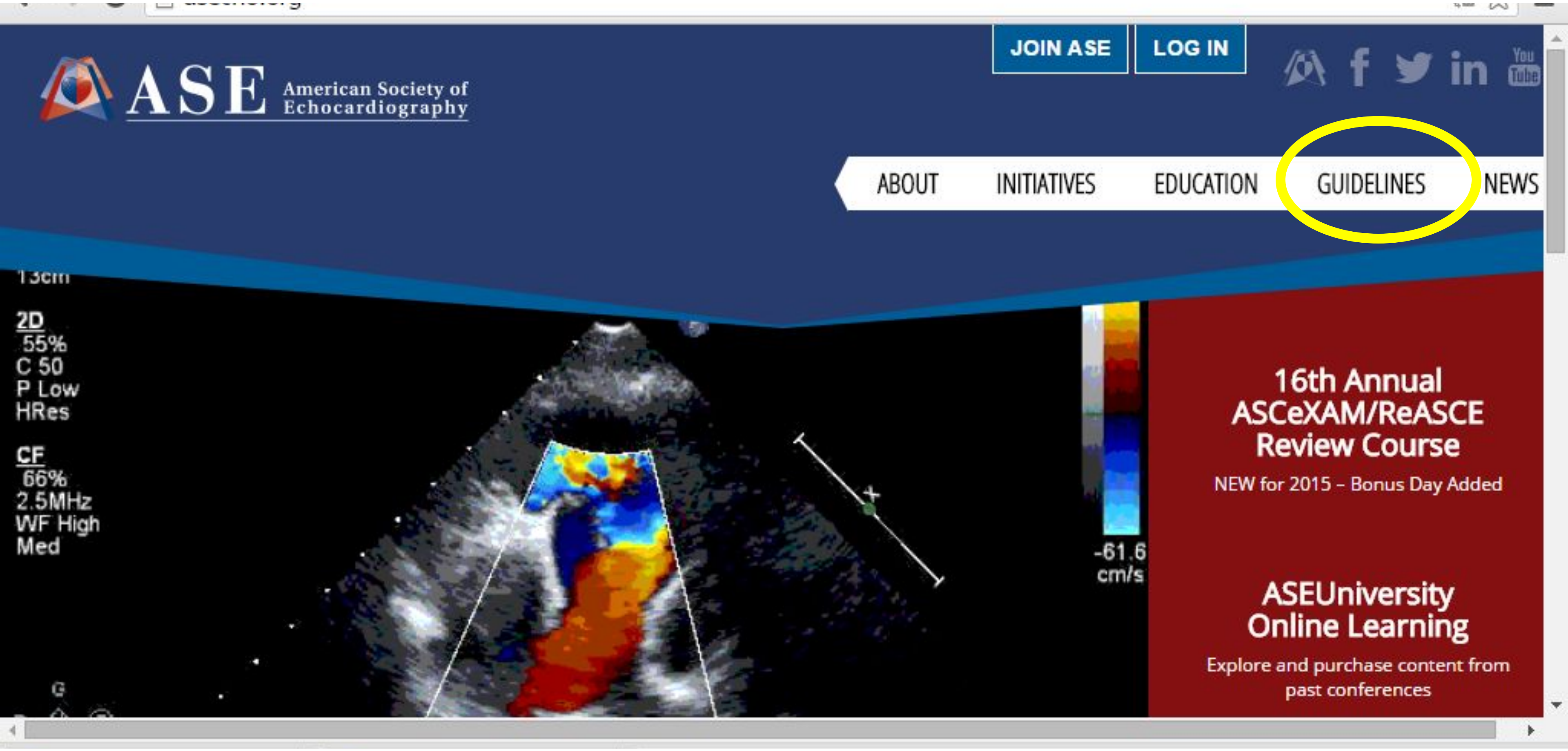
Оценка морфологии и функции правого желудочка



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GUIDELINES AND STANDARDS

Recommendations for Cardiac Chamber Quantification by Echocardiography in Adults: An Update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging

Roberto M. Lang, MD, FASE, FESC, Luigi P. Badano, MD, PhD, FESC, Victor Mor-Avi, PhD, FASE, Jonathan Afilalo, MD, MSc, Anderson Armstrong, MD, MSc, Laura Ernande, MD, PhD, Frank A. Flachskampf, MD, FESC, Elyse Foster, MD, FASE, Steven A. Goldstein, MD, Tatiana Kuznetsova, MD, PhD, Patrizio Lancellotti, MD, PhD, FESC, Denisa Muraru, MD, PhD, Michael H. Picard, MD, FASE, Ernst R. Rietzschel, MD, PhD, Lawrence Rudski, MD, FASE, Kirk T. Spencer, MD, FASE, Wendy Tsang, MD, and Jens-Uwe Voigt, MD, PhD, FESC, *Chicago, Illinois; Padua, Italy; Montreal, Quebec and Toronto, Ontario, Canada; Baltimore, Maryland; Créteil, France; Uppsala, Sweden; San Francisco, California; Washington, District of Columbia; Leuven, Liège, and Ghent, Belgium; Boston, Massachusetts*

ASE/EACI, 2015

Guidelines for the Echocardiographic Assessment of the Right Heart in Adults: A Report from the American Society of Echocardiography

Endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography

Lawrence G. Rudski, MD, FASE, Chair, Wyman W. Lai, MD, MPH, FASE, Jonathan Afilalo, MD, Msc, Lanqi Hua, RDCS, FASE, Mark D. Handschumacher, BSc, Krishnaswamy Chandrasekaran, MD, FASE, Scott D. Solomon, MD, Eric K. Louie, MD, and Nelson B. Schiller, MD, *Montreal, Quebec, Canada; New York, New York; Boston, Massachusetts; Phoenix, Arizona; London, United Kingdom; San Francisco, California*

(J Am Soc Echocardiogr 2010;23:685-713.)

Роль современных методов эхокардиографии в диагностике легочной гипертензии

М.А. САИДОВА, А.С. ЛОСКУТОВА, Е.А. КОБАЛЬ

Институт клинической кардиологии им. А.Л. Мясникова ФГБУ Российский кардиологический научно-производственный комплекс Минздрава РФ. 121552, Москва, ул. 3-я Черепковская, 15 а

The Role of Modern Echocardiography Methods in Diagnosis of Pulmonary Hypertension

M.A. SAIDOVA, A.S. LOSKUTOVA, E.A. KOBAL

Institute of Clinical Cardiology named after A.L. Myasnikov, Russian Cardiology Research and Production Complex. Tretya Cherepkovskaya st., 15a, 121552 Moscow, Russia

В работе представлены диагностические возможности современных эхокардиографических методов в исследовании структурно-функционального состояния правого желудочка, различные способы расчетов давления в легочной артерии, а также приведены нормативные показатели согласно последним рекомендациям Европейского и Американского обществ по эхокардиографии. Предложен алгоритм обследования больных с различной степенью легочной гипертензии, включающий применение новых эхокардиографических технологий.

Ключевые слова: легочная гипертензия, правый желудочек, новые методы эхокардиографии.

The review contains presentation of diagnostic possibilities of contemporary echocardiographic techniques for investigation of structural functional state of the right ventricle and various methods of estimation of pulmonary artery pressure. Normative values of various parameters are adduced according to last recommendations of European and American Electrocardiography Societies. An algorithm of examination of patients with various severity of pulmonary hypertension comprising the use of novel echocardiographic technologies is suggested.

Key words: pulmonary hypertension; pulmonary artery pressure; echocardiography.

Общие рекомендации по оценке ПЖ
(по рек. ASE/EACI, 2015)

- Размеры ПЖ и ПП
- Оценка систолической функции ПЖ хотя бы по одному показателю или нескольким:
- Фракция уменьшение площади ПЖ,
- Скорость s трикусп. кольца по тканевому допплеру
- TAPSE
- RIMP- индекс Теи – миокардиальный индекс
- Систолическое давление в ПЖ – по трикусп. регургитации и реакции НПВ

Основные доступы для оценки ПЖ

Основные доступы

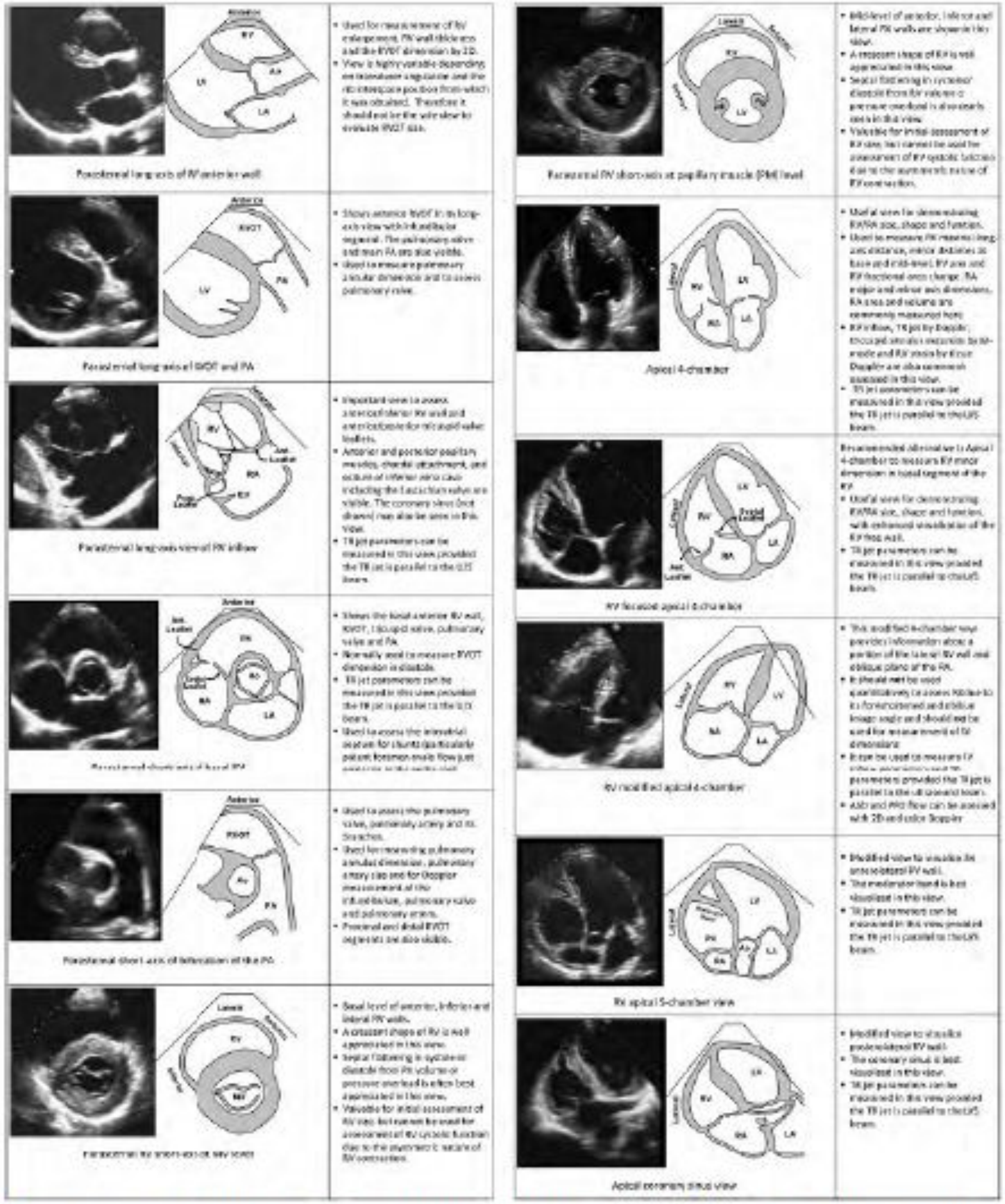
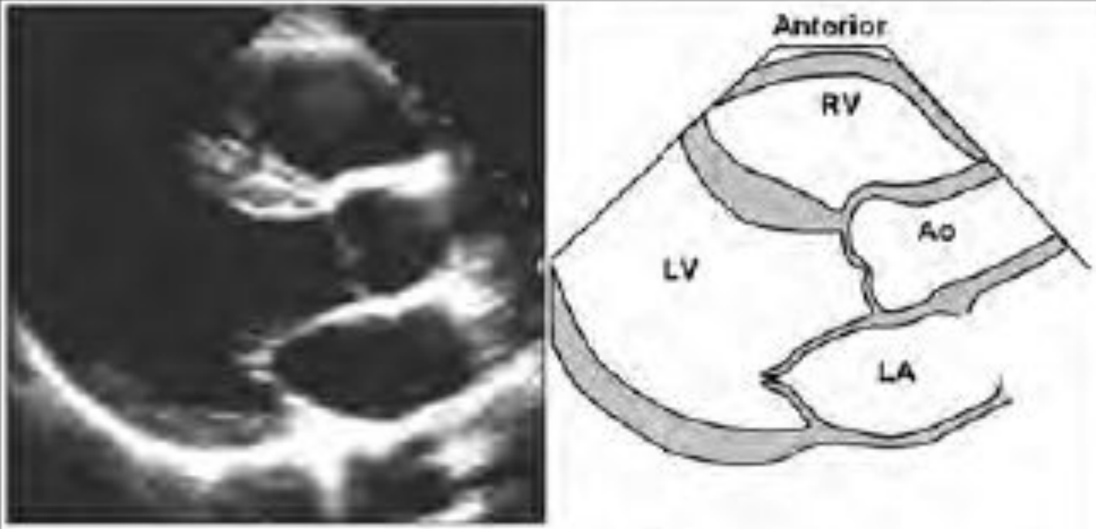
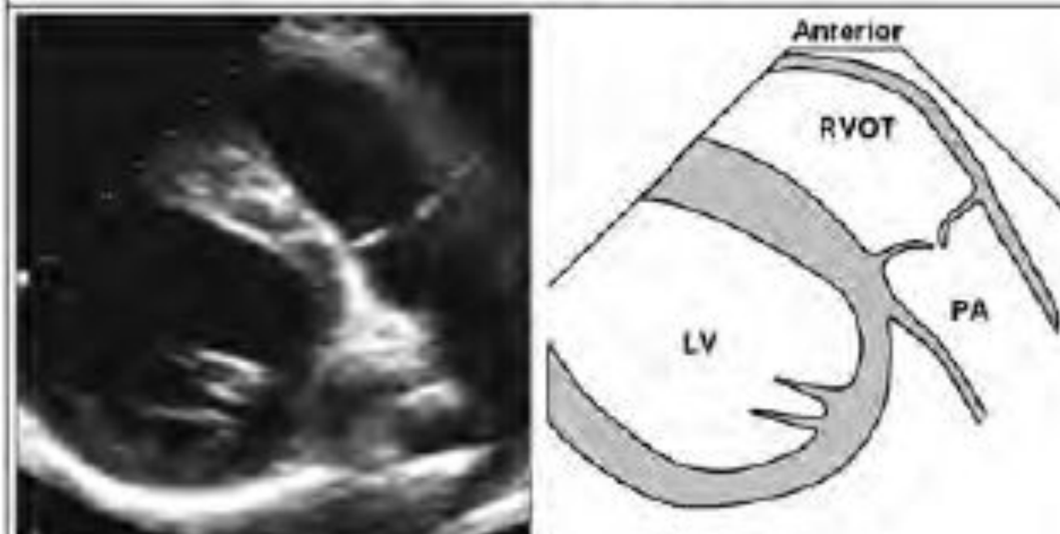
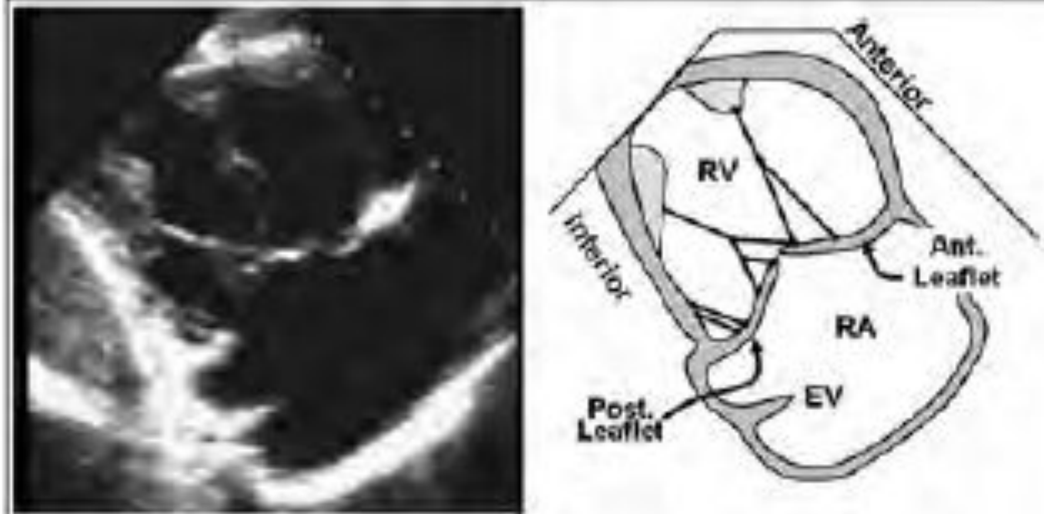


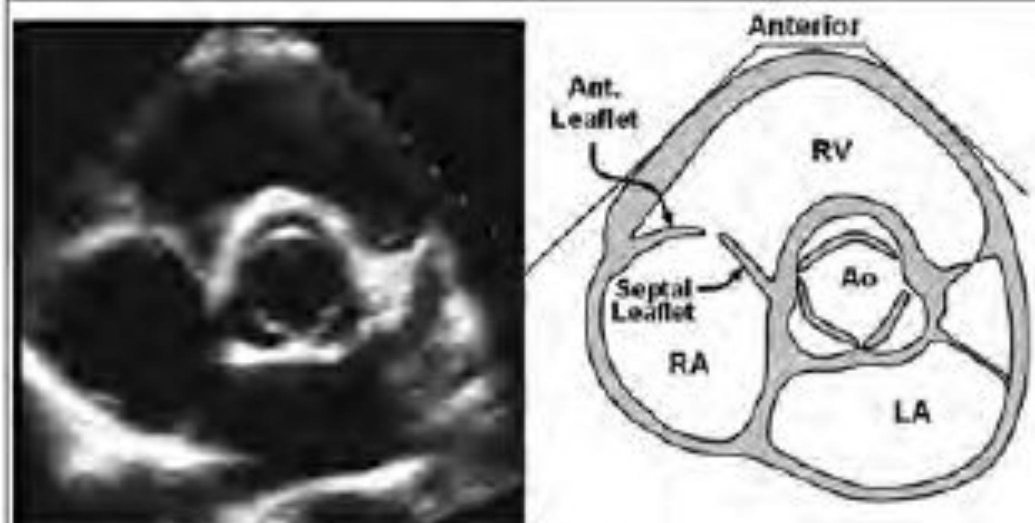
Figure 1 Views used to perform comprehensive evaluation of the right heart. Each view is accompanied by uses, advantages, and limitations of that particular view. *Ao*, aorta; *ASD*, atrial septal defect; *CS*, coronary sinus; *EF*, ejection fraction; *EV*, Eustachian valve; *LA*, left atrium; *LV*, left ventricle; *MV*, mitral valve; *PA*, pulmonary artery; *PFO*, patent foramen ovale; *PM*, papillary muscle; *RA*, right atrium; *RV*, right ventricle; *RVOT*, right ventricular outflow tract; *U/S*, ultrasound.

 Parasternal long-axis of RV anterior wall	• Used for measurement of RV enlargement, RV wall thickness and the RVOT dimension by 2D. • View is highly variable depending on transducer angulation and the rib interspace position from which it was obtained. Therefore it should not be the sole view to evaluate RVOT size.
 Parasternal long-axis of RVOT and PA	• Shows anterior RVOT in its long-axis view with infundibular segment. The pulmonary valve and main PA are also visible. • Used to measure pulmonary annular dimension and to assess pulmonary valve.



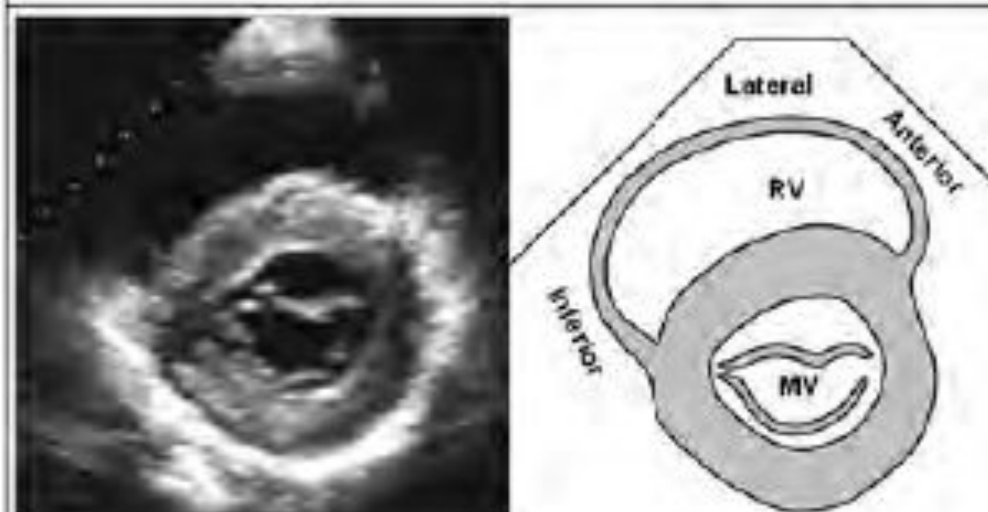
Parasternal long-axis view of RV inflow

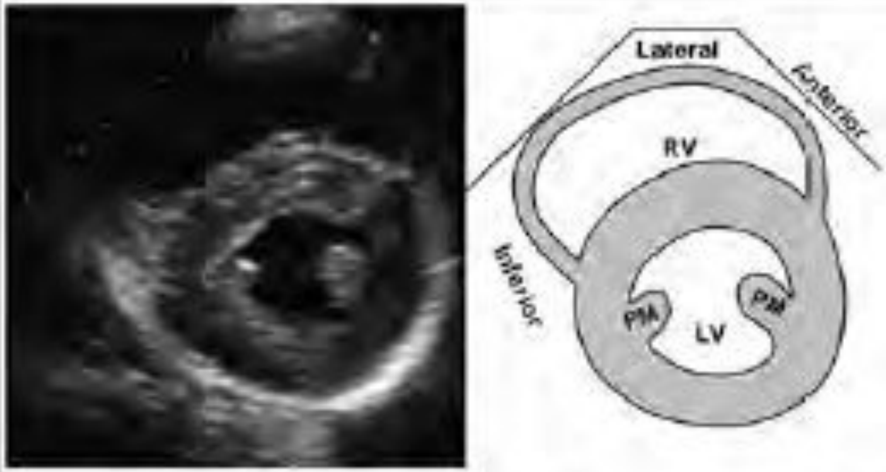
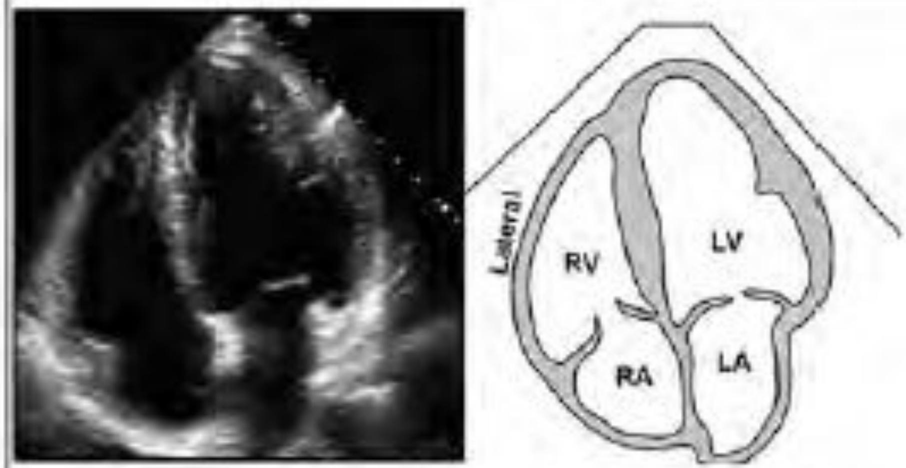
- Important view to assess anterior/inferior RV wall and anterior/posterior tricuspid valve leaflets.
- Anterior and posterior papillary muscles, chordal attachment, and ostium of inferior vena cava including the Eustachian valve are visible. The coronary sinus (not shown) may also be seen in this view.
- TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.

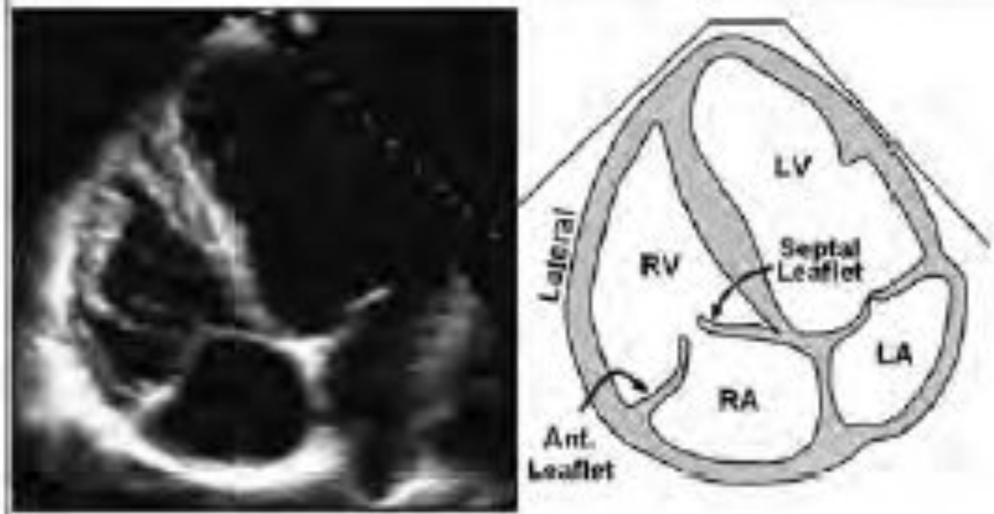


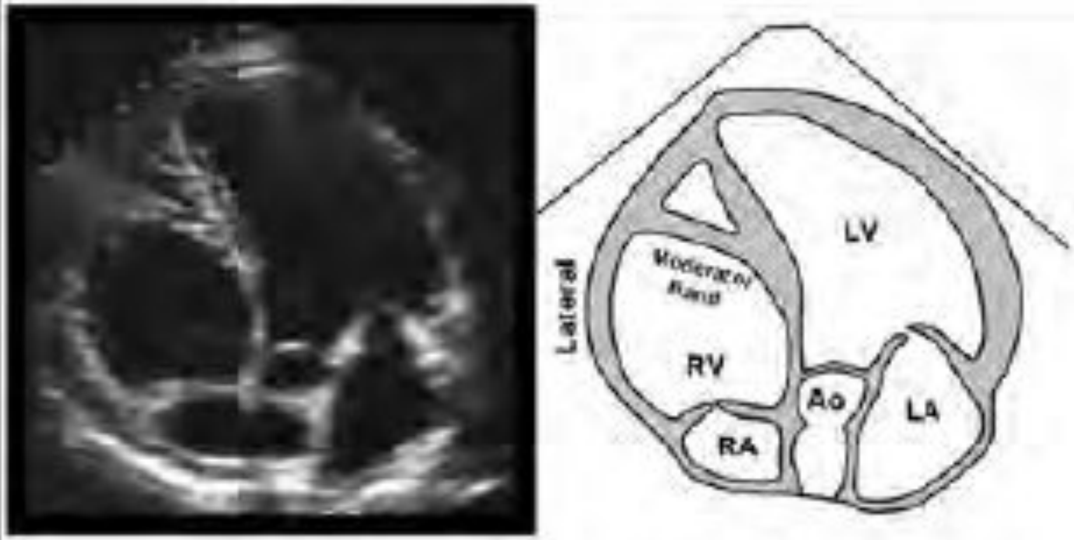
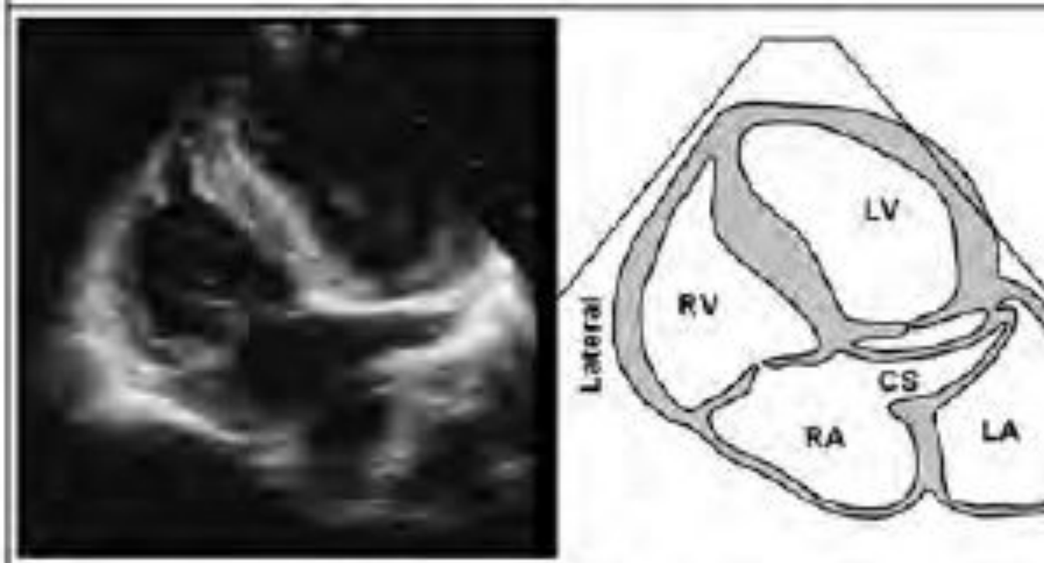
Parasternal short-axis of basal RV

- Shows the basal anterior RV wall, RVOT, tricuspid valve, pulmonary valve and RA.
- Normally used to measure RVOT dimension in diastole.
- TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.
- Used to assess the interatrial septum for shunts (particularly patent foramen ovale flow just posterior to the aortic root

 Parasternal short-axis of bifurcation of the PA	▪ Used to assess the pulmonary valve, pulmonary artery and its branches. ▪ Used for measuring pulmonary annulus dimension, pulmonary artery size and for Doppler measurement of the infundibulum, pulmonary valve and pulmonary artery. ▪ Proximal and distal RVOT segments are also visible.
 Parasternal RV short-axis at MV level	▪ Basal level of anterior, inferior and lateral RV walls. ▪ A crescent shape of RV is well appreciated in this view. ▪ Septal flattening in systole or diastole from RV volume or pressure overload is often best appreciated in this view. ▪ Valuable for initial assessment of RV size, but cannot be used for assessment of RV systolic function due to the asymmetric nature of RV contraction.

 Parasternal RV short-axis at papillary muscle (PM) level	• Mid-level of anterior, inferior and lateral RV walls are shown in this view. • A crescent shape of RV is well appreciated in this view. • Septal flattening in systole or diastole from RV volume or pressure overload is also clearly seen in this view. • Valuable for initial assessment of RV size, but cannot be used for assessment of RV systolic function due to the asymmetric nature of RV contraction.
 Apical 4-chamber	• Useful view for demonstrating RV/RA size, shape and function. • Used to measure RV maximal long-axis distance, minor distances at base and mid-level, RV area and RV fractional area change. RA major and minor axis dimensions, RA area and volume are commonly measured here. • RV inflow, TR jet by Doppler, tricuspid annulus excursion by M-mode and RV strain by tissue Doppler are also commonly assessed in this view. • TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.

	beam.
 RV focused apical 4-chamber	Recommended alternative to Apical 4-chamber to measure RV minor dimension in basal segment of the RV. • Useful view for demonstrating RV/RA size, shape and function, with enhanced visualization of the RV free wall. • TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.
 RV modified apical 4-chamber	• This modified 4-chamber view provides information about a portion of the lateral RV wall and oblique plane of the RA. • It should **not** be used quantitatively to assess RA due to its foreshortened and oblique image angle and should **not** be used for measurement of RV dimensions • It can be used to measure RV inflow parameters and TR parameters provided the TR jet is parallel to the ultrasound beam. • ASD and PFO flow can be assessed with 2D and color Doppler

 RV apical 5-chamber view	▪ Modified view to visualize the anterolateral RV wall. ▪ The moderator band is best visualized in this view. ▪ TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.
 Apical coronary sinus view	▪ Modified view to visualize posterolateral RV wall. ▪ The coronary sinus is best visualized in this view. ▪ TR jet parameters can be measured in this view provided the TR jet is parallel to the U/S beam.

Размеры ПЖ

Стандартная одно – и двухмерная ЭхоКГ

- Ограничения: зависимость от угла сканирования и получения «среза» ПЖ
- Более признано измерение ширины выносящего тракта ПЖ дистального и проксимального отделов, особенно при ЛГ
- Толщина ПСПЖ – из эпигастрального доступа
- Сравнение размеров ЛЖ и ПЖ из апикального доступа

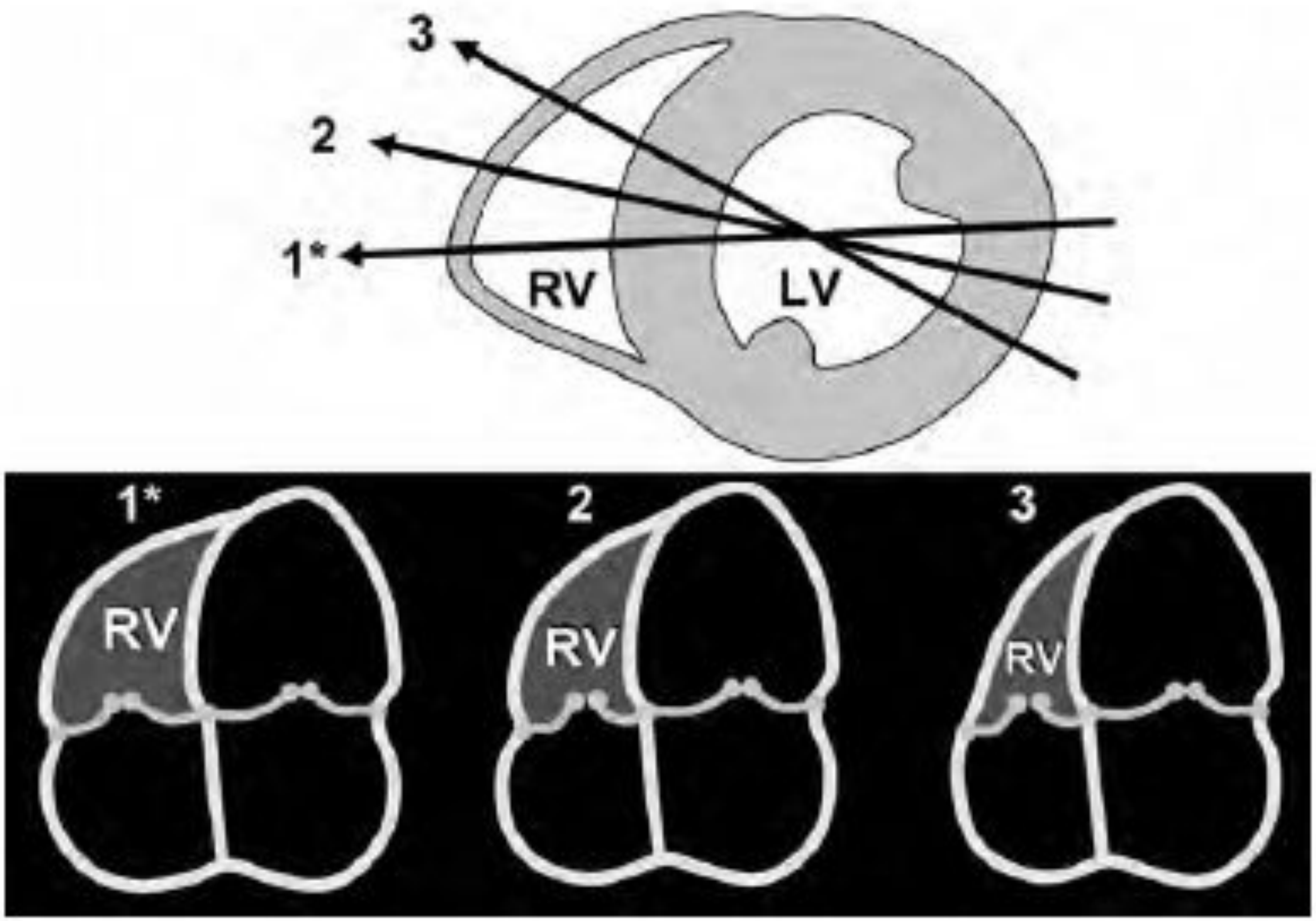


Figure 6 Diagram showing the recommended apical 4-chamber (A4C) view with focus on the right ventricle (RV) (1*) and the sensitivity of right ventricular size with angular change (2,3) despite similar size and appearance of the left ventricle (LV). The lines of intersection of the A4C planes (1*,2,3) with a mid left ventricular short-axis are shown above and corresponding A4C views below.

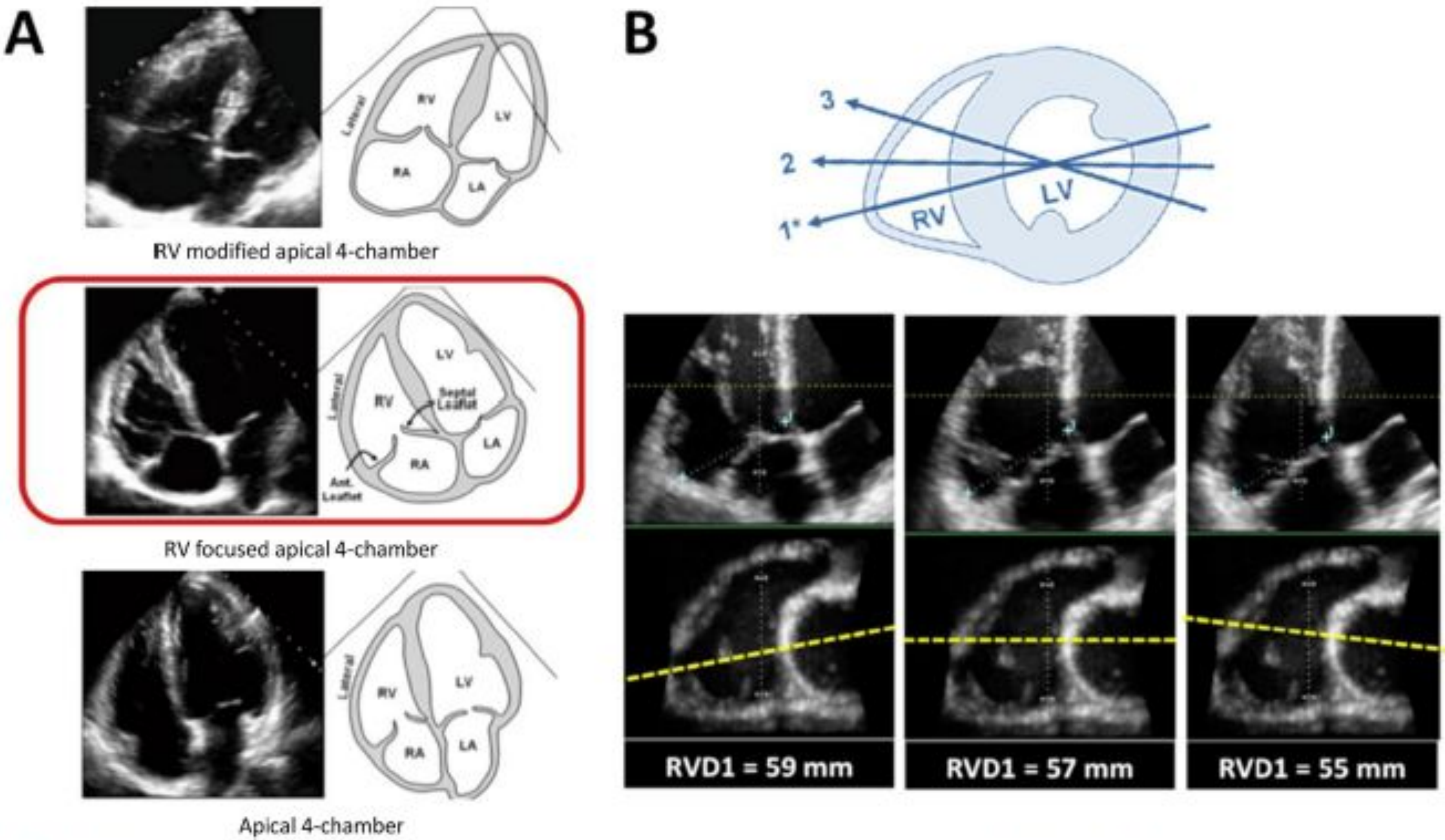


Figure 7 **(A)** Three apical images demonstrating different views of the right ventricle (RV). The middle image shows the right ventricular–focused view. **(B)** The rationale for maximizing the right ventricular basal dimension in the right ventricular–focused view. Below the cartoon, by manipulating offline the same 3D right ventricular data set, it is apparent that minor variations in the four-chamber plane position (*dashed line*) with respect to the right ventricular crescent shape may result in variability of right ventricular size when performed by linear measurements.

Parasternal long-axis of RVOT and PA

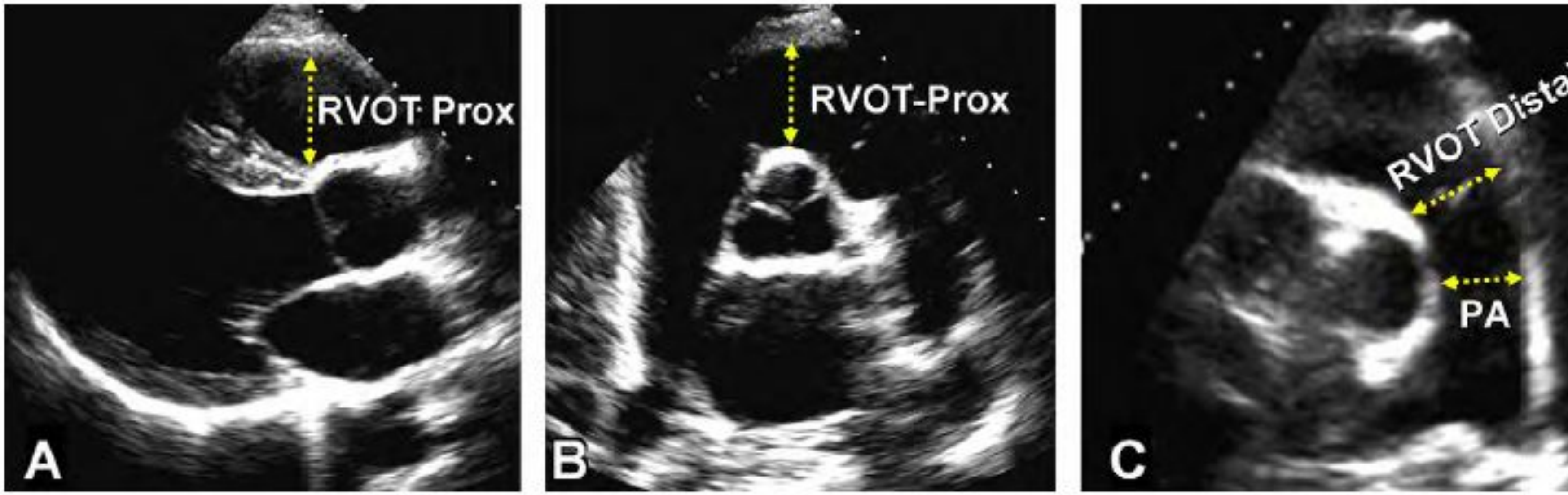


Figure 8 Measurement of right ventricular outflow tract (RVOT) dimensions at the proximal or subvalvular level (RVOT-Prox) and at the distal or pulmonic valve (RVOT-Distal) in the **(A)** parasternal long-axis RVOT anterior portion view, **(B)** basal parasternal short-axis view, and **(C)** parasternal short-axis of pulmonary bifurcation view. *PA*, Pulmonary artery dimension between valve and the bifurcation point.

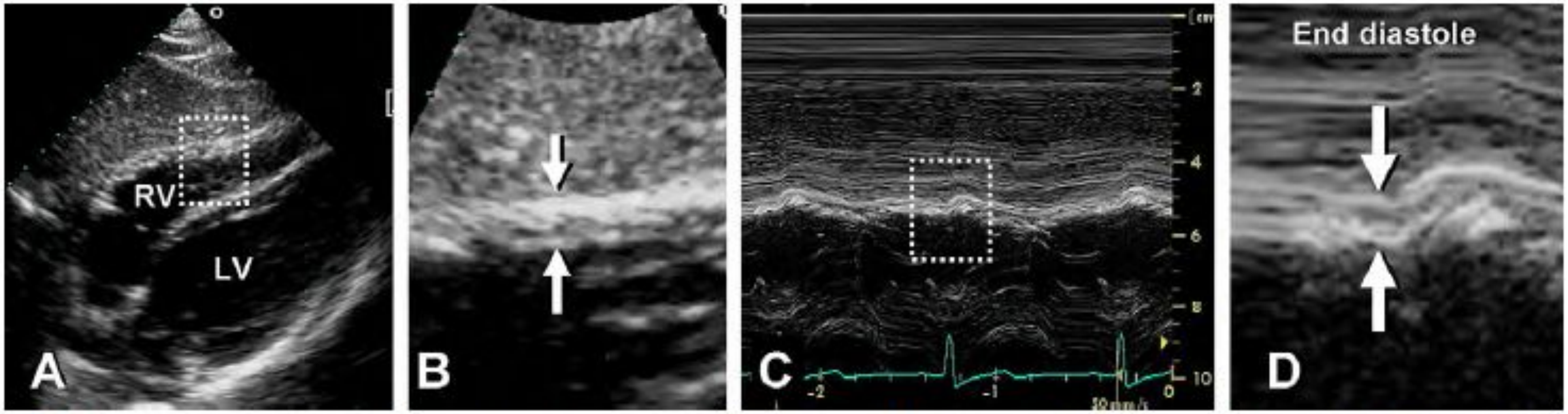


Figure 5 Measurement of end-diastolic right ventricular wall thickness. **(A)** Subcostal 2-dimensional image of right ventricular wall. **(B)** Zoom of region outlined in **(A)** with right ventricular wall thickness indicated by *arrows*. **(C)** M-mode image corresponding to *arrows* in **(B)**. **(D)** Zoom of region outlined in **(C)** with *arrows* indicating wall thickness at end-diastole.

Норма до 5 мм

- Увеличение Тпспж – при ЛГ
- Уменьшение – АДПЖ

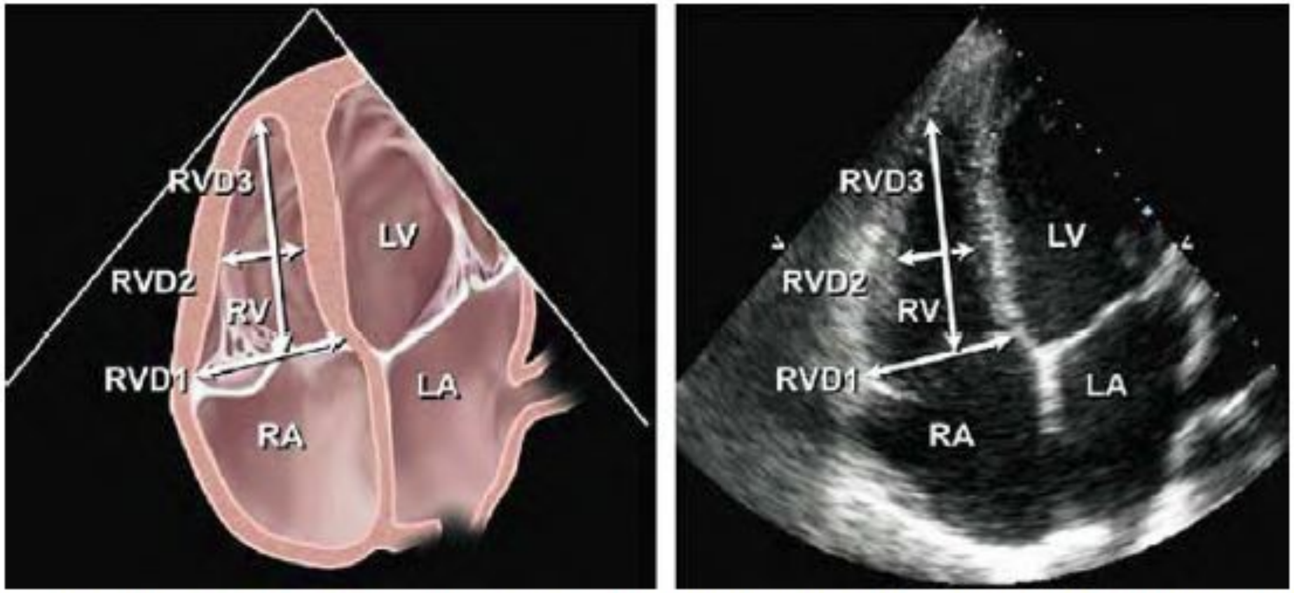


Figure 7 Diagram *(left)* and corresponding echocardiographic apical 4-chamber image *(right)* showing the right ventricular (RV) basal (RVD1) and mid cavity (RVD2) RV minor dimensions and the RV longitudinal dimension (RVD3). The transducer is adjusted to focus on the RV chamber, with the goal of maximizing RV chamber size. The RV free wall is better seen in this view, also facilitating measurements for fractional area change. Reproduced from *J Am Soc Echocardiogr.*[1]

В норме в апикальной позиции
размер ПЖ меньше ЛЖ и составляет примерно 2/3 от ЛЖ

Recommendations: Patients with echocardiographic evidence of right-sided heart disease or PH should ideally have measurements of RV basal, mid cavity, and longitudinal dimensions on a 4-chamber view. In all complete echocardiographic studies, the RV basal measurement should be reported, and the report should state the window from which the measurement was performed (ideally the right ventricle–focused view), to permit interstudy comparisons. The relative size of the right ventricle should be compared with that of the LV to help the study interpreter determine if there is RV dilatation, and the interpreter may report the right ventricle as dilated despite measuring within the normal range, on the basis of a right ventricle appearing significantly larger than the left ventricle. The upper reference limit for the RV basal dimension is 4.2 cm(Table 2).

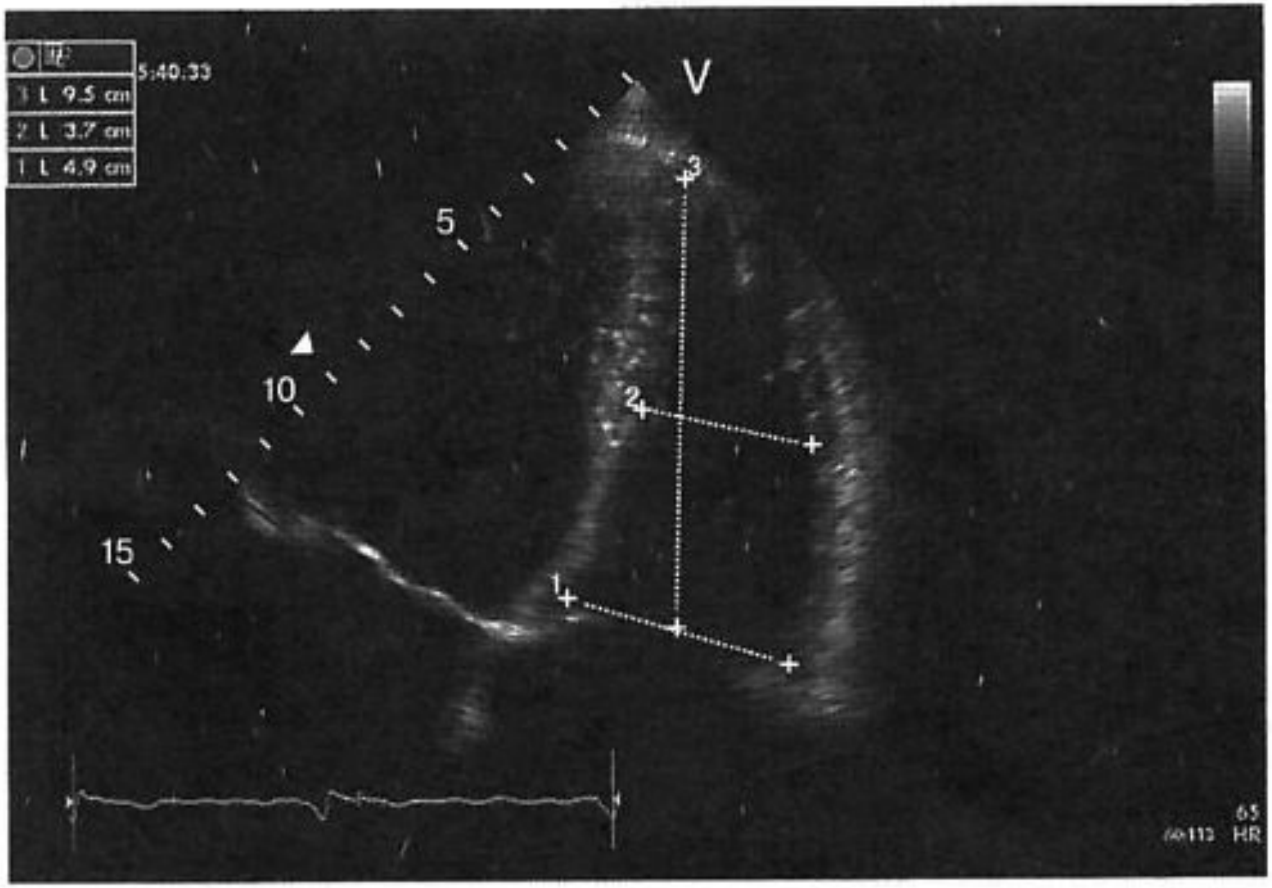


***Рис. 1.* Измерение линейных показателей ПЖ в апикальной четырехкамерной позиции по данным двумерной ЭхоКГ.**

ПЖ — правый желудочек; ЭхоКГ — эхокардиография.

Измеряют базальный и средний поперечный размеры ПЖ. Увеличение базального размера ПЖ более 4.2 см указывает на его дилатацию

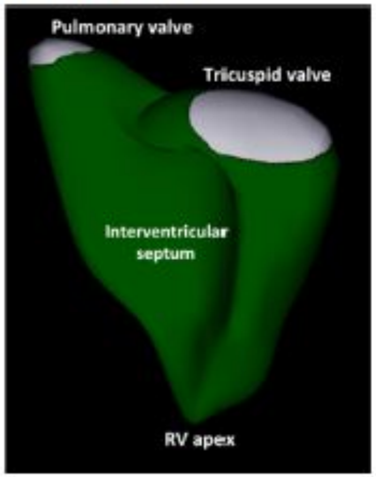
Table 7 Recommendations for the echocardiographic assessment of RV size

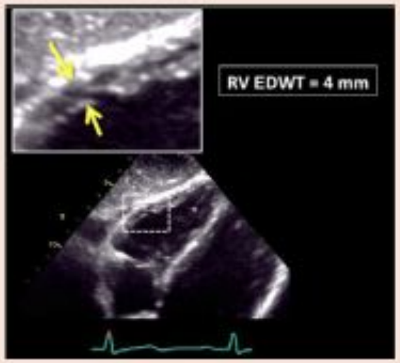
Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV linear dimensions (inflow)* 	• Basal RV linear dimension (RVD1) = maximal transversal dimension in the basal one third of RV inflow at end-diastole in the *RV-focused view* • Mid-cavity RV linear dimension (RVD2) = transversal RV diameter in the middle third of RV inflow, approximately halfway between the maximal basal diameter and the apex, at the level of papillary muscles at end-diastole.	• Easily obtainable • Simple • Fast • Wealth of published data	• RV size may be underestimated due to the crescent RV shape • RV linear dimensions are dependent on probe rotation and different RV views; in order to permit inter-study comparison, the echocardiography report should state the window from which the measurement was performed.
RV linear dimensions (outflow)*  	• Proximal RV outflow diameter (RVOT prox) = linear dimension measured from the anterior RV wall to the interventricular septal-aortic junction (in parasternal long-axis view) or to the aortic valve (in parasternal short-axis) at end-diastole • Distal RV outflow diameter (RVOT distal) = linear transversal dimension measured just proximal to the pulmonary valve at end-diastole	• Easily obtainable • Simple • Fast	• RVOT prox is dependent on imaging plane position and less reproducible than RVOT distal • Risk of underestimation or overestimation if the RV view is obliquely oriented with respect to RV outflow tract • RV outflow dimensions can be inaccurate in case of chest and spine deformities • Endocardial definition of the RV anterior wall is often suboptimal • Limited normative data is available • Regional measure; may not reflect global RV size (underestimation or overestimation)

RV areas (inflow)  	• Manual tracing of RV endocardial border from the lateral tricuspid annulus along the free wall to the apex and back to medial tricuspid annulus, along the interventricular septum at end-diastole and at end-systole • Trabeculations, papillary muscles and moderator band are included in the cavity area	• Relatively easy to measure	• Challenging in case of sub-optimal image quality of RV free wall • Challenging in the presence of trabeculation • RV size underestimation if RV cavity is foreshortened • Due to the LV twisting motion and the crescent RV shape, the end-diastolic RV image may not be in the same tomographic plane as the end-systolic one • May not accurately reflect global RV size (underestimation or overestimation)

(*Continued*)

Table 7 (*Continued*)

Echocardiographic imaging	Recommended methods	Advantages	Limitations
3DE RV volumes 	• Dedicated multibeat 3D acquisition, with minimal depth and sector angle (for a temporal resolution > 20–25 volumes/sec) that encompasses entire RV cavity • Automatically identified timing of end-diastole and end-systole should be verified • Myocardial trabeculae and moderator band should be included in the cavity	• Unique measures of RV global size that includes inflow, outflow and apical regions • Independent of geometric assumptions • Validated against cardiac magnetic resonance	• Dependent on image quality, regular rhythm, patient cooperation • Needs specific 3D echocardiographic equipment and training • Reference values established in few publications

RV wall thickness 	• Linear measurement of RV free wall thickness (either by M-mode or 2DE) performed at end-diastole, below the tricuspid annulus at a distance approximating the length of anterior tricuspid leaflet, when it is fully open and parallel to the RV free wall. • Trabeculae, papillary muscles and epicardial fat should be excluded • Zoomed imaging with focus on the RV mid-wall and respiratory maneuvers may improve endocardial border definition	• Easy to perform	• Single-site measurement • Harmonic imaging and oblique M-mode sampling may overestimate RV wall thickness • Challenging in case of thickening of visceral pericardium • There is no criterion for defining an abnormally thin RV wall

*All linear dimensions should be obtained using inner-edge-to-inner-edge method.

Table 8 Normal values for RV chamber size

Parameter	Mean ± SD	Normal range
RV basal diameter (mm)	33 ± 4	25-41
RV mid diameter (mm)	27 ± 4	19-35
RV longitudinal diameter (mm)	71 ± 6	59-83
RVOT PLAX diameter (mm)	25 ± 2.5	20-30
RVOT proximal diameter (mm)	28 ± 3.5	21-35
RVOT distal diameter (mm)	22 ± 2.5	17-27
RV wall thickness (mm)	3 ± 1	1-5
RVOT EDA (cm^2)		
Men	17 ± 3.5	10-24
Women	14 ± 3	8-20
RV EDA indexed to BSA (cm^2/m^2)		
Men	8.8 ± 1.9	5-12.6
Women	8.0 ± 1.75	4.5-11.5
RV ESA (cm^2)		
Men	9 ± 3	3-15
Women	7 ± 2	3-11
RV ESA indexed to BSA (cm^2/m^2)		
Men	4.7 ± 1.35	2.0-7.4
Women	4.0 ± 1.2	1.6-6.4
RV EDV indexed to BSA (mL/m^2)		
Men	61 ± 13	35-87
Women	53 ± 10.5	32-74
RV ESV indexed to BSA (mL/m^2)		
Men	27 ± 8.5	10-44
Women	22 ± 7	8-36

EDA, end-diastolic area; *ESA*, end-systolic area; *PLAX*, parasternal long-axis view; *RVOT*, RV outflow tract.

Систолическая функция ПЖ

8. RV Systolic Function

RV systolic function has been evaluated using multiple parameters (Table 9), including RIMP, TAPSE, 2D FAC, 3DE EF, S′, and longitudinal strain and strain rate by DTI and 2D STE.[25] Multiple studies have demonstrated the clinical utility and value of RIMP, TAPSE, 2D FAC, and S′ of the tricuspid annulus, as well as longitudinal speckle-tracking echocardiographic strain. RV EF by 3DE seems to be more reliable and have better reproducibility when properly performed, and a growing body of data are currently available to provide normal reference values (Table 10 and Supplemental Table 8).

- **Фракция изменения площади**
- **RIMP (индекс Теи по тканевому допплеру)**
- **TAPSE**
- **ФВ в трехмерном режиме**
- **Скорость сокращения s в тканевом допплере**

Оценка сократимости ПЖ (дополнение)

- **TAPSE – систолическая экскурсия кольца ТК**
- **Размер ПП отражает диастолическую дисфункцию ПЖ (наиболее признано измерять площадь ПП)**
- **Фракция изменения площади ПЖ (систола/диастола)**
- **Скорость сокращения s при тканевой допплерографии кольца ТК**
- **Индекс Теи**
- **Размеры ЛЖ: при высокой ЛГ происходит компрессия ЛЖ и нарушение его диастолического наполнения E<A**
- **Скорость повышение внутрижелудочкового давления в систолу**
- **Деформация миокарда и скорость деформации**

Фракция изменения площади ПЖ в систолу и диастолу (аналог ФВ для ЛЖ)

Норма – более 35% (по др. данным более 45%)

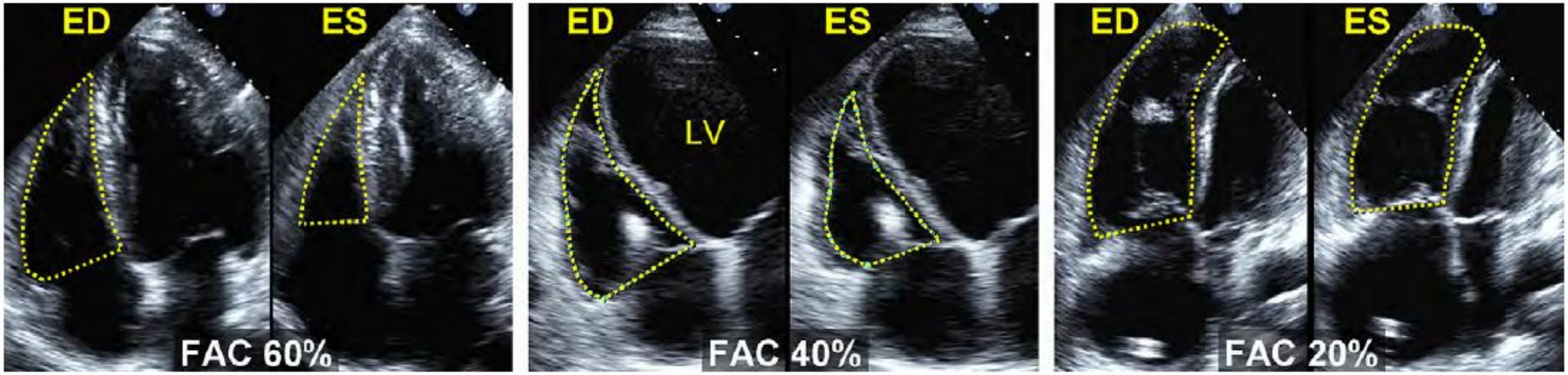


Figure 9 Examples of right ventricular fractional area change (FAC). Percentage FAC = 100 × end-diastolic area (AreaED) − end-systolic area (Area ES)/end-diastolic area. The endocardial border is traced in apical 4-chamber (A4C) views from the tricuspid annulus along the free wall to the apex, then back to the annulus, along the interventricular septum at end-diastole (ED) and end-systole (ES). Trabeculation, tricuspid leaflets, and chords are included in the chamber. *(Left)* Normal subject, FAC 60%. *(Middle)* Moderately dilated right ventricle (RV), FAC 40%, and a markedly dilated left ventricle (LV). *(Right)* Dilated RV, FAC 20%, and the LV is foreshortened as a result of optimizing the view for the right ventricular chamber.

Индекс Теи

(миокардиальный индекс, индекс функции миокарда)

8.1. RIMP. RIMP is an index of global RV performance. The isovolumic contraction time, the isovolumic relaxation time, and ejection time intervals should be measured from the same heartbeat using either PW spectral Doppler or DTI velocity of the lateral tricuspid annulus (Table 9). When using PW spectral Doppler to calculate RIMP, it important to ensure that the nonconsecutive beats have similar RR intervals. This limitation does not apply to the DTI-based RIMP measurements. RIMP can be falsely low in conditions

Индекс Теи

(миокардиальный индекс,
индекс функции
миокарда)

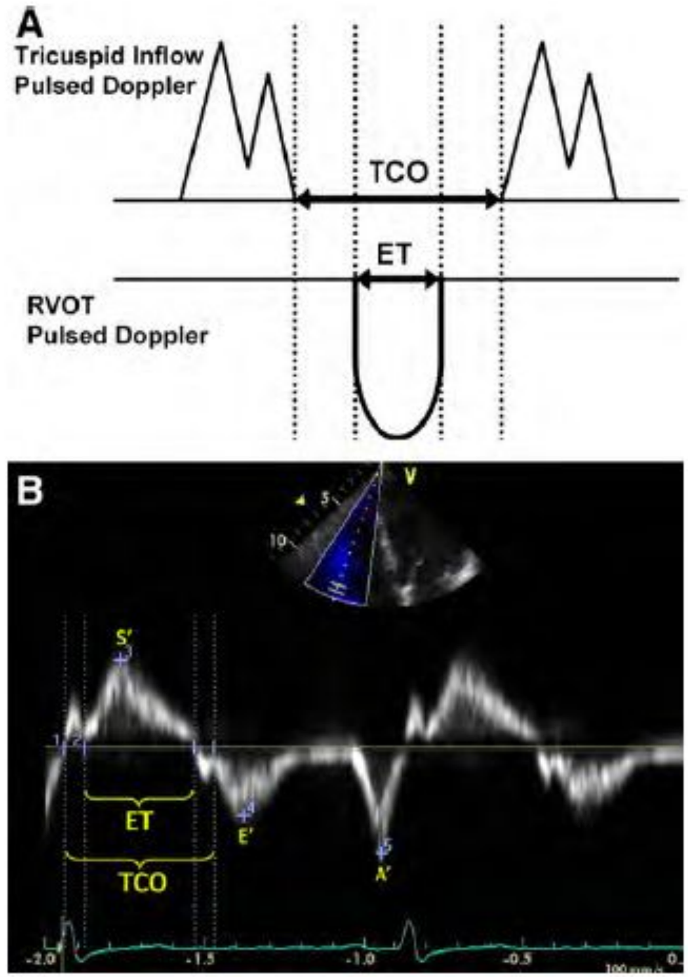


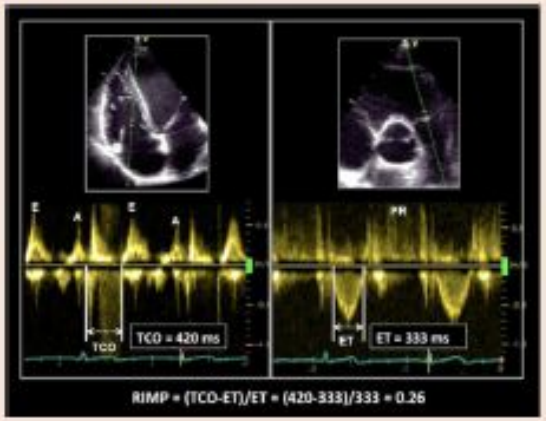
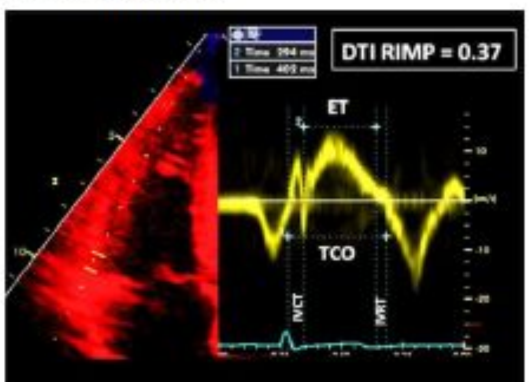
Figure 16 Calculation of right ventricular myocardial performance index (MPI) by pulsed Doppler **(A)** and pulsed tissue Doppler **(B)**. The tricuspid (valve) closure opening time (TCO) encompasses isovolumic contraction time, ejection time (ET), and isovolumic relaxation time. In the pulsed Doppler method, TCO can also be measured by the duration of the tricuspid regurgitation continuous-wave Doppler signal. MPI = (TCO − ET)/ET. Note that S′, E′, and A′ are also measured from the same pulsed Doppler tissue image.

Таблица 5.6. Оценка систолической функции желудочка и степени ее нарушения по допплеровскому индексу (индексу Tei) (Anderson B., 2000)

Функция желудочка	Допплеровский индекс (индекс Tei)
Нормальная	$<0{,}4$
Незначительно снижена	0,4–0,5
Умеренно снижена	0,5–0,9
Значительно снижена	$>1{,}0$

ТСО – время открытого ТК

Table 9 Recommendations for the echocardiographic assessment of RV function

Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV global function			
Pulsed Doppler RIMP 	RIMP (Tei index) by pulsed Doppler: RIMP = (TCO − ET)/ET	• Prognostic value • Less affected by heart rate	• Requires matching for R-R intervals when measurements are performed on separate recordings • Unreliable when RA pressure is elevated
Tissue Doppler RIMP 	RIMP by tissue Doppler: RIMP = (IVRT + IVCT)/ET = (TCO − ET)/ET	• Less affected by heart rate • Single-beat recording with no need for R-R interval matching	• Unreliable when RA pressure is elevated

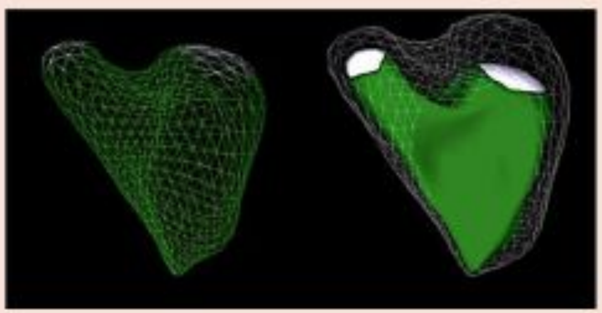
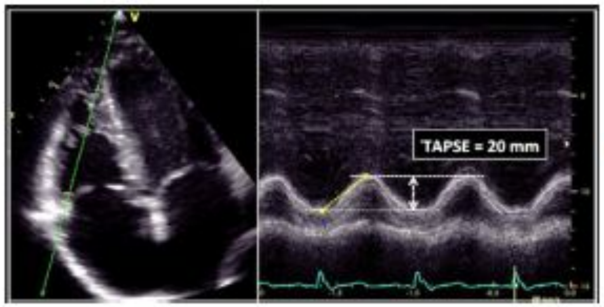
RV global systolic function			
FAC 	RV FAC in RV-focused apical four-chamber view: RV FAC (%) = 100 × (EDA − ESA)/EDA	• Established prognostic value • Reflects both longitudinal and radial components of RV contraction • Correlates with RV EF by CMR	• Neglects the contribution of RV outflow tract to overall systolic function • Only fair inter-observer reproducibility
EF 	Fractional RV volume change by 3D TTE: RV EF (%) = 100 × (EDV − ESV)/EDV	• Includes RV outflow tract contribution to overall function • Correlates with RV EF by CMR	• Dependent on adequate image quality • Load dependency • Requires offline analysis and experience • Prognostic value not established

Table 9 (*Continued*)

Echocardiographic imaging	Recommended methods	Advantages	Limitations
RV longitudinal systolic function TAPSE 	• Tricuspid annular longitudinal excursion by M-mode (mm), measured between end-diastole and peak systole • Proper alignment of M-mode cursor with the direction of RV longitudinal excursion should be achieved from the apical approach.	• Established prognostic value • Validated against radionuclide EF	• Angle dependency • Partially representative of RV global function*

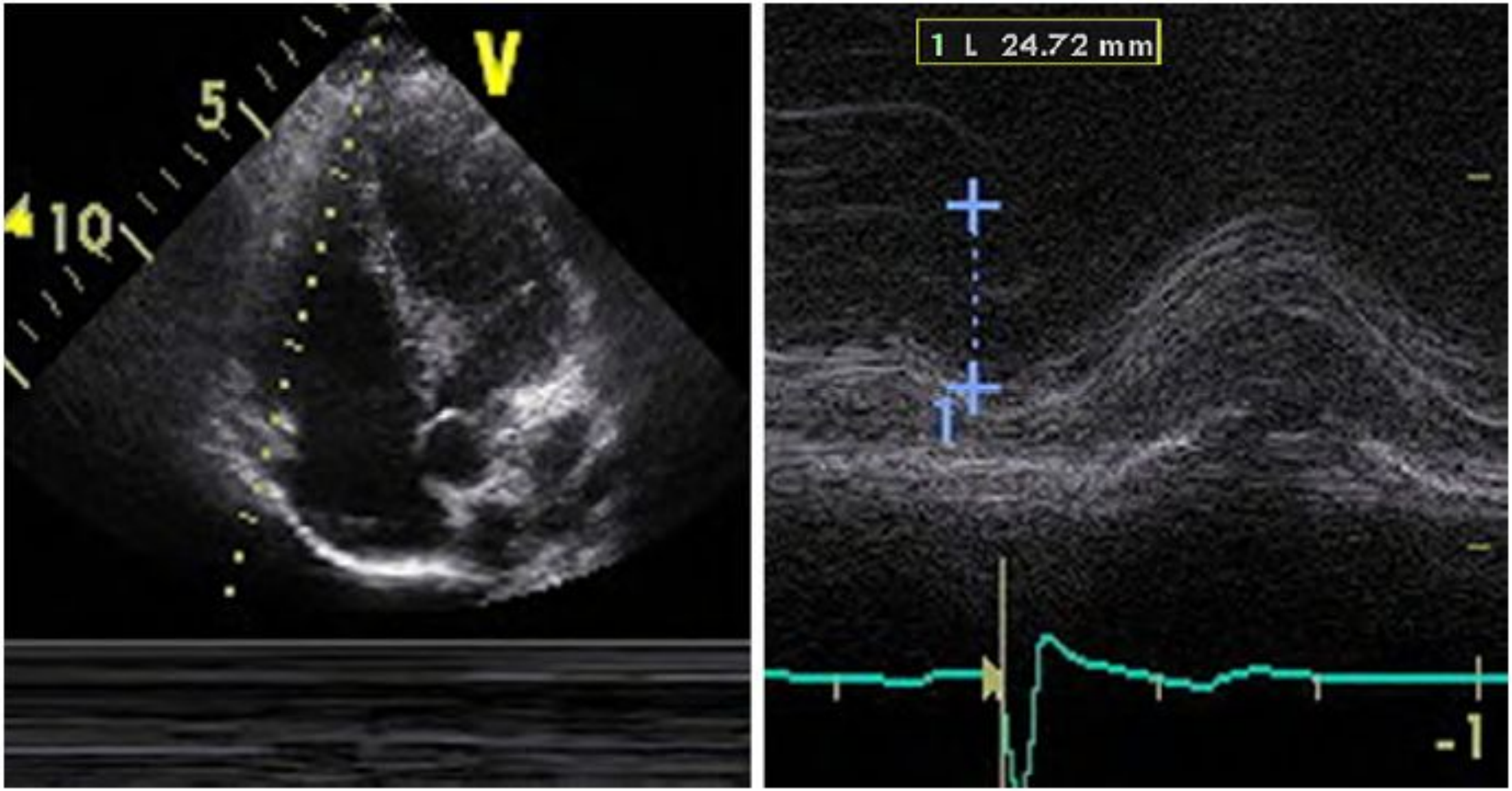
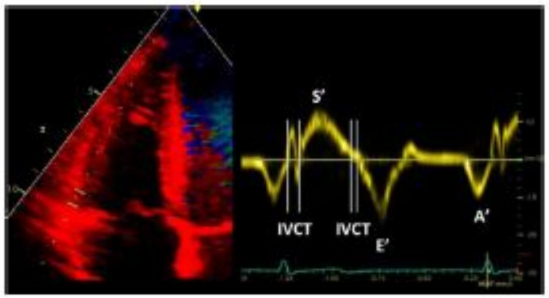
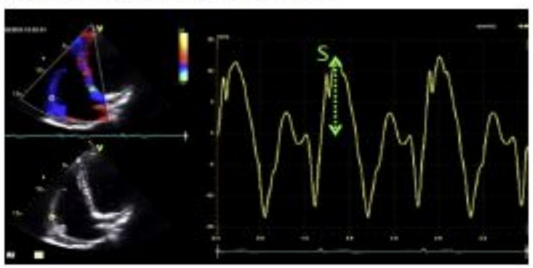
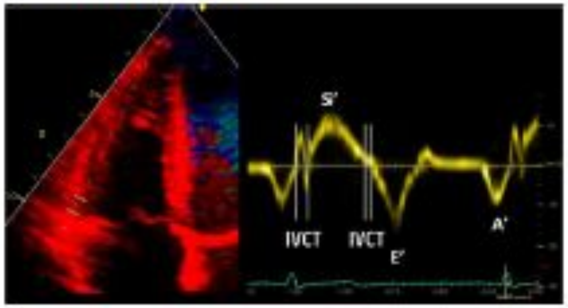
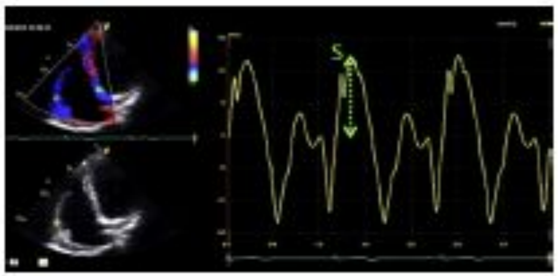
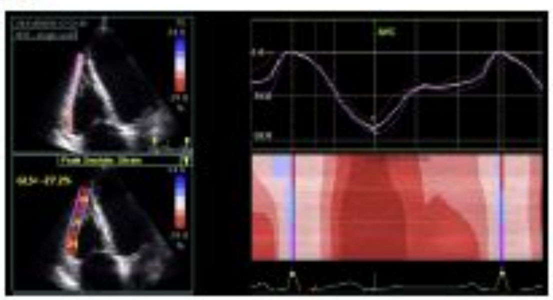


Figure 17 Measurement of tricuspid annular plane systolic excursion (TAPSE).

TAPSE менее 16 мм отражает снижение сократимости ПЖ

Pulsed tissue Doppler S wave 	• Peak systolic velocity of tricuspid annulus by pulsed-wave DTI (cm/sec), obtained from the apical approach, in the view that achieves parallel alignment of Doppler beam with RV free wall longitudinal excursion	• Easy to perform • Reproducible • Validated against radionuclide EF • Established prognostic value	• Angle dependent • Not fully representative of RV global function, particularly after thoracotomy, pulmonary thromboendarterectomy or heart transplantation
Color tissue Doppler S wave 	• Peak systolic velocity of tricuspid annulus by color DTI (cm/sec)	• Sampling is performed after image acquisition • Allows multisite sampling on the same beat	• Angle dependent • Not fully representative of RV global function, particularly after thoracotomy, pulmonary thrombendarterectomy or heart transplantation • Lower absolute values and reference ranges than pulsed DTI S' wave • Requires offline analysis
GLS 	• Peak value of 2D longitudinal speckle tracking derived	• Angle independent • Established prognostic	• Vendor dependent

Pulsed tissue Doppler S wave 	• Peak systolic velocity of tricuspid annulus by pulsed-wave DTI (cm/sec), obtained from the apical approach, in the view that achieves parallel alignment of Doppler beam with RV free wall longitudinal excursion	• Easy to perform • Reproducible • Validated against radionuclide EF • Established prognostic value	• Angle dependent • Not fully representative of RV global function, particularly after thoracotomy, pulmonary thromboendarterectomy or heart transplantation
Color tissue Doppler S wave 	• Peak systolic velocity of tricuspid annulus by color DTI (cm/sec)	• Sampling is performed after image acquisition • Allows multisite sampling on the same beat	• Angle dependent • Not fully representative of RV global function, particularly after thoracotomy, pulmonary thrombendarterectomy or heart transplantation • Lower absolute values and reference ranges than pulsed DTI S′ wave • Requires offline analysis
GLS 	• Peak value of 2D longitudinal speckle tracking derived strain, averaged over the three segments of the RV free wall in RV-focused apical four-chamber view (%)	• Angle independent • Established prognostic value	• Vendor dependent

EDA, End-diastolic area; *ESA*, end-systolic area; *ET*, ejection time; *GLS*, gold longitudinal strain; *IVCT*, isovolumic contraction time; *TCO*, tricuspid valve closure–to–opening time.

Тканевой допплер кольца ТК. Оценка скорости сокращения s

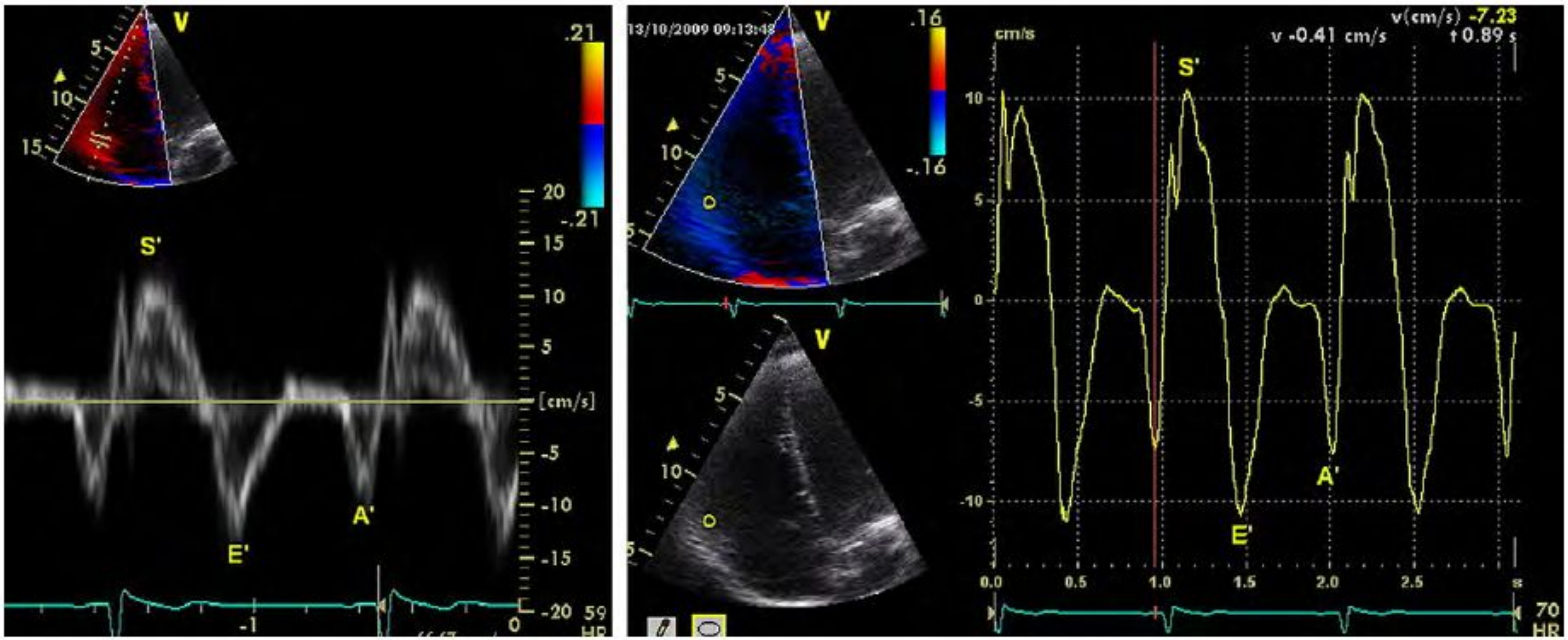


Figure 18 Tissue Doppler of the tricuspid annulus in a patient with normal right ventricular systolic function: (*left*) pulsed and (*right*) color-coded offline analysis.

При s <10 см/ск – снижение сократимости ПЖ

Table 10 Normal values for parameters of RV function

Parameter	Mean ± SD	Abnormality threshold
TAPSE (mm)	24 ± 3.5	<17
Pulsed Doppler S wave (cm/sec)	14.1 ± 2.3	<9.5
Color Doppler S wave (cm/sec)	9.7 ± 1.85	<6.0
RV fractional area change (%)	49 ± 7	<35
RV free wall 2D strain* (%)	−29 ± 4.5	>−20 (<20 in magnitude with the negative sign)
RV 3D EF (%)	58 ± 6.5	<45
Pulsed Doppler MPI	0.26 ± 0.085	>0.43
Tissue Doppler MPI	0.38 ± 0.08	>0.54
E wave deceleration time (msec)	180 ± 31	<119 or >242
E/A	1.4 ± 0.3	<0.8 or >2.0
e′/a′	1.18 ± 0.33	<0.52
e′	14.0 ± 3.1	<7.8
E/e′	4.0 ± 1.0	>6.0

MPI, Myocardial performance index.

*Limited data; values may vary depending on vendor and software version.

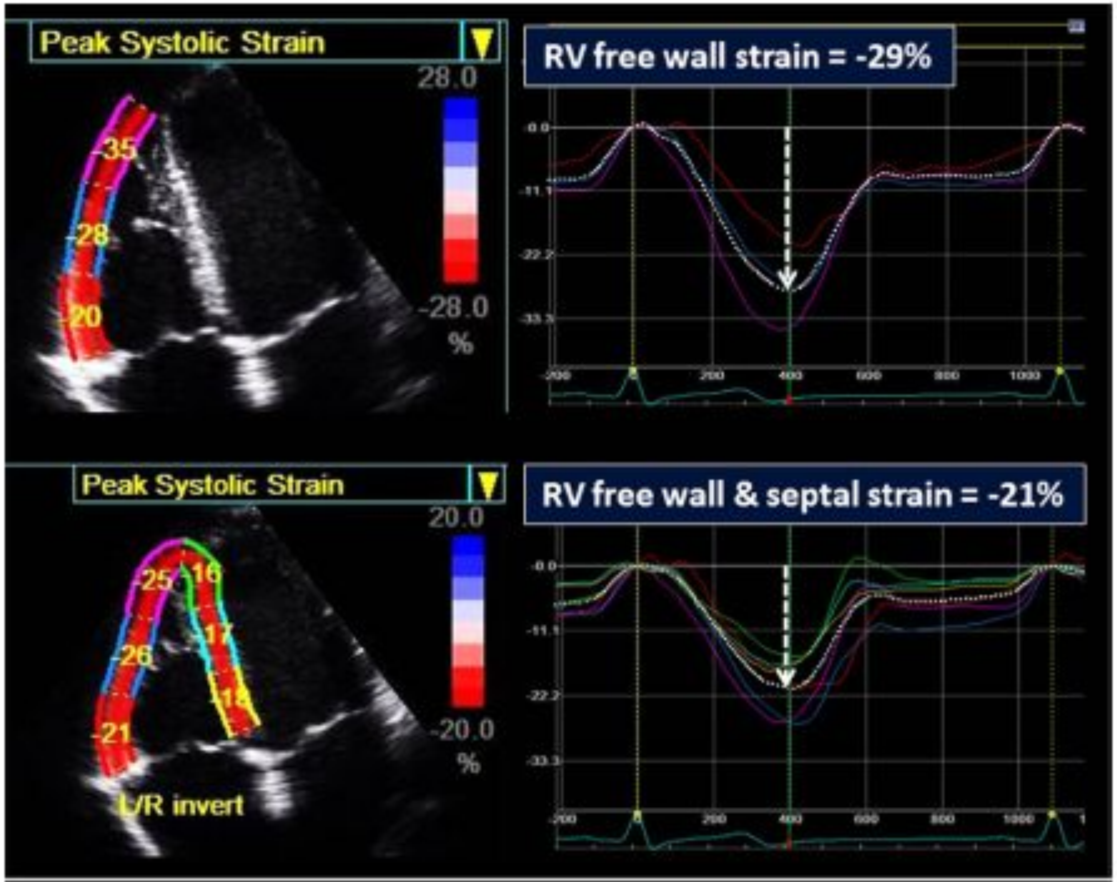


Figure 9 Measurement of RV systolic strain by 2D STE. The upper panel demonstrates RV "global" free wall strain whereby the three segments of the free wall are averaged, and the lower panel demonstrates "global" longitudinal strain of the six segments of the apical four-chamber view: three free wall and three septal segments. Note that RV longitudinal strain is significantly higher (as an absolute value) than the strain averaged from both septal and free wall segments. Until a universal standard is established, the interpretation of RV longitudinal strain values should take into account the methodology and vendor- and method-specific reference values.

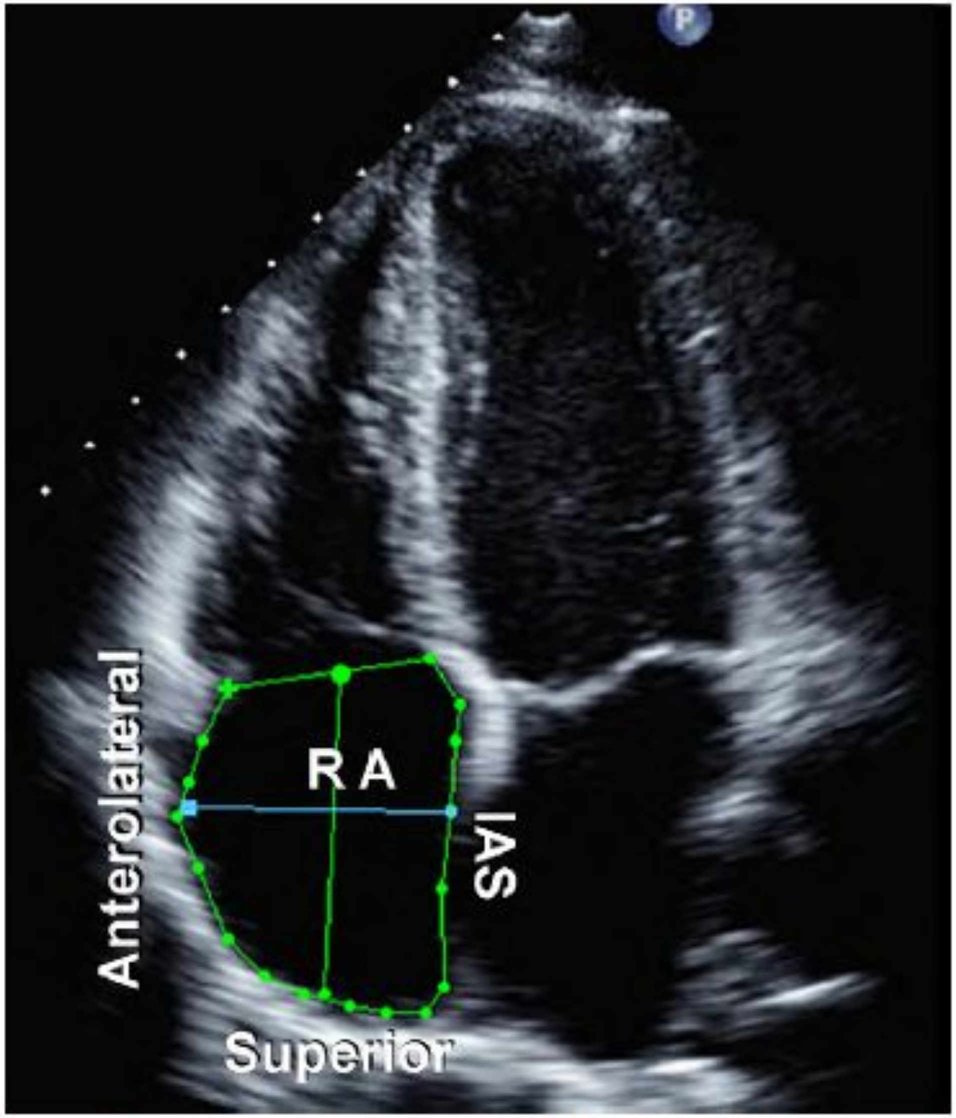


Figure 3 Tracing of the right atrium (RA) is performed from the plane of the tricuspid annulus (TA), along the interatrial septum (IAS), superior and anterolateral walls of the RA. The right atrial major dimension is represented by the *green line* from the TA center to the superior right atrial wall, and the right atrial minor dimension is represented by the *blue line* from the anterolateral wall to the IAS.

В норме в апикальной позиции
размер ПЖ меньше ЛЖ и составляет примерно 2/3 от ЛЖ

Размер ПП отражает Диастолическую функцию ПЖ
(н. до 18 см2)

Индекс эксцентричности ЛЖ

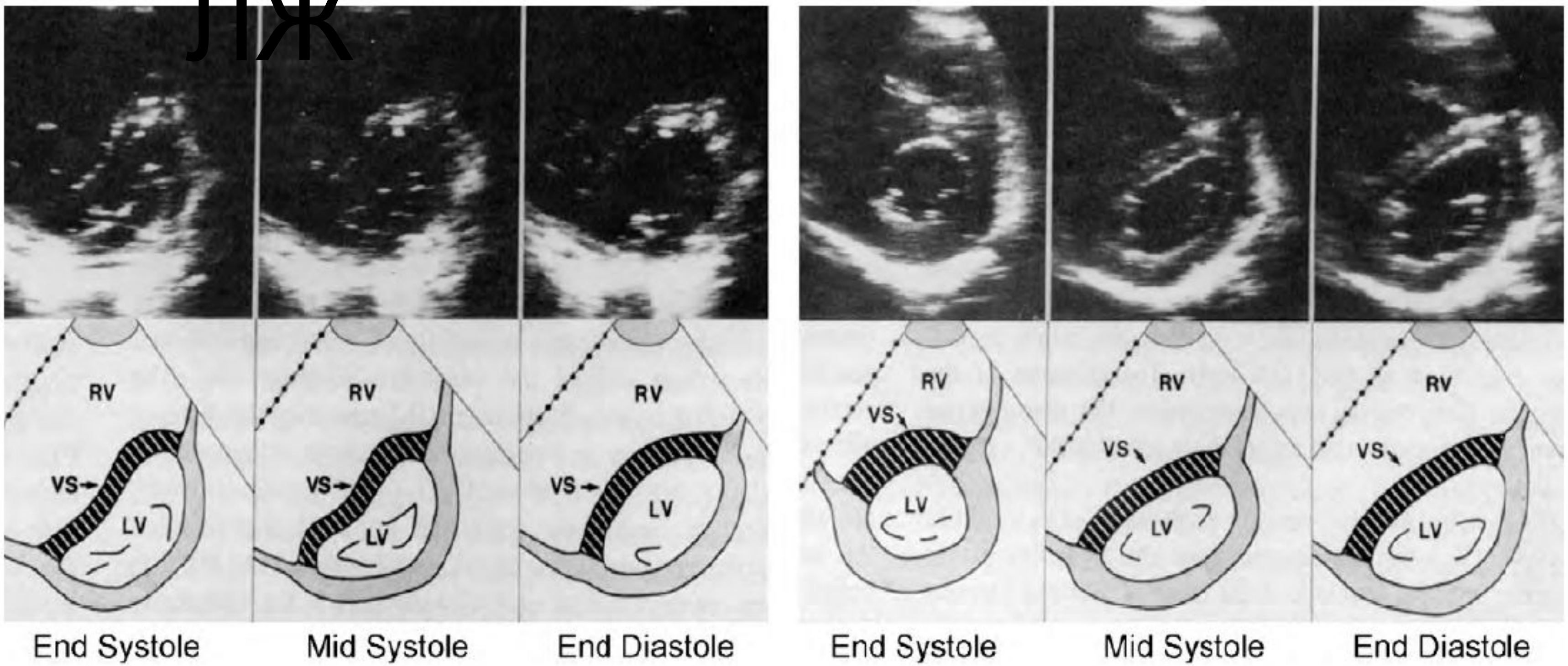


Figure 10 Serial stop-frame short-axis two-dimensional echocardiographic images of the left ventricle at the mitral chordal level with diagrams from a patient with isolated right ventricular (RV) pressure overload due to primary pulmonary hypertension *(left)* and from a patient with isolated RV volume overload due to tricuspid valve resection *(right)*. Whereas the left ventricular (LV) cavity maintains a circular profile throughout the cardiac cycle in normal subjects, in RV pressure overload there is leftward ventricular septal (VS) shift and reversal of septal curvature present throughout the cardiac cycle with most marked distortion of the left ventricle at end-systole. In the patient with RV volume overload, the septal shift and flattening of VS curvature occurs predominantly in mid to late diastole with relative sparing of LV deformation at end-systole. Reproduced with permission from *J Am Coll Cardiol*.[69]

Индекс эксцентричности ЛЖ в номе равен 1.

Скорость повышения давления в ПЖ в систолу

По трик… …ьной … …и

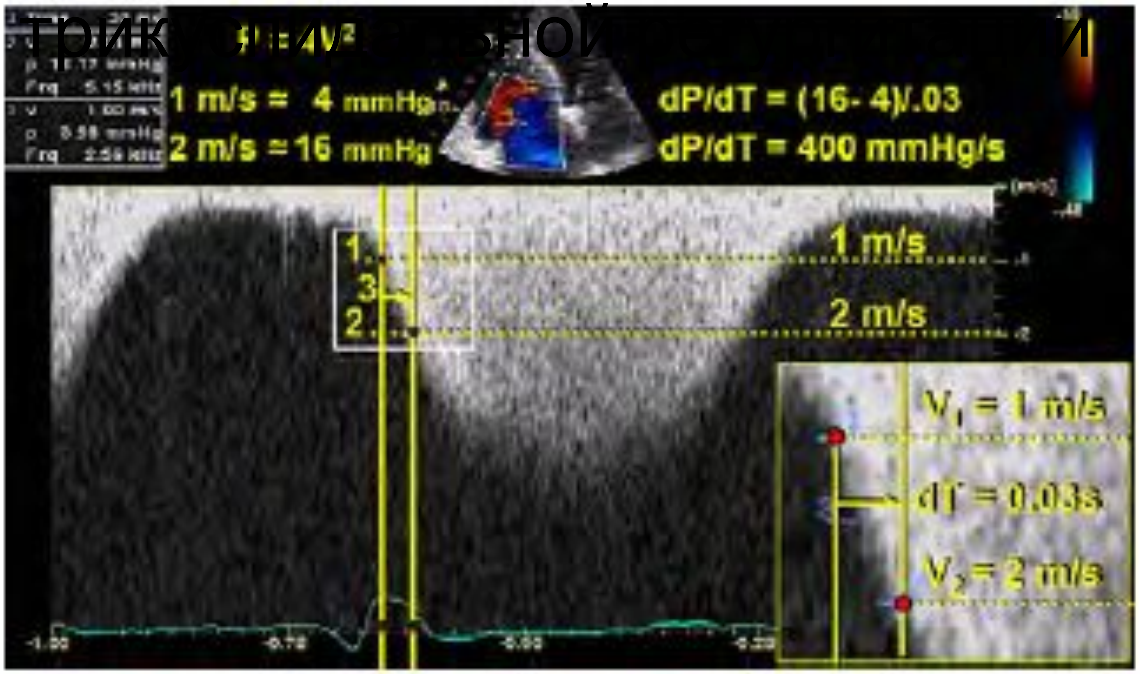


Figure 15 Point 1 represents the point at which the tricuspid regurgitation (TR) signal meets the 1 m/s velocity scale marker, while point 2 represents the point at which the TR signal meets the 2 m/s velocity scale marker. Point 3 represents the time required for the TR jet to increase from 1 to 2 m/s. In this example, this time is 30 ms, or 0.03 seconds. The dP/dt is therefore 12 mm Hg/0.03 seconds, or 400 mm Hg/s.

***Таблица 1.* Рекомендуемые параметры для оценки функции ПЖ [8]**

Показатель	Норма
Толщина свободной стенки ПЖ	<0,5 см
Базальный диаметр ПЖ	<4,2 см
Дистальный диаметр ВТПЖ (из парастернального доступа по короткой оси)	<2,7 см
Проксимальный диаметр ВТПЖ (из парастернального доступа по длинной оси)	<3,3 см
Длинник ПП	<5,3 см
Поперечник ПП	<4,4 см
Конечная систолическая площадь ПП	<18 см^2
Систолическая экскурсия кольца ТК (TAPSE)	>16 мм
Индекс функции миокарда (MPI, Tei-index)	
— по пульсовому допплеру	<0,40
— по тканевому допплеру	<0,55
Фракция укорочения ПЖ	>35%
Отношение E/A	0,8—2,1
Отношение E/E'	<6
Время замедления кровотока (DT)	>120 мс
Фракция выброса ПЖ (3D-ЭхоКГ)	>44%

Примечание. ПЖ — правый желудочек; ВТПЖ — выносящий тракт правого желудочка; ПП — правое предсердие.

Table 1 Summary of reference limits for recommended measures of right heart structure and function

Variable	Unit	Abnormal	Illustration
Chamber dimensions			
RV basal diameter	cm	>4.2	Figure 7
RV subcostal wall thickness	cm	>0.5	Figure 5
RVOT PSAX distal diameter	cm	>2.7	Figure 8
RVOT PLAX proximal diameter	cm	>3.3	Figure 8
RA major dimension	cm	>5.3	Figure 3
RA minor dimension	cm	>4.4	Figure 3
RA end-systolic area	cm^2	>18	Figure 3
Systolic function			
TAPSE	cm	<1.6	Figure 17
Pulsed Doppler peak velocity at the annulus	cm/s	<10	Figure 16
Pulsed Doppler MPI	—	>0.40	Figure 16
Tissue Doppler MPI	—	>0.55	Figures 16 and 18
FAC (%)	%	<35	Figure 9
Diastolic function			
E/A ratio	—	<0.8 or >2.1	
E/E′ ratio	—	>6	
Deceleration time (ms)	ms	<120	

FAC, Fractional area change; *MPI*, myocardial performance index; *PLAX*, parasternal long-axis; *PSAX*, parasternal short-axis; *RA*, right atrium; *RV*, right ventricle; *RVD*, right ventricular diameter; *RVOT*, right ventricular outflow tract; *TAPSE*, tricuspid annular plane systolic excursion.

Table 4 Systolic function

Variable	Studies	n	LRV (95% CI)	Mean (95% CI)	URV (95% CI)
TAPSE (mm) (Figure 17)	46	2320	16 (15-18)	23 (22-24)	30 (29-31)
Pulsed Doppler velocity at the annulus (cm/s)	43	2139	10 (9-11)	15 (14-15)	19 (18-20)
Color Doppler velocities at the annulus (cm/s)	5	281	6 (5-7)	10 (9-10)	14 (12-15)
Pulsed Doppler MPI (Figures 16 and 18)	17	686	0.15 (0.10-0.20)	0.28 (0.24-0.32)	0.40 (0.35-0.45)
Tissue Doppler MPI (Figure 18)	8	590	0.24 (0.16-0.32)	0.39 (0.34-0.45)	0.55 (0.47-0.63)
FAC (%) (Figure 8)	36	1276	35 (32-38)	49 (47-51)	63 (60-65)
RV EF (%) (Figure 8)	12	596	44 (38-50)	58 (53-63)	71 (66-77)
3D RV EF (%)	9	524	44 (39-49)	57 (53-61)	69 (65-74)
IVA (m/s^2)	12	389	2.2 (1.4-3.0)	3.7 (3.0-4.4)	5.2 (4.4-5.9)

CI, Confidence interval; *EF*, ejection fraction; *FAC*, fractional area change; *IVA*, isovolumic acceleration; *LRV*, lower reference value; *MPI*, myocardial performance index; *RV*, right ventricular; *TAPSE*, tricuspid annular plane systolic excursion; *3D*, three-dimensional; *URV*, upper reference value.

Коронарное кровоснабжение

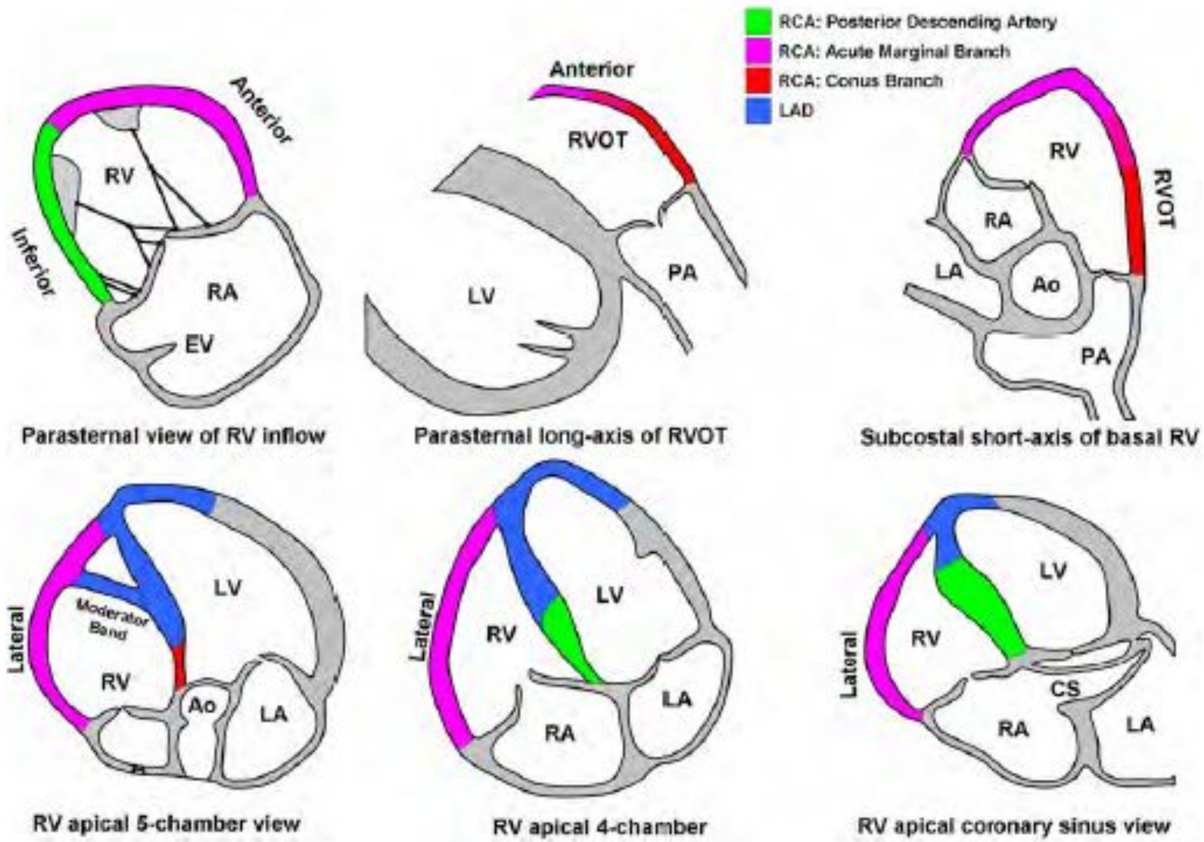


Figure 2 Segmental nomenclature of the right ventricular walls, along with their coronary supply. *Ao*, Aorta; *CS*, coronary sinus; *LA*, left atrium; *LAD*, left anterior descending artery; *LV*, left ventricle; *PA*, pulmonary artery; *RA*, right atrium; *RCA*, right coronary artery; *RV*, right ventricle; *RVOT*, right ventricular outflow tract.

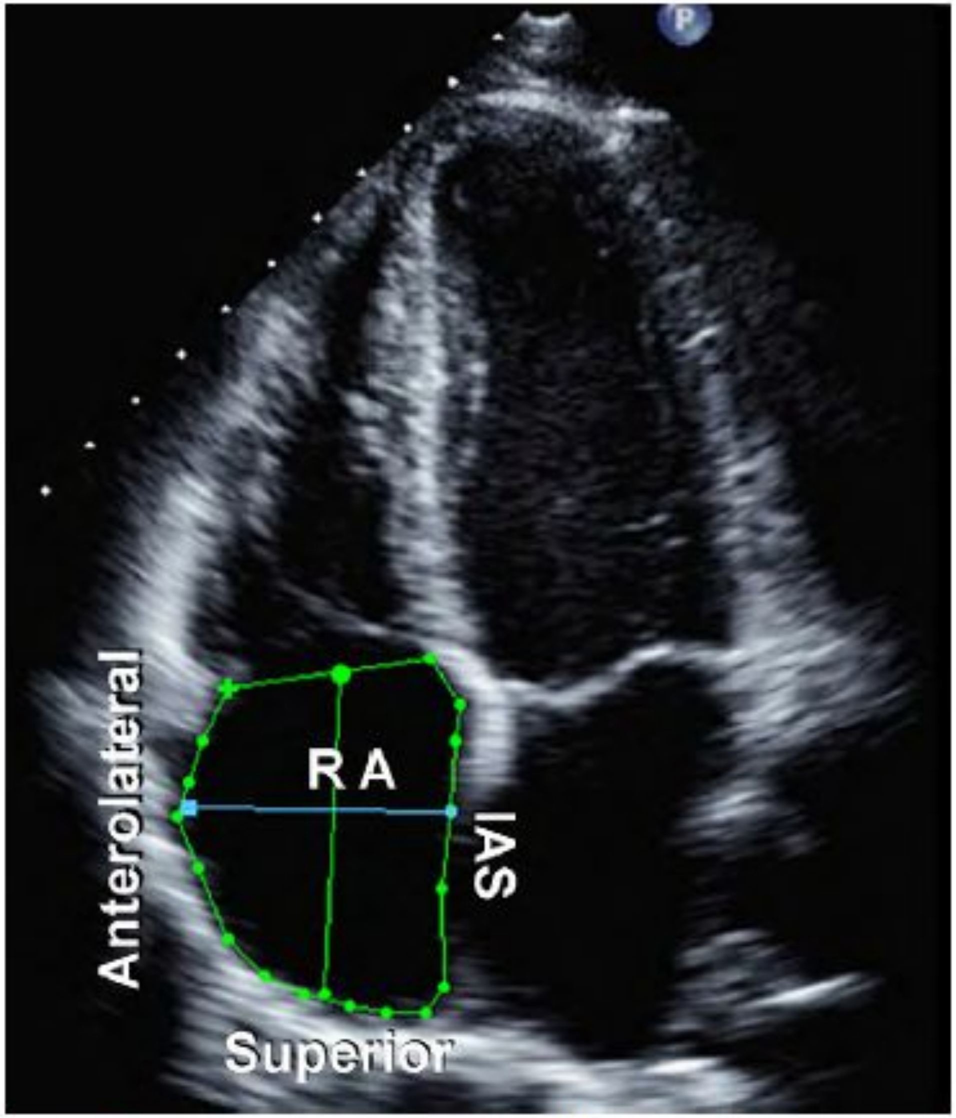


Figure 3 Tracing of the right atrium (RA) is performed from the plane of the tricuspid annulus (TA), along the interatrial septum (IAS), superior and anterolateral walls of the RA. The right atrial major dimension is represented by the *green line* from the TA center to the superior right atrial wall, and the right atrial minor dimension is represented by the *blue line* from the anterolateral wall to the IAS.

Table 2 Chamber dimensions

Dimension	Studies	n	LRV (95% CI)	Mean (95% CI)	URV (95% CI)
RV mid cavity diameter (mm) (Figure 7, RVD2)	12	400	20 (15-25)	28 (23-33)	35 (30-41)
RV basal diameter (mm) (Figure 7, RVD1)	10	376	24 (21-27)	33 (31-35)	42 (39-45)
RV longitudinal diameter (mm) (Figure 7, RVD3)	12	359	56 (50-61)	71 (67-75)	86 (80-91)
RV end-diastolic area (cm^2) (Figure 9)	20	623	10 (8-12)	18 (16-19)	25 (24-27)
RV end-systolic area (cm^2) (Figure 9)	16	508	4 (2-5)	9 (8-10)	14 (13-15)
RV end-diastolic volume indexed (mL/m^2)	3	152	44 (32-55)	62 (50-73)	80 (68-91)
RV end-systolic volume indexed (mL/m^2)	1	91	19 (17-21)	33 (31-34)	46 (44-49)
3D RV end-diastolic volume indexed (mL/m^2)	5	426	40 (28-52)	65 (54-76)	89 (77-101)
3D RV end-systolic volume indexed (mL/m^2)	4	394	12 (1-23)	28 (18-38)	45 (34-56)
RV subcostal wall thickness (mm) (Figure 5)	4	180	4 (3-4)	5 (4-5)	5 (5-6)
RVOT PLAX wall thickness (mm) (not shown)	9	302	2 (1-2)	3 (3-4)	5 (4-6)
RVOT PLAX diameter (mm) (Figure 8)	12	405	18 (15-20)	25 (23-27)	33 (30-35)
RVOT proximal diameter (mm) (Figure 8, RVOT-Prox)	5	193	21 (18-25)	28 (27-30)	35 (31-39)
RVOT distal diameter (mm) (Figure 8, RVOT-Distal)	4	159	17 (12-22)	22 (17-26)	27 (22-32)
RA major dimension (mm) (Figure 3)	8	267	34 (32-36)	44 (43-45)	53 (51-55)
RA minor dimension (mm) (Figure 3)	16	715	26 (24-29)	35 (33-37)	44 (41-46)
RA end-systolic area (cm^2) (Figure 3)	8	293	10 (8-12)	14 (14-15)	18 (17-20)

CI, Confidence interval; *LRV*, lower reference value; *PLAX*, parasternal long-axis; *RA*, right atrial; *RV*, right ventricular; *RVD*, right ventricular diameter; *RVOT*, right ventricular outflow tract; *3D*, three-dimensional; *URV*, upper reference value.

Table 3 Estimation of RA pressure on the basis of IVC diameter and collapse

Variable	Normal (0-5 [3] mm Hg)	Intermediate (5-10 [8] mm Hg)		High (15 mm Hg)
IVC diameter	≤2.1 cm	≤2.1 cm	>2.1 cm	>2.1 cm
Collapse with sniff	>50%	<50%	>50%	<50%
Secondary indices of elevated RA pressure				• Restrictive filling • Tricuspid E/E′ > 6 • Diastolic flow predominance in hepatic veins (systolic filling fraction < 55%)

Ranges are provided for low and intermediate categories, but for simplicity, midrange values of 3 mm Hg for normal and 8 mm Hg for intermediate are suggested. Intermediate (8 mm Hg) RA pressures may be downgraded to normal (3 mm Hg) if no secondary indices of elevated RA pressure are present, upgraded to high if minimal collapse with sniff (<35%) and secondary indices of elevated RA pressure are present, or left at 8 mm Hg if uncertain.

IVC, Inferior vena cava; *RA*, right atrial.

Оценка систолического и диастолического ДЛА, ЛСС

- Систолическое ДЛА – по ТР
- Диастолическая ДЛА – по ЛР
- Легочное сосудистое сопротивление

Таблица 2. Эхокардиографические критерии, соответствующие различной степени вероятности ЛГ [31]

Пиковая скорость трикуспидальной регургитации, м/с	СДЛА, мм рт.ст.	Другие критерии	Степень вероятности наличия ЛГ
<2,8	<36	Нет	Маловероятна
<2,8	<36	Да	Возможна
2,9—3,4	37—50	Нет	Возможна
>3,4	>50	Да/нет	Вероятна

Примечание. СДЛА — систолическое давление в легочной артерии; ЛГ — легочная гипертензия.

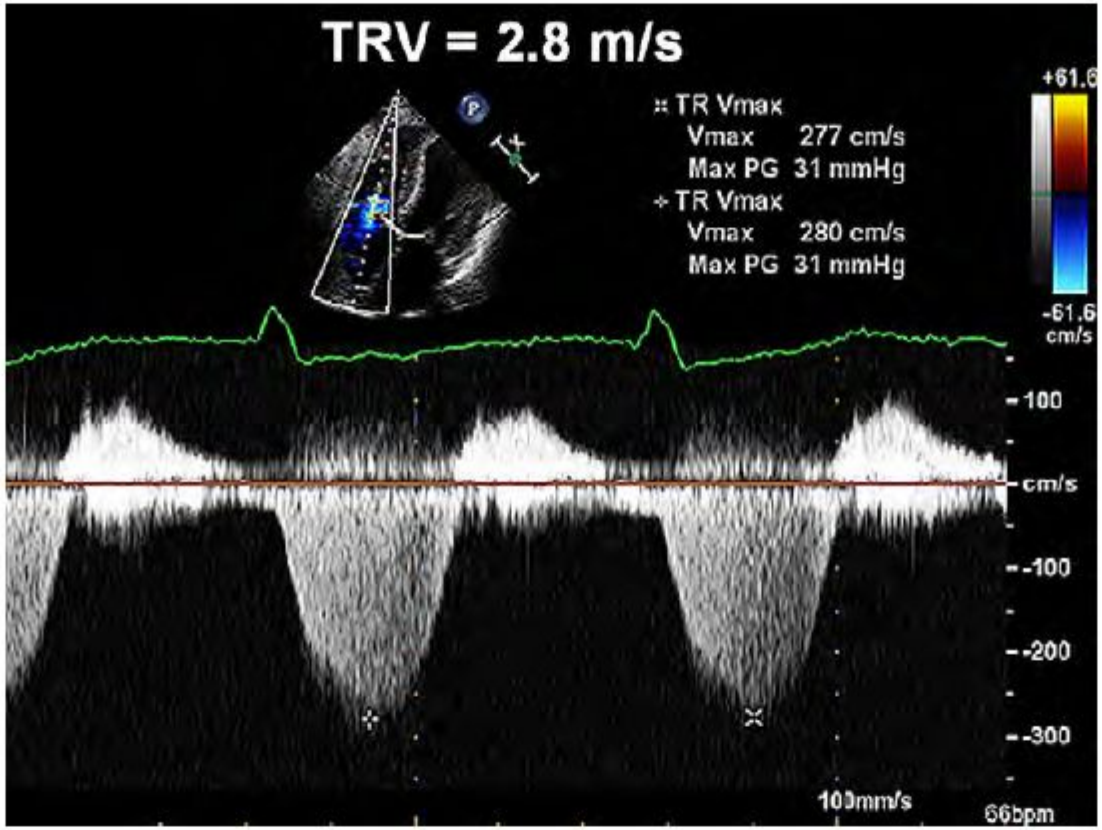
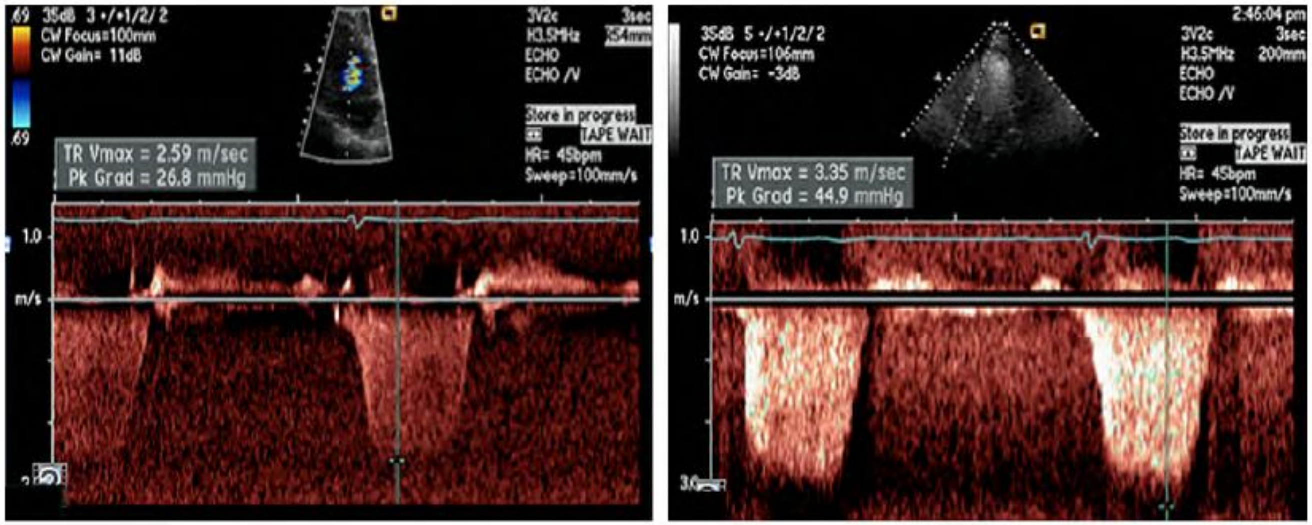


Figure 11 Doppler echocardiographic determination of systolic pulmonary artery pressure (SPAP). Spectral continuous-wave Doppler signal of tricuspid regurgitation corresponding to the right ventricular (RV)–right atrial (RA) pressure gradient. SPAP was calculated as the sum of the estimated RA pressure (RAP) and the peak pressure gradient between the peak right ventricle and the right atrium, as estimated by application of the modified Bernoulli equation to peak velocity represented by the tricuspid regurgitation Doppler signal. In this example, SPAP is estimated at 31 + central venous pressure, or 34 mm Hg, if RAP is assumed to be 3 mm Hg. Adapted with permission from *J Am Soc Echocardiogr*.[52]



A B

Figure 12 **(A)** Tricuspid regurgitation signal that is not contrast enhanced and correctly measured at the peak velocity. **(B)** After contrast enhancement, the clear envelope has been obscured by noise, and the reader erroneously estimated a gradient several points higher. As this example shows, it is critical that only well-defined borders be used for velocity measurement, as slight errors are magnified by the second-order relationship between velocity and derived pressure.

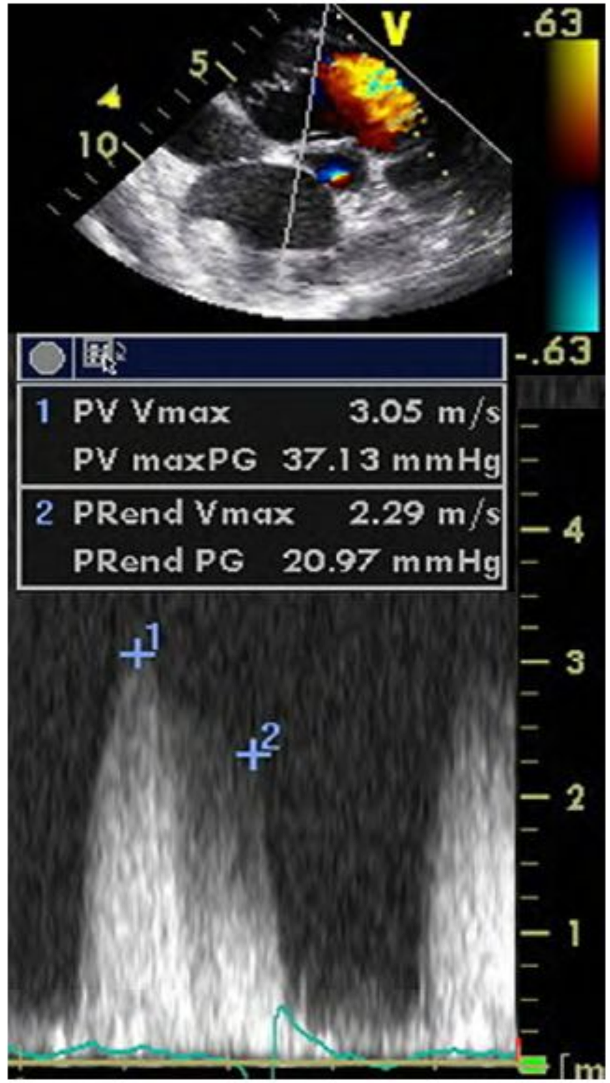


Figure 13 Doppler echocardiographic determination of pulmonary artery (PA) diastolic pressure (PADP) and mean PA pressure by continuous-wave Doppler signal of pulmonic regurgitation. Point 1 denotes the maximal PI velocity at the beginning of diastole. Mean PA pressure correlates with 4 × (early PI velocity)^2 + estimated RAP, in this example 37 mm Hg + RAP. Point 2 marks the PI velocity at end-diastole. PADP is correlated with 4 × (end PI velocity)^2 + estimated RAP. In this example, PADP is 21 mm Hg + RAP.

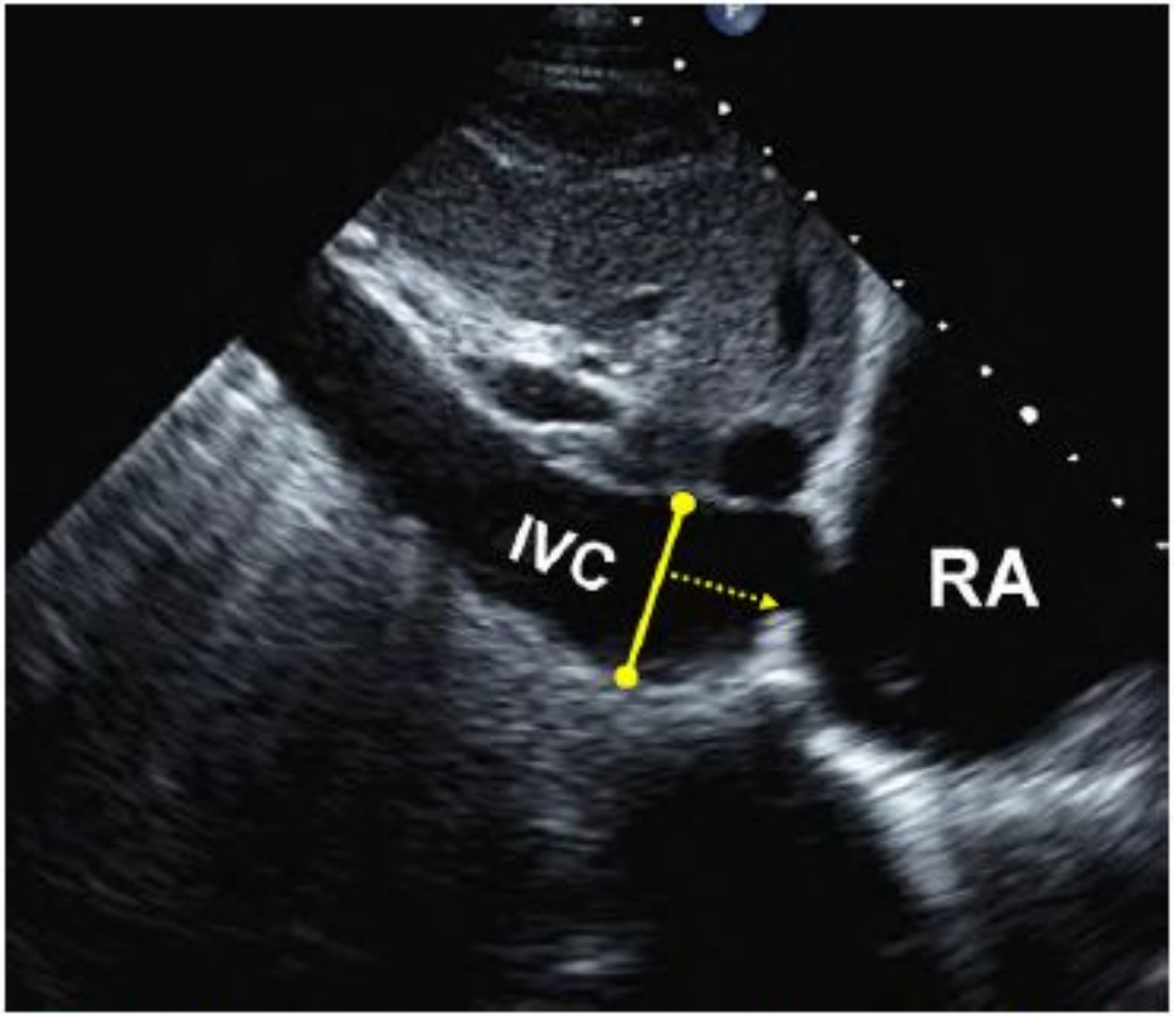


Figure 4 Inferior vena cava (IVC) view. Measurement of the IVC. The diameter *(solid line)* is measured perpendicular to the long axis of the IVC at end-expiration, just proximal to the junction of the hepatic veins that lie approximately 0.5 to 3.0 cm proximal to the ostium of the right atrium (RA).

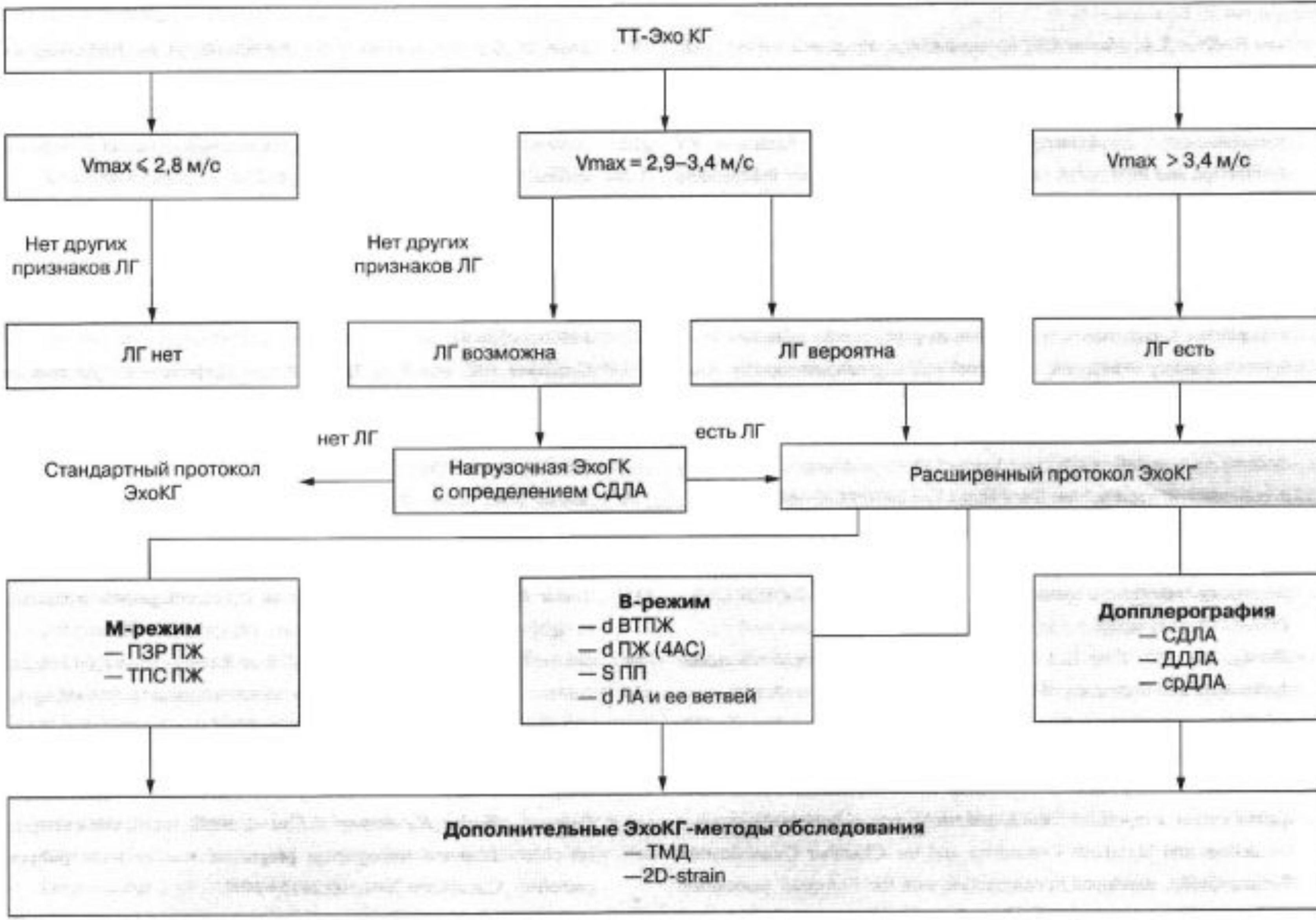


Рис. 6. **Алгоритм обследования больных с ЛГ.**

ЛГ — легочная гипертензия; ТТ-ЭхоКГ — трансторакальная эхокардиография; СДЛА — систолическое давление в легочной артерии; ПЖ — правый желудочек; ПЗР — переднезадний размер; ТПС — толщина передней стенки; d ВТПЖ — диаметр выходного тракта ПЖ; d ПЖ (4АС) — базальный диаметр ПЖ (апикальная четырехкамерная позиция); ДДЛА — диастолическое давление в легочной артерии; срДЛА — среднее давление в легочной артерии; ТДМ — тканевая допплерография миокарда; 2D-strain — двумерный стрейн.

Диастолическая функция ПЖ

В норме Е больше А

Диастолическая дисфункция ПЖ, так же, как и ЛЖ, подразделяется на несколько типов:

1) замедленная релаксация (E/A<0,8);

2) псевдонормализация (E/A от 0,8 до 2,1; E/E' >6);

3) рестрикция (E/A >2,1; DT <120 мс).

Значения пиков транстрикуспидального кровотока и ТДМ показали высокую сопоставимость с показателями гемодинамики. Так, повышение E/E' >8 ассоциируется с увеличением давления в ПП более 10 мм рт.ст. [41].

Таблица 3. **Нормативные показатели скоростных пиков транстрикуспидального кровотока и ТДМ [8]**

Показатель	Нижняя граница нормы	Среднее значение	Верхняя граница нормы
E', см/с	8	14	20
A', см/с	7	13	20
E'/A'	0,5	1,2	1,9
E/E'	2	4	6
E, см/с	35	54	73
A, см/с	21	40	58
E/A	0,8	1,4	2,1

Примечание. Пик E — максимальная скорость раннего диастолического наполнения ПЖ, определенная с помощью импульсно-волновой допплерографии транстрикуспидального кровотока; пик A — максимальная скорость позднего диастолического наполнения ПЖ, определенная с помощью импульсно-волновой допплерографии транстрикуспидального кровотока; пик E' — максимальная скорость раннего диастолического наполнения ПЖ, определенная с помощью ТДМ от кольца трикуспидального клапана; пик A' — максимальная скорость позднего диастолического наполнения ПЖ, определенная с помощью ТДМ от кольца трикуспидального клапана.

3D режим

- Измерение объемов ПЖ в систолу и диастолу
- Расчет ФВ ПЖ

- Нормативы:
- Индекс КДО – до 90 мл/м2
- Индекс КСЛ – до 45 мл/м2
- ФВ – более 45%

Тканевой допплер. Strain , Strain rate

Table 5 Longitudinal strain and strain rate

Variable	Studies	n	LRV (95% CI)	Mean (95% CI)	URV (95% CI)
2D peak strain rate at the base (s^{-1})	1	61	0.70 (0.50-0.90)	1.62 (1.50-1.74)	2.54 (2.34-2.74)
2D peak strain rate at the mid cavity (s^{-1})	2	80	0.85 (0.66-1.04)	1.54 (1.46-1.62)	2.23 (2.04-2.42)
2D peak strain rate at the apex (s^{-1})	2	80	0.86 (0.46-1.25)	1.62 (1.46-1.79)	2.39 (1.99-2.78)
2D peak strain at the base (%)	5	183	18 (14-22)	28 (25-32)	39 (35-43)
2D peak strain at the mid cavity (%)	4	125	20 (15-24)	29 (25-33)	38 (34-43)
2D peak strain at the apex (%)	4	145	19 (15-22)	29 (26-32)	39 (36-43)
Doppler peak strain rate at the base (s^{-1})	7	261	1.00 (0.63-1.38)	1.83 (1.50-2.15)	2.66 (2.28-3.03)
Doppler peak strain rate at the mid cavity (s^{-1})	5	187	0.98 (0.68-1.28)	1.88 (1.73-2.03)	2.79 (2.49-3.09)
Doppler peak strain rate at the apex (s^{-1})	5	204	1.14 (0.60-1.69)	2.04 (1.57-2.51)	2.93 (2.39-3.48)
Doppler peak strain at the apex (%)	7	290	17 (12-21)	30 (27-34)	44 (39-48)
Doppler peak strain at the base (%)	11	385	13 (9-17)	29 (27-31)	45 (41-49)
Doppler peak strain at the mid cavity (%)	7	269	13 (9-18)	31 (29-32)	48 (44-52)

CI, Confidence interval; *LRV*, lower reference value; *2D*, two-dimensional; *URV*, upper reference value.

- Двумерный стрейн (2D strain),
- Speckle Tracking Imaging

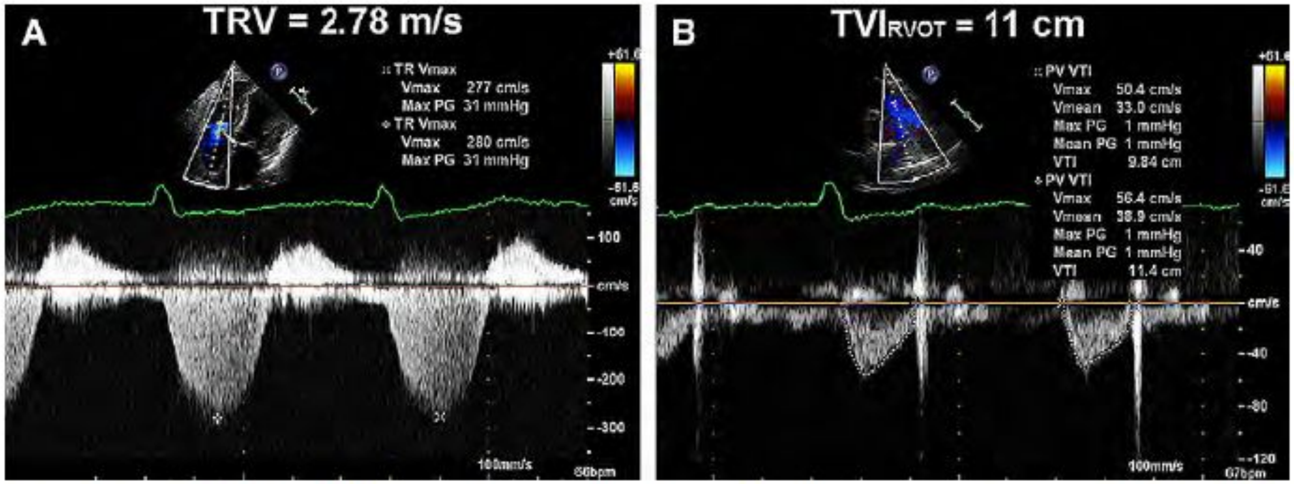


Figure 14 The two elements needed to calculate the noninvasive index of pulmonary vascular resistance (PVR) are found in this example. The ratio of peak tricuspid regurgitant velocity (TRV) (2.78 m/s) to the time-velocity integral (TVI) (11 cm) in the right ventricular outflow tract (RVOT) is abnormal at 0.25 (normal, ≤ 0.15). The estimated PVR is 2.68 using the formula (TRVmax/RVOT TVI) $\times$ 10 + 0.16.[84] Adapted with permission from *J Am Soc Echocardiogr*.[52]

Table 6 Diastolic function

Variable	Studies	n	LRV (95% CI)	Mean (95% CI)	URV (95% CI)
E (cm/s)	55	2866	35 (33-37)	54 (52-56)	73 (71-75)
A (cm/s)	55	3096	21 (19-24)	40 (38-41)	58 (55-60)
E/A ratio*	56	2994	0.8 (0.7-0.9)	1.4 (1.4-1.5)	2.1 (2.0-2.2)
Deceleration time (ms)	25	1284	120 (105-134)	174 (163-186)	229 (214-243)
IVRT (ms)	23	1241	23 (16-30)	48 (43-53)	73 (66-80)
E′ (cm/s)	40	1688	8 (7-9)	14 (13-14)	20 (19-21)
A′ (cm/s)	37	1575	7 (6-8)	13 (12-14)	20 (19-21)
E′/A′ ratio	29	1053	0.5 (0.4-0.6)	1.2 (1.1-1.3)	1.9 (1.7-2.0)
E/E′ ratio	3	359	2 (1-2)	4 (4-4)	6 (5-7)

CI, Confidence interval; *IVRT*, Isovolumic relaxation time; *LRV*, lower reference value; *URV*, upper reference value.
*Age-dependent: average E/A ratio = 1.6 in the third decade of life, decreasing by 0.1 for every subsequent decade.

Table 7 Conditions associated with right ventricular diastolic dysfunction

Condition
• Pulmonary embolism
• Pulmonary arterial hypertension
• Smoking
• Chronic obstructive pulmonary disease
• Cystic fibrosis
• Acute hypoxia
• Myocardial infarction or ischemia due to (proximal) right coronary artery lesion
• Repaired tetralogy of Fallot
• Repaired transposition of the great arteries
• Chronic heart failure
• Cardiac transplantation
• Arrhythmogenic right ventricular cardiomyopathy
• Hypertrophic cardiomyopathy
• Chagas disease
• Essential hypertension
• Aortic stenosis
• Aortic regurgitation
• Mitral regurgitation
• Myocardial infarction due to left anterior descending coronary artery lesion
• Diabetes mellitus
• Hypothyroidism
• Amyloidosis
• Rheumatoid arthritis
• Systemic sclerosis
• Antiphospholipid antibody syndrome
• Bechet's vasculitis
• β-thalassemia
• Renal transplantation
• Hepatopulmonary syndrome
• Normal neonates
• Aging