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Assessing pulmonary congestion in patients hospitalized with decompensated chronic heart failure according to lung ultrasound and remote dielectric sensing (ReDS)

Kobalava Zh.D.[1], Safarova A.F.[1,2], Tolkacheva V.V.[1], Zorya O.T.[1], Cabello Montoya F.E.[1], Nazarov I.S.[1], Lapshin A.A.[1,2], Smirnov I.P.[1], Khutsishvili N.I.[1], Galochkin S.A.[1,2], Vatsik-Gorodetskaya M.V.[2]

[1] *Peoples' Friendship University of Russia (RUDN University)*
8, Mikluho-Maklaya Str., Moscow, 117198, Russian Federation

[2] *Vinogradov City Clinical Hospital*
61, Vavilova Str., Moscow, 117292, Russian Federation

ABSTRACT

Aim. To conduct a comparative assessment of parameters and dynamics of pulmonary congestion according to lung ultrasound and remote dielectric sensing (ReDS) in patients hospitalized with decompensated chronic heart failure (CHF)

Materials and methods. The pilot single-center study included patients hospitalized with decompensated CHF. Lung ultrasound and ReDS were simultaneously performed within 24 hours from the moment of hospitalization and at discharge. Eight-zone lung ultrasound was performed with the calculation of the sum of B-lines. Pulmonary congestion was confirmed with the sum of B-lines ≥ 5. ReDS was performed according to the manufacturer's protocol. Congestion was confirmed at the value of more than 35%. To determine ReDS interoperator variability, each patient was examined by two operators who were blind to each other's findings with a 20–30-minute interval.

Results. Thirty-five patients were included in the study: 40% (n = 14) men, the average age was 71 (65.5; 78.5) years, the median NT-proBNP was 1,379 (470; 4,277) pg / l. Hydrothorax at admission was observed in 31,4% (n = 11) of patients. The incidence of pulmonary congestion according to lung ultrasound was 57.1% (n = 20): 31.4% (n = 11) of patients had mild congestion, 22.9% (n = 8) – moderate, and 2.9% (n = 1) – severe congestion. ReDS data revealed pulmonary congestion in 62.9% (n = 22) of cases, of which 37,1% (n = 13) of cases were characterized by mild, 22.9% (n = 8) – by moderate, and 2.9% (n = 1) – by severe congestion. A moderate correlation was found between ReDS (%) and lung ultrasound (sum of B-lines) findings at admission (Spearman's rank correlation coefficient = 0.402; p = 0.017). No correlation between the two methods was found at discharge (p = 0.613). The frequency of agreement between lung ultrasound and ReDS on signs of congestion at admission was 77.1% (p = 0.004) with an average Cohen's Kappa coefficient (κ = 0.53). The average interoperator variability in ReDS was 9.9%.

Conclusion. A moderate correlation was revealed between ReDS (%) and lung ultrasound (sum of B-lines) in detecting pulmonary congestion (Spearman's rank correlation coefficient = 0.402; p = 0.017). No correlation between the two methods was found at discharge (p = 0.613).

Keywords: heart failure, pulmonary congestion, lung ultrasound, remote dielectric sensing (ReDS)

Conflict of interest. The authors declare the absence of obvious or potential conflicts of interest related to the publication of this article.

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Conformity with the principles of ethics. All patients signed an informed consent to participate in the study. The study was approved by the Ethics Committee at RUDN University.

✉ *Tolkacheva Veronika V.,* tolkachevav@mail.ru

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Оценка наличия и динамики легочного застоя по данным ультразвукового и дистанционного диэлектрического исследования (REDS) у пациентов, госпитализированных с декомпенсацией хронической сердечной недостаточности

Кобалава Ж.Д.[1], Сафарова А.Ф.[1,2], Толкачева В.В.[1], Зоря О.Т.[1], Кабельо Монтойа Ф.Э.[1], Назаров И.С.[1], Лапшин А.А.[1,2], Смирнов И.П.[1], Хуцишвили Н.И.[1], Галочкин С.А.[1,2], Вацик-Городецкая М.В.[2]

[1] *Российский университет дружбы народов (РУДН)*
Россия, 117198, г. Москва, ул. Миклухо-Маклая, 8

[2] *Городская клиническая больница (ГКБ) им. В.В. Виноградова*
Россия, 117292, г. Москва, ул. Вавилова, 61

РЕЗЮМЕ

Цель: провести сравнительную оценку наличия и динамики легочного застоя по данным ультразвукового (УЗИ) и дистанционного диэлектрического (ReDS) исследования у пациентов, госпитализированных с декомпенсацией хронической сердечной недостаточности (ХСН).

Материалы и методы. В пилотное одноцентровое исследование включались пациенты, госпитализированные с декомпенсацией ХСН. В течение 24 ч от момента госпитализации и при выписке одномоментно проводились УЗИ легких и исследование с применением технологии ReDS. Ультразвуковое исследование легких выполнялось по протоколу с оценкой восьми зон и подсчетом суммы В-линий. Легочный застой подтверждался при сумме В-линий ≥5. Исследование ReDS выполнялось по протоколу производителя, застой подтверждался при получении значения более 35%. Для определения межоператорской вариабельности ReDS каждому пациенту исследование проводили два заслепленных оператора с интервалом 20–30 мин независимо друг от друга.

Результаты. В исследование были включены 35 пациентов: 40% (*n* = 14) мужчин, средний возраст 71 (65,5; 78,5) год, медиана NT-proBNP составила 1 379 (470; 4 277) пг/л. Гидроторакс при поступлении наблюдался у 31,4% (*n* = 11) пациентов. Частота легочного застоя, по данным УЗИ, составила 57,1% (*n* = 20), из них легкая степень застоя наблюдалась у 31,4% (*n* = 11), средняя – у 22,9% (*n* = 8), тяжелая – у 2,9% (*n* = 1) пациентов. Легочный застой, по данным ReDS, наблюдался у 62,9% (*n* = 22), из них легкий у 37.1% (*n* = 13), средний у 22,9% (*n* = 8), тяжелый у 2.9% (*n* = 1). Выявлена умеренная корреляционная связь между показателями ReDS (%) и УЗИ легких (сумма В-линий) при поступлении (*r* = 0,402; *p* = 0,017). При выписке корреляционной взаимосвязи между двумя методами выявлено не было (*p* = 0,613). Частота согласия по наличию или отсутствию признаков застоя, по данным обоих методов, на момент поступления составила 77,1% (*p* = 0,004) со средним значением коэффициента согласия каппа Коэна (κ = 0,53). Наблюдалась средняя межоператорская вариабельность для исследования ReDS (коэффициент вариабельности 9,9%).

Заключение. Отмечена умеренная корреляционная связь между показателями ReDS (%) и УЗИ легких (сумма В-линий) в отношении выявления легочного застоя при поступлении (*r* = 0,402; *p* = 0,017). При выписке корреляционной взаимосвязи между двумя методами выявлено не было (*p* = 0,613).

Ключевые слова: сердечная недостаточность, легочный застой, УЗИ легких, дистанционное диэлектрическое исследование (ReDS)

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источник финансирования. Авторы заявляют об отсутствии финансирования при проведении исследования.

Соответствие принципам этики. Все пациенты подписали информированное согласие на участие в исследовании. Исследование одобрено локальным этическим комитетом РУДН.

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INTRODUCTION

Determining the hydration status, including a quantitative assessment of congestion severity, is one of the urgent tasks in the treatment of decompensated heart failure in hospital and outpatient settings. Hemodynamic overload and subsequent venous congestion are links of pathophysiological reactions included in the formation of this condition.

Discharge from hospital before congestion is fully resolved increases the risk of death and re-hospitalization [1–3]. In addition, patients may experience subclinical congestion at discharge, which is detected only by laboratory and instrumental methods, and clinical manifestations may develop even before the end of the first week after the discharge [2, 3].

More than 90% of heart failure-related hospitalizations are due to pulmonary congestion (CHAMPION trial) [4]. Early detection of pulmonary congestion is extremely important, as it allows to prevent the development of a decompensation episode, start proper treatment, and improve the disease prognosis.

According to current European guidelines, chest X-ray and lung ultrasound are recommended as instrumental methods to detect pulmonary congestion in patients with acute heart failure (HF) [5, 6].

According to previously published studies, including randomized clinical trials and large foreign registries, lung ultrasound demonstrated significantly higher sensitivity and specificity in detecting pulmonary congestion and had independent prognostic value [7–9]. However, due to the limitations of these methods, a search for new methods to assess the degree of pulmonary congestion remains relevant.

A non-invasive remote dielectric sensing (ReDS) technology makes it possible to quantify the total volume of fluid in the lungs by determining the dielectric properties of the tissue. As a result of the measurement, the operator quickly and safely receives a numerical value corresponding to the percentage of fluid in the lung tissue. According to the meta-analysis, which included works published from 2017 to 2021 with the analysis of a sample of 985 patients, management of patients using the ReDS technology reduced the frequency of readmission for HF [10].

Still, studies on the comparative assessment of lung ultrasound and ReDS in patients with HF are few [11], and there are no studies involving Russian patient population.

Therefore, the aim of this study was to compare the incidence and dynamics of pulmonary congestion according to lung ultrasound and ReDS in patients hospitalized with acute decompensated heart failure (ADHF).

MATERIALS AND METHODS

The study included 35 patients hospitalized with ADHF, regardless of left ventricular ejection fraction, in the emergency hospital of V.V. Vinogradov City Clinical Hospital (Moscow). ADHF was diagnosed based on current clinical guidelines [12, 13].

The study did not include patients with severe liver diseases, immobilization, terminal somatic symptom disorders and malignant diseases, acute coronary syndrome, edema of another etiology, an electrical pacemaker, severe chest deformity, and acute infectious diseases (including COVID-19-assicuated pneumonia).

The research protocol was approved by the local Ethics Committee at RUDN University. All patients signed an informed consent to the examination procedures. The study was performed in accordance with the standards of Good Clinical Practice and the principles of the Declaration of Helsinki.

All patients included in the study underwent a standard physical, laboratory, and instrumental examination upon hospitalization and discharge, which included lung ultrasound, determination of NT-proBNP, a study using the ReDS technology, liver FibroScan, bioimpedance vector analysis of the body composition, and assessment of venous congestion according to the VExUS score. The design of the study is shown in Fig.1. The characteristics and main laboratory and instrumental parameters of the patients are presented in Table.

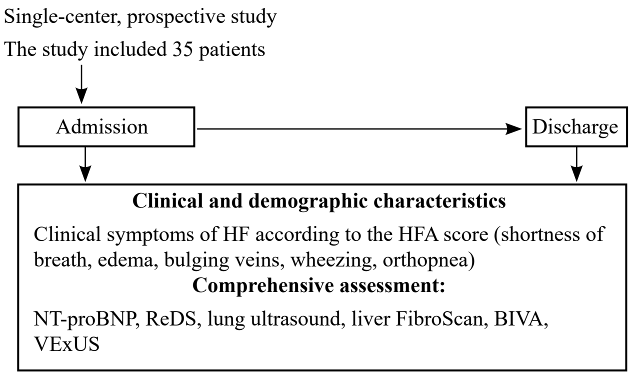

Fig. 1. Design of the study

Table

Clinical and demographic characteristics and laboratory and instrumental findings of patients included in the study, *n* = 35

Parameter	Value
Clinical and demographic characteristics	
Gender (male / female), *n* (%)	14 (40%)/21 (60%)
Age, years, *Me* (*IQR*)	71 [65.5; 78.5]
BMI, kg / m^2, *Me* (*IQR*)	34.5 [27.0; 38.6]
Smoking, *n* (%)	8 (22.9%)
LVEF, % *Me* (*IQR*)	52 [40; 55]
Arterial hypertension, *n* (%)	34 (97.2%)
Previous stroke, *n* (%)	5 (14.3%)
Coronary artery disease, *n* (%)	14 (40.0%)
Previous myocardial infarction, *n* (%)	6 (17.2%)
Atrial fibrillation / flutter, *n* (%)	22 (62.9%)
Type 2 diabetes mellitus, *n* (%)	9 (25.7%)
Chronic kidney disease, *n* (%)	22 (62.9%)
COPD / BA, *n* (%)	5 (14.3%)
SBP, mm Hg., *Me* (*IQR*)	133 [120.5; 146]
DBP, mm Hg., *Me* (*IQR*)	80 [70; 84.5]
Heart rate, beats per min, *Me* (*IQR*)	85 [74; 120]
Laboratory and instrumental characteristics at admission	
Liver stiffness, kPa, *Me* (*IQR*)	13 [6; 21]
Sum of B-lines in lung ultrasound, *Me* (*IQR*)	8 [4; 16]
BIVA, resistance, Om / m, *M* ± *SD*	394 ± 99
BIVA, reactance, Om / m, *Me* (*IQR*)	38 [31; 45]
Size of the inferior vena cava, mm, *M* ± *SD*	22 ± 5
Congestion grade according to VExUS, *n* (%)	GRADE 0: 14 (40%) GRADE 1: 3 (8.6%) GRADE 2: 6 (17.1%) GRADE 3: 12 (34.3%)
NT-proBNP, pg / ml, *Me* (*IQR*)	1,379 (470; 4,277)
ReDS findings, *M* ± *SD*	37 ± 6

Note. BMI – body mass index, LVEF – left ventricular ejection fraction, SBP – systolic blood pressure, DBP – diastolic blood pressure, BIVA – bioimpedance vector analysis.

To identify and assess the severity of pulmonary congestion, lung ultrasound was performed according to the protocol with the calculation of the number of B-lines in 8 zones along the anterior and lateral surfaces of the chest using the GE Vivid iq ultrasound system. The sum of B-lines of 6–15 was considered as mild, of 16–30 – as moderate, of more than 30 – as severe congestion.

The ReDS technology is based on the estimation of dielectric properties of the tissue. Low-power electromagnetic radiation passes through tissues from the emitter to the receiver. Since water has a very high dielectric constant, and dielectric constants of tissues are determined mainly by liquid contained in it, the assessment of changes in the parameters of radio waves makes it possible to accurately measure the total volume of liquid in the tissue. Thus, the ReDS system calculates the air-to--liquid volumetric ratio and shows the percentage of pulmonary fluid [10, 11, 14].

The study was conducted according to the manufacturer's protocol. A sensor was placed on the right side of the patient`s chest in a sitting position. The measurement took about 45 seconds (Fig.2). The manufacturer's recommended range of normal values was 20–35%. More than 35% indicated pulmonary congestion. The severity of congestion was determined by the following values: 36-40% – grade 1 (increased fluid content in the lungs), 41–50% – grade 2 (high fluid content in the lungs), more than 50% – grade 3 (extremely high fluid content in the lungs).

To determine ReDS interoperator variability, each patient was examined by two operators who were blind to each other's findings with a 20–30-minute interval.

Statistical processing of the results was performed using the MedCalc version 19.0 and SPSS (version 22.0) software. Quantitative variables were described as the arithmetic mean (*M*) and the standard deviation (*SD*) (with a normal distribution) or as the median and the interquartile range *Me (IQR)* (with a non-normal distribution).

Fig. 2. Remote dielectric sensing (ReDS) technology. The device consists of two sensors (front and rear), a computing unit, and a monitor

The nature of data distribution was determined using the Kolmogorov – Smirnov test. For normally distributed data, the significance of differences was assessed by the Student's *t*-test for dependent and independent samples. For non-normally distributed data, the significance of differences between the groups was assessed using the Mann– Whitney test for independent samples and the Wilcoxon's test for dependent samples. The differences were considered statistically significant at $p < 0.05$ (with the Bonferroni correction). The direction and strength of the correlation between the two quantitative variables were estimated by the Spearman's rank correlation coefficient (with non-normally distributed data).

To assess interoperator variability for qualitative parameters, the coefficient of agreement, or Cohen's kappa (κ) was determined, which was calculated using the formula: $\kappa = (po - pe) / (1 - pe)$, where po is actually observed agreement between operators, pe is expected agreement that would be observed by chance alone (with complete agreement, $\kappa = 1$, and in the absence of agreement, $\kappa = 0$). In the meantime, $\kappa = 0$–0.2 indicates slight agreement, $\kappa = 0.21$–0.4 – fair agreement, $\kappa = 0.41$–0.6 – moderate agreement, $\kappa = 0.61$–0.8 – substantial agreement, and $\kappa = 0.81$-1 – almost perfect agreement.

RESULTS

Pulmonary congestion at admission according to ReDS data was diagnosed in 62.9% ($n = 22$) of patients, of which 37.1% ($n = 13$) of patients had mild, 22.9% ($n = 8$) of patients – moderate, and 2.9% ($n = 1$) of patients – severe congestion. Pulmonary congestion at discharge was detected in 44% ($n = 15$) of patients. Lung ultrasound revealed pulmonary congestion at admission in 57.2% ($n = 20$) of cases, of which mild congestion was detected in 31.4% ($n = 11$) of patients, moderate – in 22.9% ($n = 8$) of patients, and severe – in 2.9% ($n = 1$) of cases. At discharge, it was detected in 16% cases ($n = 5$) (Fig.3). Hydrothorax at admission was observed in 31.4% ($n = 11$) of patients.

A moderate correlation was found between ReDS (%) and lung ultrasound (sum of B-lines) findings at admission ($r = 0.402$; $p = 0.017$). At discharge, no correlation was found between the two methods ($p = 0.613$) (Fig.4).

The frequency of agreement between the two methods on the presence or absence of signs of congestion at admission was 77.1% ($p = 0.004$) with a moderate Cohen's kappa value ($\kappa = 0.53$). At discharge, the frequency of agreement between the methods was 41.7% ($p = 0.223$), and the Cohen's kappa value was negative. Taking into account hydrothorax as a sign of congestion along with the sum of B-lines on lung ultrasound at admission, the agreement between the methods was 71.4% ($p = 0.033$), and Cohen's kappa was $\kappa = 0.388$. At discharge, taking into account hydrothorax did not change the frequency of agreement between the two methods in detecting pulmonary congestion.

The average interoperator variability for the ReDS study was revealed (the variability coefficient was

9.9%). At the same time, ReDS showed that variability between operators was 12.7% at admission and 6.6% at discharge. For the ReDS study, Cohen's kappa between operators in detecting pulmonary congestion was κ = 0.82 (κ = 0.908 at admission and κ = 0.657 at discharge).

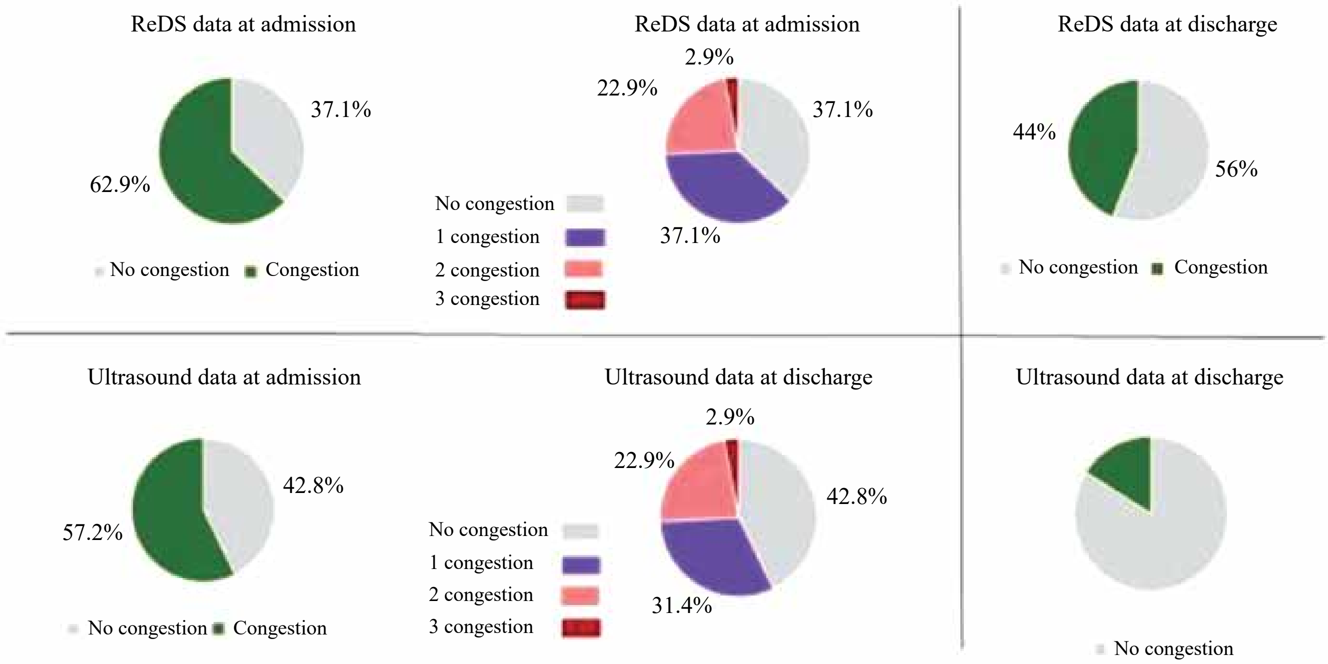

Fig. 3. The incidence of pulmonary congestion in patients with ADHF at admission and at discharge according to ReDS and lung ultrasound findings (n = 35)

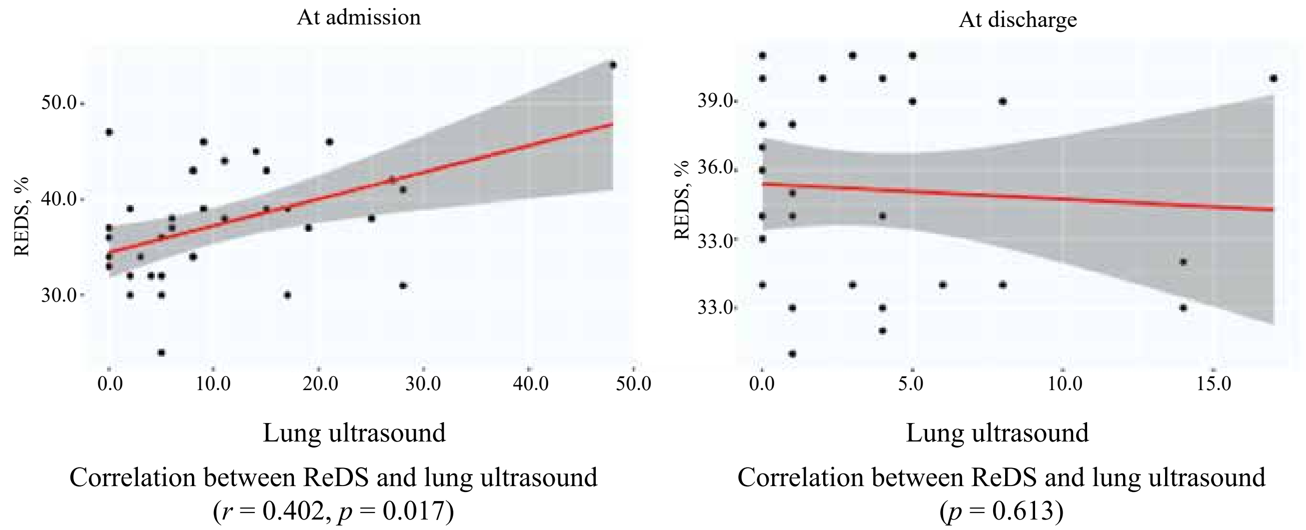

Fig. 4. Correlation between ReDS (%) and lung ultrasound (sum of B-lines) findings

DISCUSSION

The accuracy of the diagnosis of pulmonary congestion by lung ultrasound is high, the sensitivity and specificity of this method exceed 95%. The consensus of experts recommends lung ultrasound for the diagnosis of pulmonary congestion [15]. Therefore, lung ultrasound in this study was considered as the gold standard for assessing pulmonary congestion. However, this study is a semi-quantitative method and requires appropriate equipment and highly qualified specialists.

As an alternative method for quantifying the degree of congestion in the lungs and displaying the percentage of pulmonary fluid in 45 seconds, the ReDS technology can be used. This is a non-invasive method that does not require expertise.

A strong correlation was demonstrated between ReDS findings and clinical signs of pulmonary congestion in patients with ADHF during hospital stay [16]. It was shown that ReDS values were strongly correlated with other assessment methods, including high-resolution computed tomography (0.90 (95% confidence interval (CI) 0.85–0.95) [17] and right heart catheterization [18]. In a study conducted in Japan, a moderate correlation between ReDS values and high-resolution computed tomography was revealed (r = 0.65, $p < 0.001$). In addition, it was shown that the ReDS value is an independent predictor of pulmonary congestion after adjustment for N-terminal pro b-type natriuretic peptide (NT-proBNP) and patient's body weight [19].

The gold standard for quantifying the severity of pulmonary congestion is catheterization of the right heart with measurement of pulmonary capillary wedge pressure (PCWP). However, given a number of limitations, such as the invasive nature of the procedure, the risk of complications, including exacerbation of HF, especially in patients with unstable hemodynamics and those receiving anticoagulants, catheterization of the right heart is not widely used in routine clinical practice.

In a study conducted in Israel including 139 patients with HF, a positive correlation was found between the ReDS values and pulmonary artery pressure (r = 0.492, $p < 0.001$), as well as between the values of ReDS and central venous pressure (r = 0.406, $p < 0.001$). It was shown that the ReDS value (threshold value of 34%) had high sensitivity (90.7%), high specificity (77.1%), and a negative prognostic value (94.9%) in determining PCWP of 18 mm Hg [20]. In another study, a moderate correlation was found between the values of ReDS and PCWP (r = 0.698, $p < 0.001$); the ReDS value of 28% was a threshold value for predicting PCWP > 15 mm Hg with sufficiently high sensitivity (0.70) and specificity (0.75) [17].

It was shown that the ReDS technology is comparable to lung ultrasound in detecting subclinical pulmonary congestion, since ReDS values of > 35% had sensitivity of 66.7%, specificity of 87.5%, and a negative prognostic value of 93.3% compared to the sum of B-lines in lung ultrasound [11].

In our study, pulmonary congestion at admission according to ReDS data was diagnosed in 62.9% of cases, according to lung ultrasound – in 57.2% of patients. A moderate correlation was found between ReDS (%) and lung ultrasound (sum of B-lines) findings at admission (r = 0.402; p = 0.017). The interoperator variability of ReDS was also studied. The Cohen's kappa for the ReDS study in detecting pulmonary congestion was κ =0.82 (κ = 0.908 at admission and κ = 0.657 at discharge), which indicated almost complete agreement in values between the two operators. This is confirmed by the literature data. A study in Japan involving 10 healthy volunteers also demonstrated very high reliability of ReDS measurements between three operators (0.966, 95% CI: 0.952–0.976). This allows to suggest that a single ReDS measurement is reliable [21].

CONCLUSION

The remote dielectric sensing (ReDS) technology has a moderate correlation with lung ultrasound in terms of assessing pulmonary congestion in patients hospitalized with ADHF. However, it is worth noting that currently these methods can be considered as complementary, and the use of the ReDS technology in patients with HF requires further study.

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Authors' contribution

Kobalava Zh.D., Safarova A.F., Vatsik-Gorodetskaya M.V. – conception and design. Tolkacheva V.V. Zorya O.T., Cabello Montoya F.E. – analysis of the acquired data, drafting of the article. Nazarov I.S., Lapshin A.A, Smirnov I.P., Khutsishvili N.I., Galochkin S.A. – collection and processing of the materials.

Authors' information

Kobalava Zhanna D. – Dr. Sci. (Med.), Professor, Head of the Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, zkobalava@mail.ru, https://orcid.org/0000-0002-5873-1768

Safarova Ayten F. –, Dr. Sci. (Med.), Professor of the Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, aytensaf@mail.ru, https://orcid.org/0000-0003-2412-5986

Tolkacheva Veronika V. – Dr. Sci. (Med.), Associate Professor, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, tolkachevav@mail.ru, https://orcid.org/0000-0001-6847-8797

Zorya Olga T. – Cand. Sci. (Med.), Teaching Assistant, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, olyazorya2020@outlook.com, https://orcid.org/0000-0002-8855-0079

Cabello Montoya Flora Elisa – Cand. Sci. (Med.), Teaching Assistant, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, flora.cabello@mail.ru, https://orcid.org/0000-0002-2334-6675

Nazarov Ivan S. – Post-Graduate Student, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, nazarovradomla@mail.ru, https://orcid.org/0000–0002–0950–7487

Lapshin Artem A. – Cand. Sci. (Med.), Teaching Assistant, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, lapshin_aa@pfur.ru, https://orcid.org/0000-0002-4308-4764

Smirnov Ilya P. – Resident, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, zzevor@mail.ru, https://orcid.org/0009-0001-0285-1752

Khutsishvili Nutsiko I. – Post-Graduate Student, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, nutsiko.khutsishvili@gmail.com, https://orcid.org/0009-0009-2669-8092

Galochkin Svyatoslav A. – Cand. Sci. (Med.), Associate Professor, Department of Internal Medicine with a Course in Cardiology and Functional Diagnostics named after academician V.S. Moiseev, RUDN University, Moscow, galochkin-sa@rudn.ru, https://orcid.org/0000-0001-7370-8606

Vatsik-Gorodetskaya Maria V. – Cand. Sci. (Med.), Deputy Chief Physician for Anesthesiology and Resuscitation, V. V. Vinogradov City Clinical Hospital, Moscow, m.vatsyk@gmail.com, https://orcid.org/0000-0002-6874-8213

(✉) **Tolkacheva Veronika V.**, tolkachevav@mail.ru

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