Ultrasound Diagnosis of Congestion in the Pulmonary and Systemic Circulations in Patients with Atrial Fibrillation and Chronic Heart Failure

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Research article

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Abstract

Background

Fluid retention is one of the most common reasons for the heart failure decompensation. The purpose of the study is to estimate the sensitivity, specificity of the ultrasound method for evaluating congestive phenomena in the systemic and pulmonary circulations in patients with the atrial fibrillation (AF) and chronic heart failure (CHF).

Methods

The study includes 28 patients with the paroxysmal AF with and without CHF, who were planned for the radiofrequency pulmonary veins isolation. The maximum and minimum diameters of the right superior pulmonary vein and inferior vena cava on exhalation were measured echocardiographically. An average pressure in the right and left atria was measured intraoperatively. Correlation between the maximum and minimum diameters of the right superior pulmonary vein and an average pressure in the left atria and between inferior vena cava on exhalation and an average pressure in the right atria was calculated. The sensitivity, specificity of ultrasound methods for evaluating congestive phenomena in the systemic and pulmonary circulations was evaluated.

Results

There was positive correlation between the minimum diameter of right superior pulmonary vein and invasive mean pressure in the left atrium ($R=0.65$, $P<0.05$), between invasive measured mean pressure in the right atrium and the diameter of the inferior vena cava on exhalation ($R=0.49$, $P<0.05$). Sensitivity of the method – maximum diameters of the right superior pulmonary vein greater than 21.7 mm are ultrasound criteria for venous pulmonary hypertension is 75%, specificity – 86%. Sensitivity of the method minimum diameters of the right superior pulmonary vein greater than 10.5 mm are ultrasound criteria for venous pulmonary hypertension is 85%, specificity – 86%. The sensitivity of the inferior vena cava diameter exceeding 18,5 mm on exhalation is 100%, the specificity is 92%.

Conclusions

The new ultrasound method of congestion diagnostics in the pulmonary circulation by the maximum and/or minimum diameter of the right superior pulmonary vein can be effectively applied in clinical practice in the same way as the well-known technique of congestion diagnostics in the systemic circulation by the diameter of the inferior vena cava in patients with the atrial fibrillation and chronic heart failure.

Background

Heart failure is one of main reasons for the hospital admission with a high risk of readmission [1]. According to randomized studies, the higher the functional class (FC) of chronic heart failure (CHF), the higher the risk of atrial fibrillation (AF) [2]. In large European registries, the prevalence of AF among patients hospitalized for CHF ranged from 35– 42% [3, 4]. Joining AF to CHF worsens not only the patient quality of life, but also increases the number of hospitalizations and mortality [5].

The most of patients with heart failure (76%) admitted for inpatient treatment are “wet” and “warm”, i.e. the congestive type with a normal peripheral perfusion [6]. However, patients complain of dyspnea at rest only in 44% of cases [7]. Thus, it is important to perform instrumental diagnostics of the fluid retention in patients with CHF as early as possible in order to prevent its decompensation consisting in a progressive accumulation of fluid in the body. When underestimated by clinicians, the severity of CHF results in inappropriate therapy, including loop diuretics non– prescription or their doses are incorrect [8] and, as a consequence, the number of “wet” patients increases.

According to the recommendations for the diagnostics and treatment of CHF, congestion in the systemic and pulmonary circulations is diagnosed by signs and symptoms; however, they show either low specificity or low sensitivity and allow to diagnose the blood congestion only in the later stages [9, 10]. Among instrumental diagnostic methods, the pneumonography can determine congestion in the lungs and pleural fluid, but 20% of patients with congestion have a “normal” chest X– ray [11]. As compared to the chest X– ray, the number of B– lines on lung ultrasonography more effectively excludes the interstitial edema and pleural effusion. However, the disadvantage of this method is a late diagnostics of congestion in the pulmonary circulation (at the stage of interstitial edema); besides, the method does not allow to differentiate the reason of the interstitial pulmonary edema from the alveolar one [11]. The echocardiographically determined ratio of the maximum rate of the left ventricular (LV) filling in the early diastole phase and the maximum rate of movement of the fibrous annulus of the mitral valve in the early diastole phase $E/e' \geq 15$ correlates with the increased pressure of the left ventricular filling, while $E/e' < 8$ is indicative of its normal value. However, at values of E/e' ranging from 8 to 15, a wide range of the early diastolic pressure in the left ventricle is detected; this requires additional diagnostics for this group of patients [12]. The sensitivity of $E/e' > 12$ is 66%; the specificity is 55% [11].

In the presence of the rightventricular (RV)insufficiency, the raising of end– diastolic pressure in RV and pressure in the right atrium (RA), as well as a difficulty in blood flow to the heart are observed; as a result, the inferior vena cava (IVC) expands and its collapse during inspiration decreases. The expanded IVC without signs of collapse indicates a significant pressure increase in RA – more than 15 mm Hg [13]. The sensitivity of the sign “IVC collapse less than 50%” as an indicator of RA pressure increase is 12%; the specificity is 27%. The sensitivity of the sign “IVC diameter during inspiration below 12 mm” as an indicator of RA pressure increase is 67%; the specificity is 91% [11].

The cardiac catheterization with a direct pressure measurement in the atria and in the pulmonary artery with the estimation of pulmonary capillary wedge pressure (PCWP) is the gold standard of the congestive phenomena diagnostics in CHF. Nevertheless, the invasiveness of this method significantly limits its wide application in clinical practice; this requires available and easily reproducible instrumental methods allowing one to diagnose the congestive phenomena in pulmonary and systemic circulations even in early stages of CHF. It is necessary for the appropriate therapy, including diuretic one, thus preventing CHF decompensation.

The purpose of the study is to estimate the sensitivity, specificity of the new ultrasound diagnostic of the venous pulmonary hypertension by the maximum and minimum diameters of the right superior pulmonary vein (RSPV) in the same way as the well-known technique the congestive phenomena in the systemic circulation by the IVC diameter on exhalation in patients with paroxysmal AF with and without CHF.

Methods

We prospectively recruited 64 adult subjects who were examined in the cardiology department with paroxysmal AF in Cardiology Research Institute of Tomsk NRMC (Tomsk, Russia) from March to May 2019. The presence of cardiovascular diseases (coronary artery disease, essential hypertension), paroxysmal AF were the inclusion criteria. All patients with or without chronic heart failure (CHF) were planned for the radiofrequency pulmonary veins isolation (PVI). CHF was diagnosed in accordance with the latest recommendations on CHF diagnostics [9, 10]. Individuals without established CHF were asymptomatic patients with paroxysmal AF. The exclusion criteria were the acute coronary syndrome, pulmonary embolism, congenital and acquired heart valve diseases, presence of thyroid diseases, menopausal disorders, acute and chronic kidney diseases, acute and chronic pulmonary diseases, and cancer diseases. 28 patients with the paroxysmal AF were divided into two groups depending on the presence or absence of CHF in the diagnosis. 1 group – 19 patients at the age of 61.72±3.66 with CHF of the functional class (FC) I– III by NYHA (New York Heart Association) classification. 2 group – 9 patients without CHF at the age of 55.83±6.62. The control group consisted of 44 practically healthy people in the age 35.02±2.44 who were preventively examined in Clinic Uralskaya, LLC (Ekaterinburg, Russia).

The transthoracic echocardiography was performed in the sinus rhythm by the Philips HD–15 device (USA) according to the standard protocol in all patients. Additionally, the maximum and minimum diameter of RSPV was determined from the suboccipital view. The maximum diameter of RSPV was determined in the ventricular systole phase; the minimal diameter was determined in the atrial systole phase [14, 15].

Additionally, the average wedge pressure in the pulmonary artery (PAWP) was calculated by the following formula [16]:

average PAWP = 1.24 E/e'+1.9, where E is the peak rate of early diastolic filling of left ventricle (LV) according to the data of Doppler sonography of the transmitral flow and e' is the peak rate of the early diastolic movement of the lateral segment of the mitral valve according to the data of pulse– wave tissue Doppler.

Besides, the average right atrial pressure (RAP) was calculated by the following formula [17]: average RAP = 1.7 E/e'+0.8, where E is the peak rate of early diastolic filling of the RV according to the data of

Doppler sonography of the diastolic flow through the tricuspid valve and e' is the peak rate of the early diastolic movement of the lateral segment of the tricuspid valve according to the data of pulse– wave tissue Doppler.

An average pressure in the right and left atria was measured intraoperatively by the direct method in patients with paroxysmal AF before radiofrequency PVI.

The informed consent for research was obtained from all the patients. All patients gave the written consent for participation in the study, which was approved by the local ethic committee of the Cardiology Research Institute of Tomsk (Russia).

Statistical analysis of study results was carried out taking into account the Student's criterion according to the parameters of a small sample. Statistically significant differences were considered at $p<0.05$. The data is presented as M±m, where M is the average of the measured values and m is the error rate. To determine the relationship between the indicators, a linear Pearson– Spearman correlation coefficient was calculated. Using ROC analysis, the reliability of the ultrasound diagnostics model of the venous pulmonary hypertension was verified by the maximum and minimum diameters of the right superior pulmonary vein. The ROC curves were constructed using the SPSS– IBM package. To assess the quality of this model, we used the area under the ROC curve (AUC, area under curve). The sensitivity, specificity of the ultrasound method for the venous pulmonary hypertension diagnostics by the maximum and minimum diameters of RSPV were evaluated [18].

Results

28 patients (12 men and 16 women) with the paroxysmal AF were studied, who were planned for the radiofrequency PVI. Generally, AF progressed in patients with coronary artery disease (64%) and with essential hypertension (61%).

CHF of FC I– III by the NYHA (New York Heart Association) classification was diagnosed in 19 patients according to the clinical diagnosis based on the medical history; namely, 2 patients had FC I; 12 patients had FC II; 5 patients had FC III.

The duration of AF in the first group was 7.00 ± 2.28 years, the duration of arterial hypertension was 20.75 ± 4.88 years. In addition to the primary therapy, 9 patients had diuretic medication: mineralocorticoid receptor antagonists (MCRA) and indapamide. In 4 patients torasemide in a dose of 2.5 to 5 mg was prescribed. Table 1 presents a total characteristic of the patients.

Table 1
The characteristic of the patients

Parameter	Patients with AF and CHF (n = 19)	Patients with AF without CHF (n = 9)	Control values (n = 44)
Gender (male)	6 (31.6%)	6 (66.7%)ˆ	26 (38.6%)
Age (years)	61.72 ± 3.66ˆ	55.83 ± 6.62ˆ	35.02 ± 2.44
Coronary artery disease: effort of exertion	15*	3	
Arterial hypertension	14	8	
Postinfarction cardiosclerosis		1	
Acute stroke in the past	3	0	
Dilated cardiomyopathy	2	0	
Type 2 diabetes	2	1	
Paroxysmal AF	19	9	
Duration of AF, years	7.00 ± 2.28*	3.60 ± 1.80	
Duration of hypertension, years	20.75 ± 4.88*	9.43 ± 3.98	
CHF (functional class):			
FC I	2	0	
FC II	12*	0	
FC III	5*	0	
Obesity	8	4	
Therapy: Beta– adrenoblockers	7	2	
ACEI/ARB	10*/9*	1	
MCRA/indapamide and hydrochlorothiazide/torasemide	4/5*/4	0/0/0	
Calcium antagonists	3	0	
Statins	11	3	

Note: ACEI/ARB is the angiotensin converting enzyme inhibitors/ angiotensin receptor blockers. MCRA is the mineralocorticoid receptor antagonists. * indicates the significance of the differences between groups of patients, $p < 0.05$. ˆ indicates the significance of differences between groups of patient and control group, $p < 0.05$.

Parameter	Patients with AF and CHF (n = 19)	Patients with AF without CHF (n = 9)	Control values (n = 44)
Antiarrhythmic therapy	13	3	

Note: ACEI/ARB is the angiotensin converting enzyme inhibitors/ angiotensin receptor blockers. MCRA is the mineralocorticoid receptor antagonists. * indicates the significance of the differences between groups of patients, $p < 0.05$. ^ indicates the significance of differences between groups of patient and control group, $p < 0.05$.

AF duration in the second group was 3.60 ± 1.80 years, the duration of arterial hypertension was 9.43 ± 3.98 years. Patients in this group received the basic therapy without diuretic medication.

Patients from the control group were significantly younger than in the examined one. We were not able to find practically healthy people at the same age as the patients from the examined groups.

Patients with AF with and without CHF, as compared to the control group, according to echocardiography, had the dilatation of the left atrium (LAVI) (67.70 ± 1.91 ml.; 68.00 ± 3.17 ml. and 49.29 ± 4.33 ml., respectively, Table 2), the maximum diameter of RSPV (22.39 ± 0.95 mm.; 21.44 ± 1.67 mm. and 13.50 ± 0.44 mm., respectively, Images 1 A, 2A, 3A) and the minimum diameter of RSPV (11.78 ± 1.19 mm.; 11.33 ± 1.29 mm., and 6.42 ± 0.17 mm., respectively, Images 1B, 2B, 3B); the average E/e' was the same in both groups (patients with AF with and without CHF); it was 8.92 ± 0.73 and 8.62 ± 1.31, respectively. This indicates that values of the average E/e' are in the grey zone and require additional investigation in order to clarify the presence or absence of hypertension in the left atrium [10]. For the patients with AF, with and without CHF, the calculated wedge pressure is significantly higher than that of the control group, but lower than 12, i.e. it is within the range of reference values [19].

Table 2
Echocardiographic and invasive parameters of hemodynamics

Parameter	Control values (n = 44)	Patients with AF and CHF (n = 19)	P	Patients with AF without CHF (n = 9)	P	P'
LAVI, ml	49.29 ± 4.33	50.25 ± 7.65	< 0,001	40.26 ± 3.17	< 0,001	0,80
Simpson's ejection fraction, %	62.89 ± 1.47	58.63 ± 6.79	0,75	65.5 ± 2.66	0,80	0,18
Transmitral E/A	1.61 ± 0.07	0.77 ± 0.05	< 0,001	0.75 ± 0.08	< 0,001	0,7
Septal e'	13.25 ± 0.63	7.03 ± 0.74	< 0,001	6.88 ± 0.79	< 0,001	0,85
LV lateral e'	17.85 ± 0.94	10.03 ± 0.87	< 0,001	10.62 ± 1.94	< 0,001	0,48
Average E/e'	6.83 ± 0.29	8.92 ± 0.73	< 0,001	8.62 ± 1.31	< 0,001	0,70
Calculated PAWP, mm Hg	1.97 ± 0.004	11.48 ± 1.04	< 0,001	10.82 ± 1.64	< 0,001	0,49
Maximum pulmonary vein diameter, mm	13.50 ± 0.44	22.39 ± 0.95	< 0,001	21.44 ± 1.67	< 0,001	0,25
Minimum pulmonary vein diameter, mm	6.42 ± 0.17	11.78 ± 1.19	< 0,001	11.33 ± 1.29	< 0,001	0,90
Invasively measured pressure in the LA, mm Hg	2– 12 (7.9) [19]	14.68 ± 1.40		15.00 ± 2.63		0,85
PASP, mm Hg	15.23 ± 1.24	36.11 ± 4.64	< 0,001	29.33 ± 3.28	< 0,001	0,18
Transtricuspid E/A	1.58 ± 0.07	0.82 ± 0.04	< 0,001	0.91 ± 0.12	< 0,001	0,06
RV lateral e'	15.00 ± 0.82	8.73 ± 0.83	< 0,001	8.30 ± 1.12	< 0,001	0,60
IVC, cm	17.60 ± 0.76	22.41 ± 1.35	< 0,001	21.89 ± 2.40	< 0,001	0,70

Note: LAVI is the left atrial indexed volume, E/A is the ratio of the blood flow velocity in the phase of early diastolic ventricular filling to the filling velocity in the late atrial filling phase; average E/e' is the ratio of the early– diastolic blood flow velocity to the velocity of the lateral part and the medial part of the fibrous annulus of the mitral valve; PCWP is the pulmonary capillary wedge pressure; PASP is the pulmonary artery systolic pressure; IVC is the inferior vena cava; RAP – right atrial pressure. P indicates the significance of the differences between each group of patients and the control group. P' indicates the significance of the differences between groups of patients.

Parameter	Control values (n = 44)	Patients with AF and CHF (n = 19)	P	Patients with AF without CHF (n = 9)	P	P'
Calculated RAP, mm Hg	3.68 ± 0.24	10.36 ± 0.81	< 0,001	11.57 ± 2.55	< 0,001	0,20
Invasively measured pressure in the RA, mm Hg	1– 7 (3.9) [19]	6.75 ± 0.63		6.13 ± 1.13	< 0,001	0,29
Note: LAVI is the left atrial indexed volume, E/A is the ratio of the blood flow velocity in the phase of early diastolic ventricular filling to the filling velocity in the late atrial filling phase; average E/e' is the ratio of the early– diastolic blood flow velocity to the velocity of the lateral part and the medial part of the fibrous annulus of the mitral valve; PCWP is the pulmonary capillary wedge pressure; PASP is the pulmonary artery systolic pressure; IVC is the inferior vena cava; RAP – right atrial pressure. P indicates the significance of the differences between each group of patients and the control group. P' indicates the significance of the differences between groups of patients.						

Table 3
Correlation of invasively measured pressure in the left atrium with echocardiographic parameters

Parameter	Invasively measured pressure in the LA, mm Hg	Invasively measured pressure in the RA, mm Hg
LA volume, ml	– 0,12	
Average E/e'	– 0,29	
Calculated PAWP, mm Hg	– 0,11	
Maximum pulmonary vein diameter, mm	– 0,06	
Minimum pulmonary vein diameter, mm	0,65*	
PASP, mm Hg	0,21	0,54
IVC, cm		0,49*
Calculated RAP, mm Hg		0,16
Note: * – statistically significant correlation, p < 0.05		

Thus, according to the existing ultrasound methods for the congestion detection in the pulmonary circulation, patients with the paroxysmal AF, regardless of CHF diagnosed by cardiologists, had no venous pulmonary hypertension. However, the invasively measured pressure in LA was found to be elevated both in the group of patients with AF and CHF (14.68 ± 1.40 mm Hg) and in the group with AF and without CHF (15.00 ± 2.63 mm Hg). This shows the presence of the venous pulmonary hypertension and CHF in patients of both groups.

There was an average positive correlation between the minimum diameter of right superior pulmonary vein and invasive mean pressure in the left atrium ($r = 0.65$, $p < 0.05$). There was not a correlation between the maximum diameters of the right superior pulmonary vein and invasive mean pressure in the left atrium ($r = -0.06$, statistically insignificant). There was not a correlation between the average E/e' and invasive mean pressure in the left atrium ($r = -0.29$, statistically insignificant).

ROC analysis was performed to verify the reliability of the ultrasound diagnostics model of the venous pulmonary hypertension by the maximum and minimum diameters of the right superior pulmonary vein. For the maximum diameter of the pulmonary vein, AUC = 0.599 ($p < 0.05$), which indicates that this model has an average degree of quality. The equilibrium point is the value of the maximum diameter of RSPV– 21.7 mm, which corresponds to the limit of the norm (sensitivity– 75%, specificity– 86%).

For the minimum diameter of the pulmonary vein, AUC = 0.613 ($p < 0.05$), which indicates that this model has an average degree of quality. The equilibrium point is the minimum diameter of RSPV– 10.5 mm, which corresponds to the limit of the norm (sensitivity– 85%, specificity– 86%).

Thus, the method for determining venous pulmonary hypertension by measuring the maximum and/or minimum diameters of the pulmonary vein can be effectively used as the noninvasive diagnostics of the venous congestion in the pulmonary circulation.

For the patients AF with and without CHF, the calculated pressure in RA was 10.36 ± 0.81 and 11.57 ± 2.55 mm Hg, respectively; under the invasive measurement method it was, respectively, 6.75 ± 0.63 and 6.13 ± 1.13 mm Hg. This indicates that the pressure calculated echocardiographically is overrated.

There was a positive correlation between invasive measured mean pressure in RA and IVC diameter on exhalation ($r = 0.49$, $p < 0.05$).

For the maximum diameter of the IVC obtained the following graph ROC curve with AUC = 0.832 ($p < 0.05$), indicating that this model has a very good degree of quality. The equilibrium point is the value of the diameter of the IVC – 18.5, which corresponds to the limit of the norm (sensitivity – 100%, specificity – 92%).

Discussion

It is known, that in AF arrhythmogenesis, PVs play an essential role as a trigger or driver of AF [20, 21]. Prior studies using cardiac imaging modalities demonstrated that AF patients had significantly enlarged PVs compared to controls [22]. This finding suggests that structural alteration of the PVs is related to AF development. This study shows that patients with paroxysmal AF with and without CHF, as compared to the control group, according to echocardiography, had the dilatation of the maximum diameter of RSPV and the minimum diameter of RSPV. There was a positive correlation between the minimum diameter of right superior pulmonary vein and invasive mean pressure in the left atrium ($R = 0.65$, $P < 0.05$). The study showed that asymptomatic patients with AF had an increased invasive-measured pressure in LA and structural changes in LA and pulmonary veins that do not differ from patients with AF and CHF. This suggests that in CHF diagnostics, it is better to rely not on symptoms and signs, but on changes in the structure and function of the heart detected by the echocardiography.

In this study, the sensitivity, specificity of ultrasound methods of congestion diagnostics in the pulmonary and systemic circulations were determined as compared to the gold standard, i.e. the invasive pressure measurement in the left and right atria of the heart.

The method of non-invasive diagnostics of venous pulmonary hypertension is based on measuring the maximum diameter of any of the visible pulmonary veins that flow into LA during diastole of the heart, and the minimum diameter during atrial systole. If the maximum diameter of any visible pulmonary vein is greater than 18 mm and its minimum diameter is greater than 9 mm, venous congestion in the pulmonary circulation is diagnosed [14]. Sensitivity of the method – maximum diameter of the right superior pulmonary vein greater than 21.7 mm are ultrasound criteria for venous pulmonary hypertension is 75%, specificity – 86%. Sensitivity of the method minimum diameter of the right superior pulmonary vein greater than 10.5 mm are ultrasound criteria for venous pulmonary hypertension is 85%, specificity – 86%.

In 24 from 28 patients with AF in this study the pressure in LA was elevated and amounted to 14.79 ± 1.18 mm Hg. While average E/e' in patients with AF, with and without CHF, was 8.92 ± 0.73 and 8.62 ± 1.31, respectively, which refers to the gray zone of values that require additional examination methods to determine the pressure LA [10]. There was not a correlation between the average E/e' and invasive mean pressure in the left atrium ($r = -0.29$, statistically insignificant). A systematic review of nine studies reported only modest correlations of E/e’ with invasive filling pressures in heart failure patients with preserved ejection fraction, because some of these studies didn't show corellation as in our one. [23].

It is known that the presence of congestion in the pulmonary circulation and the diuretic medication necessity in addition to the primary therapy, which prevents the development of CHF decompensation [10]. In this study, in addition to the primary therapy, only 9 patients were prescribed diuretic therapy: MRCA, indapamide and 4 patients with torasemide at a dose of 2.5–5 mg, while venous pulmonary hypertension was detected in 24 patients by invasive and new ultrasound methods by measuring the maximum and/or minimum diameter of the pulmonary vein. It is known that fluid retention in the body in CHF can lead to the development of atrial myocardial edema [24]. While the appointment of adequate diuretic therapy in patients with paroxysmal AF joined to CHF leads to lower frequency of the arrhythmia recurrence [25].

It should be noted that previously known ultrasound methods for detecting congestion in the pulmonary circulation also did not show signs of increased pressure in LA. The calculated PAWP in patients with AF, with and without CHF, was also uninformative in view of finding values within the reference values – 11.48 ± 1.04 and 10.82 ± 1.64 mm Hg, respectively.

Thus, the diagnostics of CHF and congestion phenomena in the pulmonary circulation and, as a consequence, inappropriate therapy is observed, including the lack of prescribing or incorrect correction of doses of loop diuretics.

It should be noted that the method of ultrasound diagnostics of venous pulmonary hypertension by examining the maximum and minimum diameters of the pulmonary veins in patients with CHF allows not only to diagnose venous pulmonary hypertension, but also to evaluate the effectiveness of diuretic therapy. In patients with venous congestion in the pulmonary circulation, the maximum and minimum diameters of the visualized pulmonary veins decrease in response to adequate diuretic therapy [26].

Determination of congestion in the systemic circulation in clinicians often does not cause difficulties, because in contrast to congestion in the pulmonary circulation, the clinician can objectively assess the presence of edema and increase in the size of the liver by percussion and palpation. However, it is mandatory to differentiate edema of the lower extremities, which occur in varicose veins of the lower extremities, lymphostasis, and an increase in the size of the liver in liver diseases, including the widespread steatohepatosis in recent years.

The study determined the sensitivity, specificity of ultrasound method for congestion diagnostics in the systemic circulation by the diameter of IVC on exhalation with the gold standard – invasive measurement of pressure in RA. The sensitivity of the inferior vena cava diameter exceeding 18,5 mm on exhalation is 100%, the specificity is 92%. There was a positive correlation between invasive measured mean pressure in RA and the systolic pressure in the pulmonary artery ($r = 0.54$, $p < 0.05$) and maximum diameter of IVC ($r = 0.49$, $p < 0.05$).

Limitations. We studied a small number of participants. The studied patients did not have a large range of atrial pressure, which may underestimate the real relationship between the maximum and/or minimum diameter of the PVs and the pressure in the LA.

Conclusion

The new ultrasound method of congestion diagnostics in the pulmonary circulation by a maximum and/or minimum diameter of RSPV in the same way as the well-known technique of congestion in the systemic circulation by the diameter of IVC in patients with AF and CHF can be effectively used in everyday clinical practice allowing an adequate diuretic therapy, can significantly reduce the number of CHF decompensation cases.

Abbreviations

ACEI – angiotensin converting enzyme inhibitors

AF – atrial fibrillation

ARB – angiotensin receptor blockers

CHF – chronic heart failure

FC – functional class

IVC – inferior vena cava

LAVI – left atrial indexed volume

LV – left ventricle

MCRA – mineralocorticoid receptor antagonists

PASP – pulmonary artery systolic pressure

PAWP –pulmonary artery wedge pressure

PCWP – pulmonary capillary wedge pressure

PVI – pulmonary veins isolation

RA – right atrium

RAP – right atrial pressure

RSPV – right superior pulmonary vein

RV – right ventricle

Declarations

Ethics approval and consent to participate

The informed consent for research was obtained from all the patients. All patients gave the written consent for participation in the study, which was approved by the local ethic committee of the Cardiology Research Institute of Tomsk (Russia).

Consent to publish

Not applicable.

Availability of data and materials

The dataset used for the current study is available from the corresponding author on reasonable request.

Competing Interests

The authors declare no competing interests.

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Authors' Contributions

Venera Kirillova: Conceptualization Ideas, Methodology, Data Curation, Formal analysis, Writing - Original Draft, Andrey Smorgon: Investigation, Alla Garganeeva: Supervision, Project administration, Writing - Review & Editing, Roman Batalov: Supervision, Project administration, Viktor Meshchaninov: Validation, Visualization, Ludmila Sokolova: Validation, Maria Blagodareva: Statistical Analysis, Mikhail Khlynin: Writing - Original Draft, Writing - Review & Editing, and Sergey Popov: Funding acquisition Acquisition of the financial support for the project leading to this publication.

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References

1. Dharmarajan K, Hsieh AF, Lin Z, et al. Diagnoses and timing of 30– day readmissions after hospitalization for heart failure, acute myocardial infarction, or pneumonia. JAMA. 2013;309:355–63.
2. The SOLVDI. Effect of enalapril on mortality and the development of heart failure in asymptomatic patients with reduced left ventricular ejection fraction. N Engl J Med. 1992;327(10):685–91.
3. Cleland JG, Swedberg K, Follath F, Komajda M, Cohen– Solal A, Aguilar JC, et al. e EuroHeart Failure survey programme– a survey on the quality of care among patients with heart failure in Europe. Part I: patient characteristics and diagnosis. Eur Heart J. 2003;24(5):442–63.
4. Maggioni AP, Dahlström U, Filippatos G, Chioncel O, Leiro MC, Drozdz J, et al. EURObservational Research Programme: the heart failure pilot survey (ESC– HF Pilot). Eur J Heart Fail. 2010;12(10):1076–84.
5. Wang TJ, Larson MG, Levy D, et al. Temporal relations of atrial fibrillation and congestive heart failure and their joint influence on mortality: the Framingham Heart Study. Circulation. 2003;107(23):2920–5.
6. Sato N, Kajimoto K, Asai K, Mizuno M, Minami Y, Nagashima M, et al. Acute decompensated heart failure syndromes (ATTEND) registry. A prospective observational multicenter cohort study: rationale, design, and preliminary data. Am Heart J. 2010;159(6):949–55. . DOI:10.1016 / j. ahj. 2010.03.019.

7. Abraham WT, Fonarow GC, Albert NM, Stough WG, Gheorghiade M, Greenberg BH, et al. Predictors of in– hospital mortality in patients hospitalized for heart failure: insights from the Organized Program to Initiate Lifesaving Treatment in Hospitalized Patients with Heart Failure (OPTIMIZE– HF). J Am Coll Cardiol. 2008;52(5):347–56. DOI:10.1016 / j. jacc. 2008.04.028.
8. Fomin IV. Chronic heart failure in Russian Federation: what do we know and what to do. Russian Journal of Cardiology. 2016;(8):7–13. (In Russ.).
9. Mareev VYu, Fomin IV, Ageev FT, et al. Clinical guidelines. Chronic heart failure (CHF). Russian Heart Failure Journal. 2017;18(1):3–40. (in Russ).
10. Ponikowski P, Voors AA, Anker SD, Bueno H, Cleland JG, Coats AJ, et al. 2016 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: The Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC) Developed with the special contribution of the Heart Failure Association (HFA) of the ESC. European Heart Journal. 2016;37(27):2129–200. DOI:10.1093/eurheartj/ehw128.
11. Mullens W, Damman K. Harjola V– P. The use of diuretics in heart failure with congestion — a position statement from the Heart Failure Association of the European Society of Cardiology. Eur J Heart Fail. 2019;21:137–55. doi:10.1002/ejhf.1369.
12. Ommen SR, Nishimura RA, Appleton CP, Miller FA, Oh JK, Redfield MM, et al. Clinical utility of doppler echocardiography and tissue doppler imaging in the estimation of left ventricular filling pressures. A comparative simultaneous doppler-catheterization Study. Circulation. 2000;102:1788–94.
13. Ciozda W, Kedan I, Kehl DW, Zimmer R, Khandwalla R, Kimchi A. The efficacy of sonographic measurement of inferior vena cava diameter as an estimate of central venous pressure. Cardiovascular Ultrasound. 2016;14:33. DOI 10.1186/s12947-016-0076– 1.
14. Kirillova VV. Method for ultrasonic early diagnosis of venous pulmonary hypertension for patients with chronic heart failure. Patent RF №. 2016;2 634:633. (in Russ.).
15. Kirillova VV. Early ultrasound diagnostic venous pulmonary hypertension. Eur J Heart Failure. 2017;19(Suppl 1):496.
16. Nagueh SF, Middleton KJ, Kopelen HA, et al. Doppler tissue imaging: a noninvasive technique for evaluation of left ventricular relaxation and estimation of filling pressures. JACC. 1997;30:1527–33.
17. Nagueh MF, Kopelen HA, Zoghbi WA, et al. Estimation of mean right atrial pressure using tissue Doppler imaging. Am J Cardiol. 1999;84:1448–51.
18. Karmazanovsky GG. Estimation of the Diagnostic Method Value ("Sensitivity”"Specificity” and "General Accuracy”). Annaly khirurgicheskoy gepatologii = Annals of HPB Surgery. 1997; 2:139–142. (In Russ.).
19. Braunwald E, Brockenbrough EC, Franm CJ, et al. Left Atrial and Left Ventricular Pressures in Subjects without Cardiovascular Disease. Circulation. 1961;XX1V:267–9.
20. Haissaguerre M, Jais P, Shah DC, Takahashi A, Hocini M, Quiniou G, et al. Spontaneous initiation of atrial fibrillation by ectopic beats originating in the pulmonary veins. N Engl J Med. 1998;339:659–66.

21. Haissaguerre M, Sanders P, Hocini M, Jais P, Clementy J. Pulmonary veins in the substrate for atrial fibrillation: the “venous wave” hypothesis. J Am Coll Cardiol. 2004;43:2290–2.
22. Tsao HM, Yu WC, Cheng HC, Wu MH, Tai CT, Lin WS, et al. Pulmonary vein dilation in patients with atrial fibrillation: detection by magnetic resonance imaging. J Cardiovasc Electrophysiol. 2001;12:809–13.
23. Nauta F, Hummel YM, Meer P, Lam CSP, Voors AA, Melle JP. Correlation with invasive left ventricular filling pressures and prognostic relevance of the echocardiographic diastolic parameters used in the 2016 ESC heart failure guidelines and in the 2016 ASE/EACVI recommendations: a systematic review in patients with heart failure with preserved ejection fraction European. Journal of Heart Failure. 2018;20:1303–11. doi:10.1002/ejhf.1220.
24. KirillovaVV. Myocardial remodeling in patients with atrial fibrillation in chronic heart failure. Translational medicine. 2018;5(2):15–21. (in Russ.).
25. KirillovaVV. Method of treatment of paroxysmal atrial fibrillation in chronic heart failure patients with arterial hypertension. The invention of the utility model. 2019;29:2703517. (In Russ.).
26. Kirillova VV. Ultrasound criteria of the diuretic therapy effectiveness in chronic heart failure. The Siberian Medical Journal. 2018;33(2):51–5. (In Russ.).

Figures

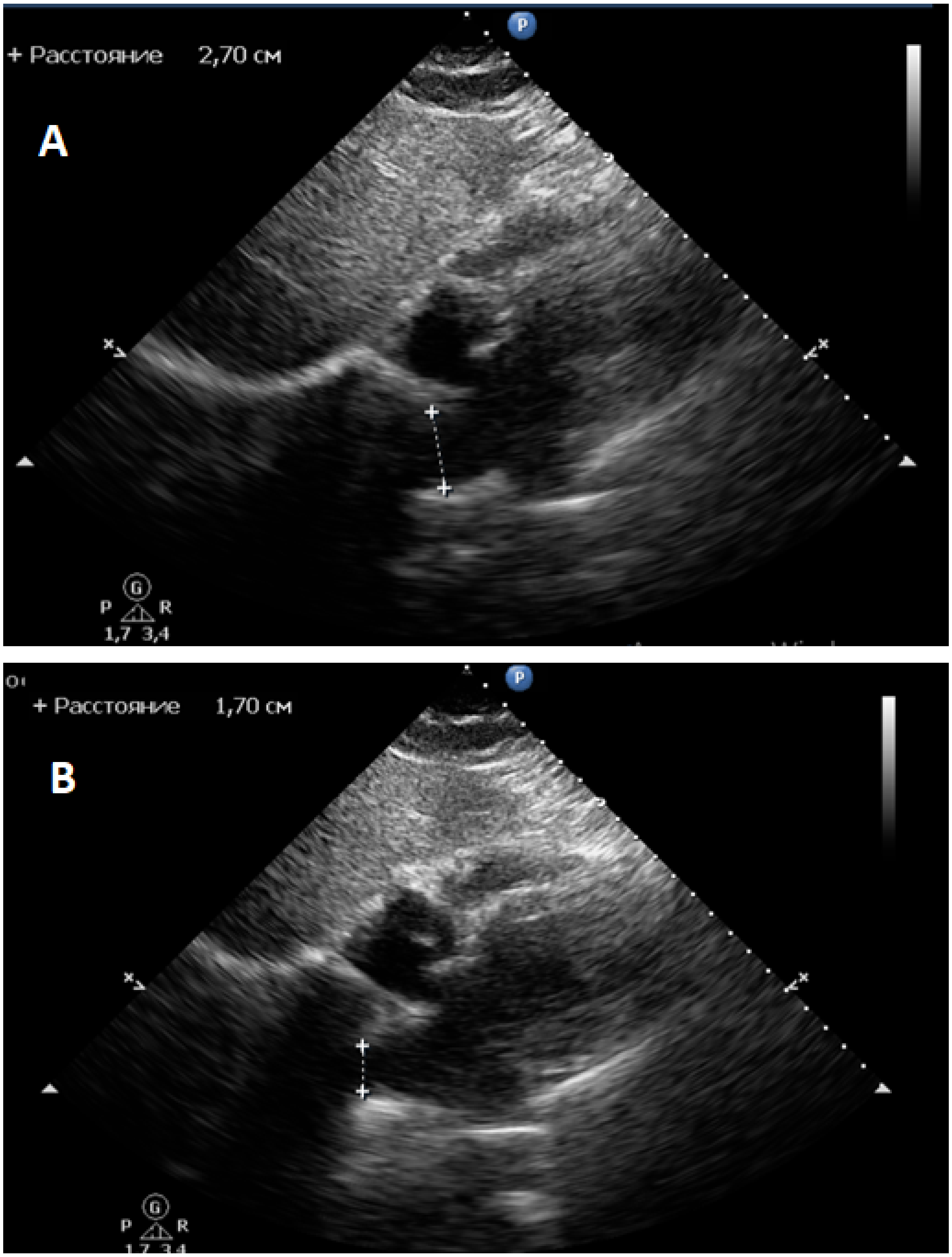

Figure 1

A. The maximum diameter of RSPV in patients with AF and CHF Note: the maximum diameter of RSPV is a 27 mm B. The minimum diameter of RSPV in patients with AF and CHF Note: the minimum diameter of RSPV is a 17 mm

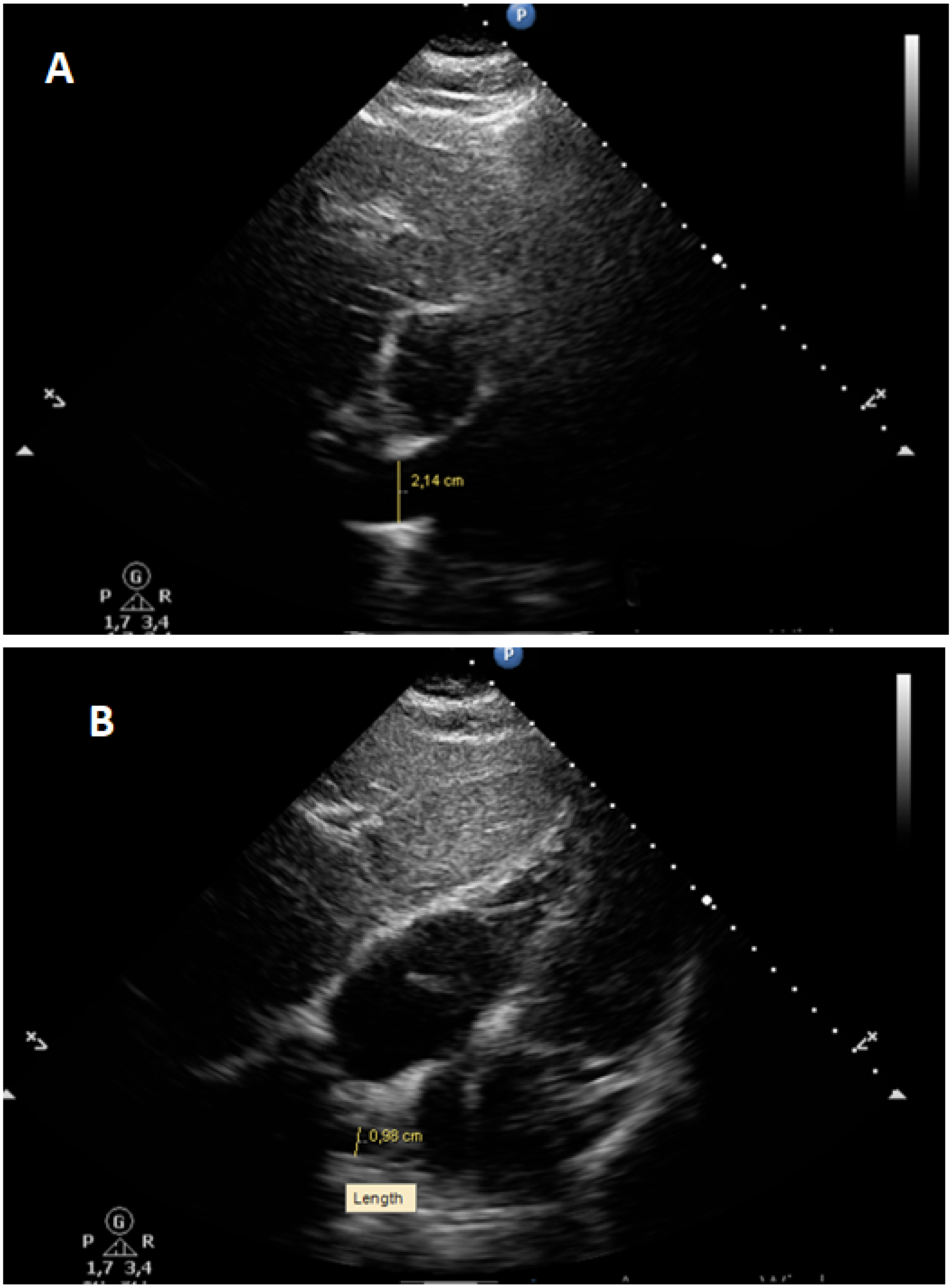

Figure 2

A. The maximum diameter of RSPV in patients with AF and without CHF Note: the maximum diameter of RSPV is a 21.4 mm B. The minimum diameter of RSPV in patients with AF and without CHF Note: the minimum diameter of RSPV is a 9.8 mm

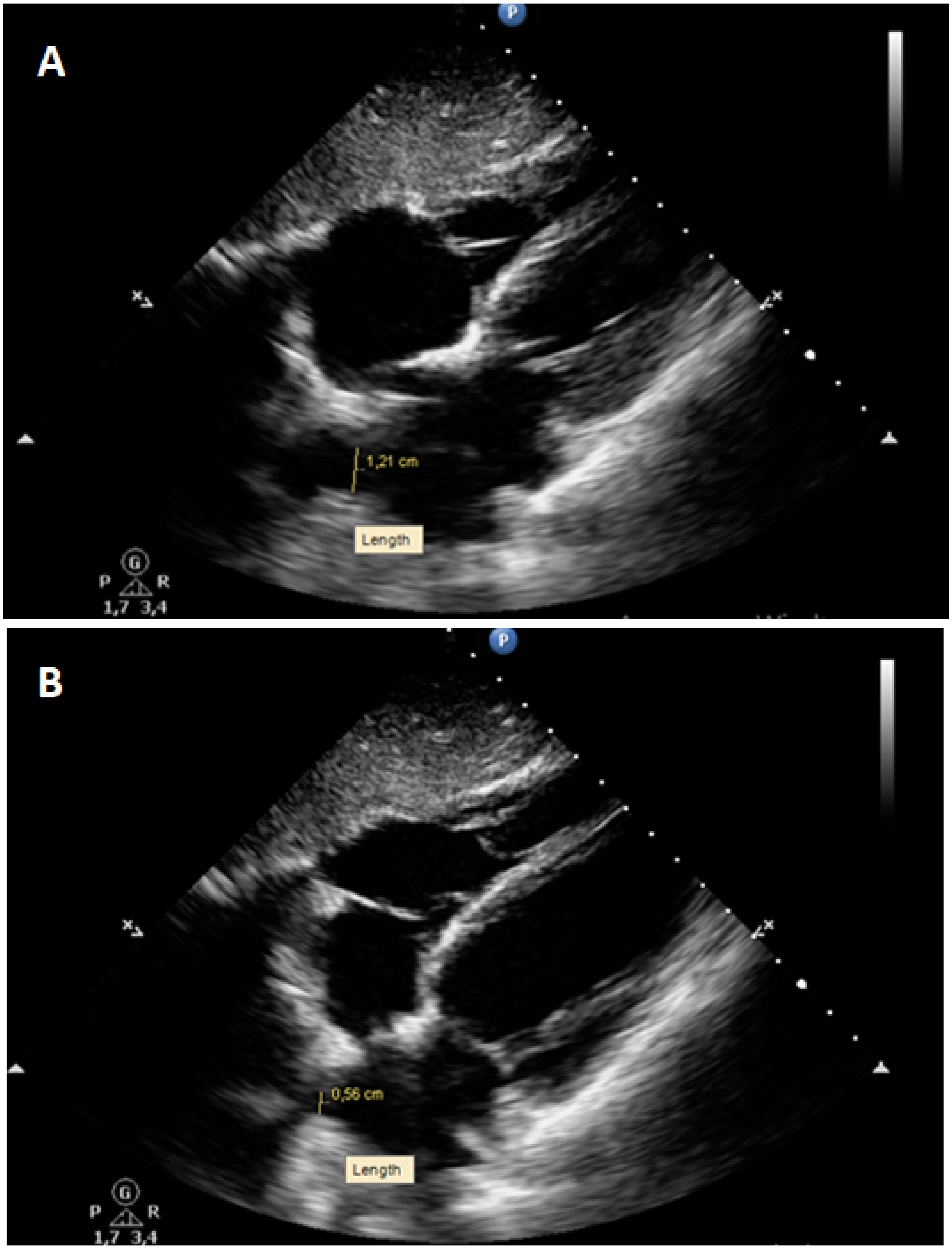

Figure 3

A. The maximum diameter of RSPV in control values Note: the maximum diameter of RSPV is a 12.1 mm
B. The minimum diameter of RSPV in control values Note: the minimum diameter of RSPV is a 5.6 mm