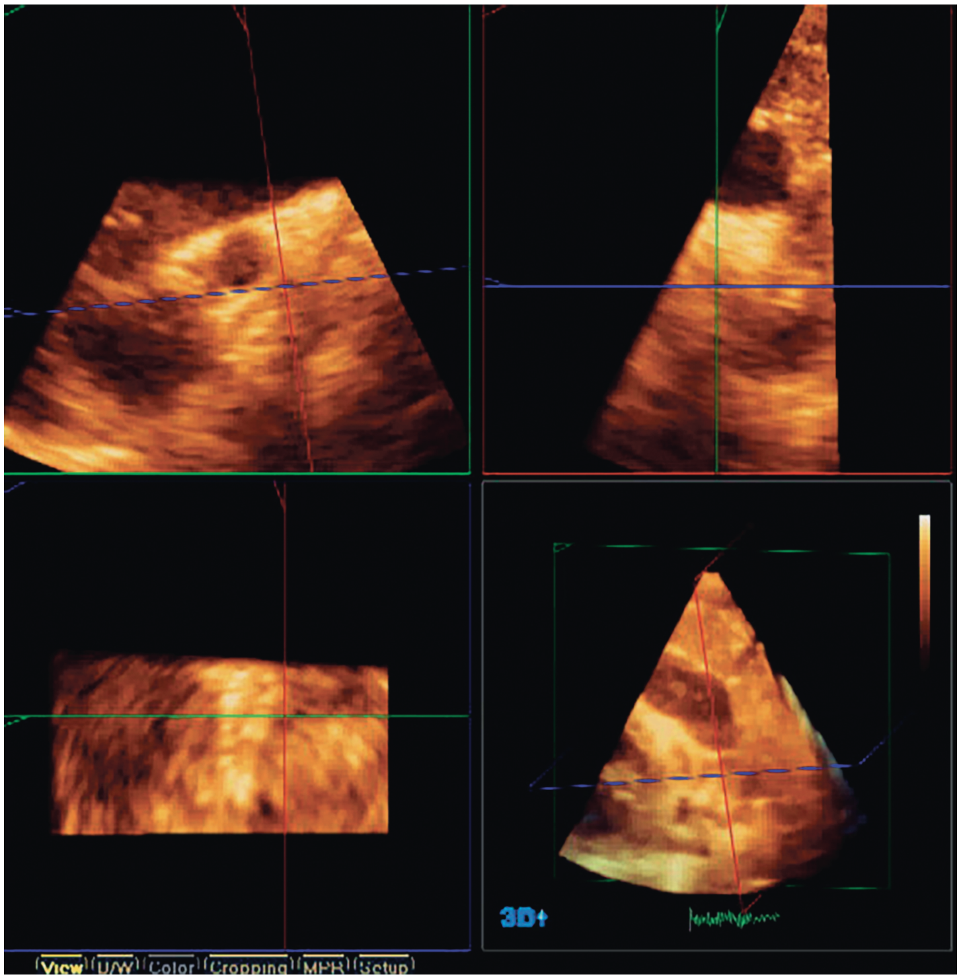

Fig. 5. **Multi-plane reformatted window. Three different projections are visible: the coronary (green square), sagittal (red square) and transverse (blue square). The pulmonary end of the duct is marked by the intersection point of the green and red lines in the blue square**

Рис. 5. **Многоплоскостное переформатированное окно. Видны три разные проекции: коронарная (зеленый квадрат), сагиттальная (красный квадрат) и поперечная (синий квадрат). Легочный конец протока отмечен точкой пересечения зеленой и красной линий в синем квадрате**

underwent 2D echocardiography, 3D echocardiography, and angiography independently by different physicians. The 3D echocardiography study was performed according to guidelines developed in 2008 by specialists at the Mayo Clinic and Loma Linda University Medical Center, USA [29]. Multiplanar reformatting (MPR) imaging was used to simultaneously identify the PDA in three planes (Fig. 5). This unique method allows for precise visualization of the dynamic morphology of the heart.

Based on the results of the study, the following data were obtained on the average PDA size [29]: at its pulmonary end — 1.8±0.5 mm, ranging from 1.1 to 3.4 mm; at the aortic end — from 3.4 to 11 mm, with an average of 7.7±1.4 mm; and on the average ductal length, which was 7.6±1.8 mm, ranging from 2.8 to 10 mm. The ductal length measured using 2D echocardiography averaged 7.1±1.7 mm, while that measured using 3D echocardiography averaged 7.6±1.8 mm. 3D echocardiographic measurement of the PDA length showed better results compared to measurement by angiography, which averaged 7.8±2.3 mm. However, the authors state that “with 2D echocardiography, the PDA length was significantly underestimated compared to measurement by angiography” [29].

At the same time, a 2014 study conducted by scientists from Tanta University yielded similar data as their colleagues from Ain Shams University Hospital, in their investigation of 24 patients using 3D echocardiography. Based on the results obtained, the authors present the following data: "The diameter of the pulmonary end from 1.9 to 3.4 mm with a mean value of 2.6±0.61 mm; the diameter of the aortic end from 3.5 to 9 mm with a mean value of

5.74±1.74 mm; “duct length from 4 to 10 mm with a mean value of 7.29±1.87 mm” [30].

These studies clearly demonstrate the advantages of 3D echocardiography compared to two-dimensional examination [29, 30] and the ability to compete with the rather invasive diagnostic method of angiography, considered the “gold standard” for PDA assessment.

CONCLUSION

Three-dimensional echocardiography is a fairly accurate method for both qualitative and quantitative examination of the right ventricle. Right ventricular myocardial mass assessment is essential for evaluating pathological changes associated with volume and pressure overload in the right ventricle. This is feasible thanks to already developed methods for calculating right ventricular myocardial mass, such as the “Exact Radius Method”, “Simplified Radius Method”, “Longitudinal Plane Method”, “Bullet Method”, and “Three Segment Method”. Patent ductus arteriosus is one of the most common congenital pathologies in the neonatal period. Its assessment using real-time three-dimensional echocardiography allows for the determination of the shape, size (arterial, median, and pulmonary ends), and position of the ductus. Two-dimensional echocardiography is inferior to three-dimensional echocardiography in visualizing the PDA, but its results are comparable to those of angiography and may become an alternative in the future.

ADDITIONAL INFORMATION

Author contribution. Thereby, all authors made a substantial contribution to the conception of the study, acquisition, analysis, interpretation of data for the work, drafting and revising the article, final approval of the version to be published and agree to be accountable for all aspects of the study.

Competing interests. The authors declare that they have no competing interests.

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