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# INTERSTITIAL SYNDROME AND ALVEOLAR CONSOLIDATION: SONOGRAPHIC MARKERS OF HEMODYNAMIC PULMONARY EDEMA IN INFANTS

© A.A. Mohammad, I.I. Akinshin, E.V. Sinelnikova, A.Yu. Rotar, V.G. Chasnyk, I.V. Solodkova E.V. Baryshek

St. Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, Russia

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With the purpose of evaluating the possibility of describing hemodynamic pulmonary edema in infants with congenital heart disease using the previously suggested sonographic phenomena "alveolar consolidation" and "interstitial syndrome" in adults, 131 children of both genders were examined at the age of 1-246 days. Of these infants, 47 had congenital heart anomalies, 51 had chronic somatic pathology and patent foramen ovale, and 33 had a somatic pathology associated with either congenital heart disease or small heart abnormalities. The duration of observation and the number of sessions of ultrasound scanning were determined by the health status dynamics of the infants. All infants were described in terms of 179 characteristics of physical examination and laboratory and instrumental findings obtained through standard procedures. Echocardiography and ultrasound lung scans were performed with LOGIQ E (General Electric) and HD11 (Philips) using linear, convex, and sector transducers (7-12, 3-5, and 1.7-4.0 MHz respectively). In addition to standard protocols of heart and lung description, we also registered the square of consolidated parcels summarized for all lung segments, the number of B-lines summarized for all lung segments, and the swing of diaphragm and lung movement and calculated the diaphragm and lung swing ratio. An attempt to describe the differences between pulmonary circulation in terms of ultrasound sonography for heart defects associated and not associated with blood filling in the lungs was successful. The total area of air-free/consolidated subpleural parcels of lungs and the extent of interstitial lung syndrome were the most informative sonographic characteristics. It was concluded that interstitial edema and alveolar consolidation, described in terms of transthoracic ultrasound sonography, are recommended for use as markers of the disorders of pulmonary circulation associated with congenital heart malformations in infants.

**Keywords:** newborn; ultrasound sonography; interstitial lung disease; consolidation; hemodynamic pulmonary edema.

# ИНТЕРСТИЦИАЛЬНЫЙ СИНДРОМ И АЛЬВЕОЛЯРНАЯ КОНСОЛИДАЦИЯ КАК СОНОГРАФИЧЕСКИЕ МАРКЕРЫ ГЕМОДИНАМИЧЕСКОГО ОТЕКА ЛЕГКИХ У ДЕТЕЙ РАННЕГО ВОЗРАСТА

© А.А. Мохаммад, И.И. Акиншин, Е.В. Синельникова, А.Ю. Ротарь, В.Г. Часнык, И.В. Солодкова, Е.В. Барышек

ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России

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С целью оценки возможности использования предложенных ранее для взрослых пациентов ультразвуковых сонографических феноменов «альвеолярная консолидация» и «интерстициальный синдром» в выявлении гемодинамического отека легких при врожденных пороках сердца у детей раннего возраста был обследован 131 ребенок в возрасте 1–246 дней. Из них 47 детей имели врожденные пороки сердца, 51 ребенок — хроническую соматическую патологию в сочетании с открытым овальным окном, а 33 ребенка — соматическую патологию, не ассоциированную ни с врожденными пороками, ни с малыми аномалиями сердца. Длительность наблюдения и количество сеансов УЗ-сканирования определялись тяжестью и динамикой состояния ребенка. Формализованная карта включала в себя 179 признаков, зарегистрированных в ходе физикального, инструментального и лабораторного исследований, проведенных в соответствии с действующими клиническими рекомендациями. Ультразвуковое исследование сердца и легких проводили при помощи ультразвуковых сканеров LOGIQ E (General Electric) и HD11 (Philips) с использованием линейного, конвексного и секторного датчиков с частотами 7–12, 3–5 и 1,7–4,0 МГц соответственно. Дополнительно к стандартным характеристикам

описания сердца и легких регистрировали суммарную по всем сегментам площадь консолидированных участков легких, суммарное по всем сегментам легких количество В-линий, амплитуду движения диафрагмы, амплитуду движения легких, а также рассчитывали отношение амплитуд движения диафрагмы и легких. Попытка описания гемодинамики в малом круге кровообращения в терминах ультразвуковой сонографии легких для случаев дефектов, достоверно влияющих на наполнение малого круга кровообращения и достоверно не влияющих, оказалась успешной. Наиболее информативными характеристиками были ультразвуковая суммарная площадь безвоздушных субплевральных участков легочной ткани и выраженность интерстициального синдрома в легких. Сделан вывод о том, что ультразвуковые показатели интерстициального отека и альвеолярной консолидации целесообразно использовать в качестве маркеров гемодинамических нарушений в малом круге кровообращения при врожденных пороках сердца у детей раннего возраста.

**Ключевые слова:** новорожденные дети; ультразвуковая диагностика; интерстициальный синдром; консолидация; гемодинамический отек легких.

## BACKGROUND

The last decade was marked by progress in the field of diagnostics of lung diseases, particularly with the use of ultrasound imaging. The accumulation of experience in the use of transthoracic ultrasonography in the diagnostics of a sufficiently wide range of pathology attributed to the competence of internists, surgeons [10], and pediatricians [5, 19]. Moreover, special attention is paid to investigate the possibilities of employing sonography in intensive care units and newborn departments, that is, where diagnostics is required right at the patient's bed; however, until now, these studies remain at the level of pilot projects [18, 23, 24].

Transthoracic ultrasonography of the lungs is possible because of the presence of extracellular fluid in the lung tissue. Extracellular fluid first makes the alveolar walls thicker (first phase) and then fills the alveoli (second phase) because of inflammatory or hemodynamic edema. In the first phase, the disturbance of the normal air-liquid ratio is visualized as an artifact (reverberation) that represents as linear hyperechogenic signals that can be counted and called comets [3, 4, 6, 9, 14, 15, 17] or B-lines [13, 21]. The emergence of such lines is usually considered as evidence of the so-called interstitial syndrome [12, 16, 22, 23]. During the second phase, the alveoli are filled with liquid, the pulmonary consolidation areas are visualized and counted and are called "alveolar consolidation" [11, 23].

Ultrasonography was repeatedly utilized to determine the state of the lungs in cardiac pathology in adults [7, 8, 20] than in children. This is largely because of the complex features of heart failure formation in early childhood, which in most cases makes it impossible to classify confidently.

*The aim of the study* is to evaluate the possibilities of using two ultrasonographic phenomena, namely, "alveolar consolidation" and "interstitial syndrome," in detecting hemodynamic pulmonary edema in congenital heart diseases in young children.

## MATERIALS AND METHODS

The study was conducted in the neonatal resuscitation and neonatal departments of Pediatric Department No. 3 of St. Petersburg State Pediatric Medical University.

A formalized card included 179 signs recorded during the course of physical, instrumental, and laboratory studies performed in accordance with current clinical guidelines [1, 2].

Ultrasound examination of the heart and lungs was performed using GE LOGIQ E and Philips HD11 ultrasound scanners with linear, convex, and sector probes at 7-12, 3-5, and 1.7-4.0 MHz, respectively. During the examination, the patient lay in supine position, then in prone position, and, in some cases, in the edgewise position. Diagnostic programs were expanded as part of an in-depth description of lung conditions through ultrasonography. The following sonographic characteristics of the lungs were recorded [10, 19, 24]:

1) The area of the consolidated lung sites in $mm^2$ (AirLessTotal), total for all segments.
2) The number of B-lines in units (SDtot), total for all lung segments.
3) The amplitude of diaphragm excursion, mm (DiafMove)
4) The amplitude of lung movement, mm (LungMove)
5) The ratio of the amplitudes of the diaphragm excursion and lung movement in units, calculated value (DiafLung)

Overall, 131 pediatric patients of both genders (53% were boys) aged 1-246 days were examined. Because the present study considered the presence of any anatomical possibility of blood exchange between the small and large circulatory systems, the functioning open oval window (OOW) and open arterial duct (OAD) were considered a defect at any age. Table 1 presents the distribution of the pediatric patients examined into groups.

The duration of observation and the number of sessions of ultrasound scanning were determined by the severity and dynamics of the child's condition. Table 2 presents the most common characteristics of the examined patients.

In general, the proportion of the pediatric patients with severe condition at the start of the study was approximately 30%.

*Table 1*

Total number of pediatric patients examined and their distribution into the diagnosis groups

*Таблица 1*

Общее количество обследованных детей и их распределение по группам диагнозов

| Primary diagnosis | Number of pediatric patients | Age (days) | Number of studies |
|---|---|---|---|
| Total number of the patients examined | 131 | 1-246 | 240 |
| Number of pediatric patients with congenital heart disease | 47 | 2-246 | 74 |
| Number of pediatric patients with other pathologies, including:<br>• other pathology + open oval window | 84<br>51 | 1-130<br>5-97 | 91<br>76 |

*Table 2*

Brief general description of the patients examined

*Таблица 2*

Краткая общая характеристика обследованных

| Characteristic | Mean value (*M*) | Average error from *M* | Range of values |
|---|---|---|---|
| Gestational age at birth (weeks) | 33.4 | 0.3 | 24-42 |
| Body length at birth (cm) | 43.6 | 0.5 | 28-59 |
| Body weight at birth (g) | 2054 | 64 | 640-4650 |
| Apgar 1 (points) | 7 (median) | – | 1-9 |
| Apgar 5 (points) | 7 (median) | – | 1-9 |
| Body weight as of the day of examination | 2656 | 76 | 650-5790 |

*Table 3*

Distribution of pediatric patients with cardiac pathology according to the main diagnoses

*Таблица 3*

Распределение детей с патологией сердца по основным диагнозам

| Defect | Age (days) at the time of examination | Number of pediatric patients | Number of studies | Dimensions (mm) | |
|---|---|---|---|---|---|
| | | | | Max | Min |
| Only OOW | 1-166 | 57 | 79 | 3.7 | 1.0 |
| OOW in the complex | 5-246 | 30 | 49 | 4.2 | 1.0 |
| Only OAD | 8-39 | 5 | 8 | 3.0 | 1.0 |
| OAD in the complex, including: | 2-104 | 20 | 36 | 4.5 | 1.0 |
| • Closed during the follow-up | 25-97 | 2 | 7 | 2.0 => 0.0 | |
| Only IASD | 9-73 | 7 | 8 | 8.0 | 2.0 |
| IASD in the complex | 9-159 | 9 | 14 | 8.0 | 3.0 |
| Only IVSD | 20-124 | 8 | 9 | 10.0 | 2.0 |
| IVSD in the complex | 2-246 | 25 | 38 | 10.0 | 1.0 |
| Pulmonary artery stenosis in the complex | 10-86 | 3 | 7 | – | – |
| Anomalous pulmonary veins drainage in the complex | 2-125 | 2 | 3 | – | – |

*Примечание:* ООО — открытое овальное окно; ОАП — открытый артериальный проток; ДМПП — дефект межпредсердной перегородки; ДМЖП — дефект межжелудочковой перегородки.
*Note:* OOW, open oval window; OAD, open arterial duct; IASD, interatrial septal defect; IVSD, interventricular septal defect

Table 3 shows the distribution of pediatric patients with cardiac pathologies according to the main diagnoses. The exclusion criteria for pediatric patients in this group are as follows: the presence of pneumonia, meconium aspiration, bronchopulmonary dysplasia, and respiratory distress syndrome.

In most pediatric patients, the functioning OOW, which in some cases reaches a diameter of 4.2 mm, was determined steadily with discharge of blood from left to right. However, when blood dynamics was observed, only two cases had cessation of blood flow through it.

*Table 4*

Variants of the combinations of various defects

*Таблица 4*

Варианты комбинаций пороков и открытого овального окна

| Defect | Age (days) | Number of pediatric patients | Number of studies | Dimensions (mm) | |
|---|---|---|---|---|---|
| | | | | Max | Min |
| OOW<br>+ OAD | 5-104 | 13 | 26 | 4.2<br>4.0 | 1.0<br>1.0 |
| OOW<br>+ IVSD | 2-246 | 11 | 15 | 4.0<br>10.0 | 1.0<br>1.0 |
| IASD<br>+ IVSD | 9-159 | 6 | 10 | 8.0<br>10.0 | 3.5<br>3.0 |
| OOW<br>+ IVSD<br>+ OAD | 17-61 | 3 | 7 | 4.0<br>8.0<br>4.5 | 1.0<br>3.0<br>1.5 |
| IASD<br>+ OAD | 77-97 | 1 | 2 | 8<br>2 => 0.0 | |
| IVSD<br>+ OAD | 46-73 | 1 | 3 | 3.2<br>3.0 | |
| OOW<br>+ IVSD<br>+ OAD<br>+ anomalous pulmonary vein drainage | 2 | 1 | 1 | 2.5<br>2.5<br>3.0 | |
| IASD<br>+ IVSD<br>+ anomalous pulmonary vein drainage | 118-125 | 1 | 2 | 3<br>7 => 4 | |
| OOW<br>+ OAD<br>+ PAS | 10-67 | 1 | 4 | 1.0<br>2.0<br>– | |
| IASD<br>+ IVSD<br>+ PAS | 45 | 1 | 1 | 5.0<br>3.0<br>– | |
| OOW<br>+ IVSD<br>+ PAS | 58-86 | 1 | 2 | 3.0<br>8.0<br>– | |

*Примечание:* ООО — открытое овальное окно; ОАП — открытый артериальный проток; ДМПП — дефект межпредсердной перегородки; ДМЖП — дефект межжелудочковой перегородки; СЛА — стеноз легочной артерии.
*Note:* OOW, open oval window; OAD, open arterial duct; IASD, interatrial septal defect; IVSD, interventricular septal defect; PAS, pulmonary artery stenosis

*Table 5*

Distribution of pediatric patients without heart and lung diseases by diagnoses

*Таблица 5*

Распределение детей без поражения сердца и легких по диагнозам

| Diagnosis | Number of the patients examined | Age (days) at the time of examination | Number of studies |
|---|---|---|---|
| Intra-amniotic infection of the fetus | 31 | 2-97 | 40 |
| Hypoxic injury of the CNS | 32 | 1-130 | 51 |
| Diseases of the GIT, moderate hypotrophy | 21 | 1-166 | 23 |

*Примечание:* ЦНС — центральная нервная система; ЖКТ — желудочно-кишечный тракт
*Note:* CNS, central nervous system; GIT, gastrointestinal tract

The presented data reveals that of all the examined pediatric patients, only three had a pulmonary circuit disorder.

OAD was recorded in 53% of the pediatric patients in the cardiological group in a period of 2-104 days, and its closure was recorded in only two patients in the late period. This was because OAD was part of a combination of defects and not a single defect in most cases (see Table 4).

Table 5 presents the distribution of pediatric patients without heart and lung disorders. The inclusion criterion of the patients in the comparison group was the

*Table 6*

Significance of the characteristics describing interstitial syndrome and alveolar consolidation and pulmonary heart in pediatric patients with an OOW and incomplete drainage of pulmonary veins through ultrasonography

*Таблица 6*

Значение характеристик, описывающих интерстициальный синдром и альвеолярную консолидацию, а также характеристик правых отделов сердца в терминах ультразвуковой сонографии у детей с открытым овальным окном и неполным дренажом легочных вен

| Defect type | Characteristic | Mean value | | *T* | *p* |
|---|---|---|---|---|---|
| | | 0* | 1* | | |
| OOW without other defects | AirlessTotal | 96.88000 | 64.97468 | 1.15164 | 0.250829 |
| | SDtot | 10.70400 | 9.94937 | 0.77272 | 0.440593 |
| | LA | 10.53660 | 10.57568 | –0.10054 | 0.920032 |
| | RV | 9.71099 | 10.10000 | –0.64921 | 0.517238 |
| | PA | 7.90408 | 8.55541 | –1.02932 | 0.304793 |
| | $PAV_{max}$ | 1.30029 | 1.13615 | 1.06965 | 0.286201 |
| | PAP | 25.77027 | 23.11087 | 1.18104 | 0.239960 |
| Incomplete drainage of pulmonary veins combined with other defects | **AirlessTotal** | **78.44000** | **299.0000** | **–2.02040** | **0.044669** |
| | SDtot | 10.40000 | 13.0000 | –0.65700 | 0.511934 |
| | LA | 10.53472 | 12.1500 | –0.88738 | 0.376072 |
| | RV | 9.84056 | 10.6667 | –0.40327 | 0.687348 |
| | PA | 8.18343 | 8.2333 | –0.02079 | 0.983440 |
| | $PAV_{max}$ | 1.22556 | 1.5167 | –0.48593 | 0.627602 |
| | PAP | 24.90254 | 15.8000 | 1.06322 | 0.289851 |

*Примечание:* 0* — нет дефекта, 1* — есть дефект, выделено существенное различие; LA — диаметр левого предсердия (мм); RV — диаметр правого желудочка (мм); PA — диаметр легочной артерии (мм); $PAV_{max}$ — максимальная скорость кровотока в легочной артерии (м/с); PAP — среднее давление в легочной артерии (мм Hg).

*Note:* 0*, no defect; 1*, presence of a defect, an essential difference is allocated; LA, diameter of the left atrium (mm); RV, diameter of the right ventricle (mm); PA, diameter of the pulmonary artery (mm); PAV, blood peak flow in the pulmonary artery (m/s); PAP, average pressure in the pulmonary artery (mm Hg); OOW, open oval window

absence of history of pathology of the heart and lungs according to clinical, instrumental, and laboratory signs and absence of such pathology at the time of the study.

Due to the multifactor data of the phenomena under study, multiple regression analysis and routine parametric estimation methods (Student–Fischer *t*-test) were used to analyze obtained results. The data was statistically analyzed by the standard tools of Statistica for Windows ver. 6 (StatSoft Inc., No. AX204B521115F60).

## RESULTS

An attempt to describe the hemodynamics of the pulmonary circuit with defects are priori known to affect (incomplete drainage of the pulmonary veins) and do not affect (OOW) the filling of the pulmonary circuit through ultrasonography appeared to be successful (see Table 6). Furthermore, no differences were observed between groups of pediatric patients with and without a functioning oval window on the basis of the registered characteristics, despite the fact that the size of the window in a significant proportion of the children was quite large (see Table 3). In incomplete drainage of the pulmonary veins, there was a significant 3.8 times increase in the area of alveolar consolidation (AirLessTotal) ($p = 0.045$), with no differences in the size of the left atrium, right ventricle, pulmonary artery diameter, blood peak flow, and mean pulmonary artery pressure due to the presence of compensating defects.

Considering that the sample had a large number of complex defects, multiple linear regression modeling (stepwise inclusion) was performed, with a preliminary choice of factors at the level of interconnection not exceeding 0.4. A total of 19 models were created with explained dispersion level of 35%-82% with the included characteristics, namely, AirLessTotal, SDtot, LungMove, and DiafMove, treated in combination and individually. Tables 7 and 8 show the results of the modeling using SDtot and RV characteristics, control, physical, and laboratory characteristics, as well as characteristics of the heart and right lung segment in terms of ultrasonography. The regression of coefficients equation presented in Table 7, which shows an insignificant correlation of the characteristics (Durbin–Watson correlation coefficient of 0.26), provide 78% of the explained

*Table 7*

Results of the regression modeling of the SDtot characteristic value. Regression summary for dependent variable: SDtot (ivan_data_w9), R = 0.93244324, $R$ = .93244324 $R^2$ = .86945039 Adjusted $R^2$ = .76263707 F(9,11) = 8.1399 $p$ < .00099 Std. Error of estimate: 2.4241 Durbin-Watson $d$ = 1.472474, Serial Corr. 0.263094

*Таблица 7*

Результаты регрессионного моделирования значения характеристики SDtot. Regression Summary for Dependent Variable: SDtot (ivan_data_w9), $R$ = .93244324 $R^2$ = .86945039 Adjusted $R^2$ = .76263707 F(9,11) = 8.1399 $p$ < .00099 Std. Error of estimate: 2.4241 Durbin-Watson $d$ = 1.472474, Serial Corr. 0.263094

| Characteristics studied | BETA | Std. Err. of BETA | B | Std. Err. of BETA | $p$-level |
|---|---|---|---|---|---|
| Intercept | | | **100.0492** | **19.64767** | **0.000348** |
| *m* | **–0.856598** | **0.259351** | **–0.0041** | **0.00125** | **0.007042** |
| CardRate | **–0.992885** | **0.167861** | **–0.6257** | **0.10579** | **0.000101** |
| AirLessTotal | **0.316251** | **0.130543** | **0.0523** | **0.02160** | **0.033851** |
| $PAV_{max}$ | –0.237113 | 0.130261 | –7.3759 | 4.05203 | 0.096003 |
| $pO_2$ | –0.107595 | 0.141044 | –0.0469 | 0.06149 | 0.461603 |
| PA | **–0.659042** | **0.233702** | **–2.9361** | **1.04117** | **0.016667** |
| RespRate | **0.405810** | **0.161775** | **0.6498** | **0.25902** | **0.029065** |
| DiafLung | 0.280194 | 0.133050 | 2.0494 | 0.97313 | 0.058991 |
| mass | 0.425926 | 0.321814 | 0.0022 | 0.00163 | 0.212513 |

*Примечание: m* — масса тела при рождении (г); CardRate — частота сердечных сокращений в момент исследования (1/мин); $pO_2$ — напряжение кислорода в плазме крови в момент исследования (мм Hg); RespRate — частота дыханий в момент исследования (1/мин); mass — масса тела в момент исследования (г); прочие обозначения — см. пояснения к табл. 6 и в тексте, выделены существенные значения.
*Note:* m, birth weight (g); CardRate, the heart rate at the time of the study (1/min); PO, oxygen tension in blood plasma at the time of the study (mm Hg); RespRate, respiration rate at the time of the study (1/min); mass, body mass at the time of the study (d); other designations, see the explanations to Table 6 and in the text; the significant values are highlighted

*Table 8*

Results of the regression modeling of the RV characteristic value. Regression summary for dependent variable: RV (ivan_data_w9) $R$ = .69223739 $R^2$ = .47919260 Adjusted $R^2$ = .41932968 F(10,87) = 8.0048 $p$ < .00000 Std. Error of estimate: 2.1761 Durbin-Watson $d$ = 1.263156, Serial Corr. 0.3680869

*Таблица 8*

Результаты регрессионного моделирования значения характеристики RV. Regression Summary for Dependent Variable: RV (ivan_data_w9) $R$ = .69223739 $R^2$ = .47919260 Adjusted $R^2$ = .41932968 F(10,87) = 8.0048 $p$ < .00000 Std. Error of estimate: 2.1761 Durbin-Watson $d$ = 1.263156, Serial Corr. 0.3680869

| Исследуемые характеристики | BETA | Std. Err. of BETA | B | Std. Err. of BETA | $p$-level |
|---|---|---|---|---|---|
| Intercept | | | 1.230303 | 1.595912 | 0.442850 |
| **M** | **0.238464** | **0.099291** | **0.000708** | **0.000295** | **0.018449** |
| **PAP** | **0.312879** | **0.085093** | **0.093431** | **0.025410** | **0.000408** |
| **LA** | **0.272323** | **0.094498** | **0.300839** | **0.104394** | **0.004980** |
| **SDtot** | **0.316294** | **0.105903** | **0.146247** | **0.048967** | **0.003664** |
| **OAD** | **–0.200700** | **0.084468** | **–0.618692** | **0.260388** | **0.019695** |
| **OOO** | **0.245074** | **0.086941** | **0.572891** | **0.203234** | **0.005966** |
| **DMPP** | **0.189365** | **0.089900** | **0.430067** | **0.204173** | **0.038051** |
| **PA** | **–0.158417** | **0.080136** | **–0.087918** | **0.044474** | **0.050225** |
| **AirLessTotal** | **–0.202964** | **0.099895** | **–0.003599** | **0.001771** | **0.045227** |
| Days | 0.167797 | 0.092230 | 0.013347 | 0.007337 | 0.072302 |

*Примечание:* OAD — диаметр функционирующего артериального протока (мм); OOO — диаметр функционирующего овального окна в комплексе дефектов (мм); DMPP — диаметр дефекта межпредсердной перегородки (мм); Days — день жизни на момент обследования; прочие обозначения — см. пояснения к табл. 6, 7 и в тексте, выделены существенные значения.
*Note:* OAD, diameter of the functioning arterial duct (mm); OOO, diameter of the functioning oval window in the complex of defects (mm); DMPP, diameter of interatrial septal defect (mm); Days, the day of life at the time of the examination; other designations, see the explanations in Tables 6 and 7 and in the text; the significant values are highlighted

dispersion of the SDtot characteristic value, thereby reflecting the severity of the interstitial syndrome.

The negative coefficients with statistically significant characteristics for m, CardRate, and PA, which indicate that the SDtot value is greater in pediatric patients born with a low body weight and who have bradycardia with a small pulmonary artery diameter at the time of examination, is of particular interest. Together with the positive coefficients for the AirLessTotal and RespRate characteristics, the model correctly describes the known fundamental regularities, and the coefficient values indicate that pulmonary artery diameter greatly contributed to the formation of the interstitial syndrome compared to the birth weight.

Table 8 presents the coefficients of the characteristics of the regression equation that determines the size of the right ventricle. In accordance with classical notions of physiology, it was assumed that the interstitial syndrome and alveolar consolidation, with their sufficient severity and duration, affect the size of the right ventricle on a par with, for example, the effect of the size of the septal defects. The coefficients of the regression equation presented in Table 8, with a moderate interrelation of characteristics (Durbin–Watson correlation coefficient of 0.37) indicated 42% of the explained dispersion of the RV characteristic value.

Apparently, ultrasonographic characteristics reflecting the interstitial syndrome and alveolar consolidation reliably determine the size of the right ventricle.

The negative coefficient for the OAD characteristic is explained by the fact that a significant number of OAD, such as 7 of 12 without taking into account the complex with an OOW (see Table 4), were involved in complex defects for which a decrease in the discharge along the duct leads to an increase in blood flow in another defect. This also explains the effect of the diameter of the oval window. The negative coefficient in the PA characteristic is natural, and the negative coefficient in the AirLessTotal characteristic has no explanation and requires additional study using detailed measurement of the pressures within the cardiac chambers.

## DISCUSSION

Our results confirm the expediency of using the descriptions of interstitial syndrome and alveolar consolidation in terms of ultrasonography to assess the severity of hemodynamic pulmonary edema in young children.

The frequency of inclusion of SDtot and AirLessTotal characteristics in regression models that describe the state of children's lungs with congenital heart diseases through indirect signs is extremely high.

SDtot (more often) and AirLessTotal (less often) characteristics were included in almost all models, and the results of the modeling almost always corresponded to the classical notions of clinical physiology in describing the hemodynamics of the pulmonary circuit. The rare inclusion of DiafMove, LungMove, and DiafLung characteristics in the models was somewhat surprising, which can be partly explained by the low extensibility of the lungs at this age and the fact that the diaphragm is of less importance in organizing external respiration in infants.

The rarer inclusion of the AirLessTotal characteristic can be explained by technical difficulties in calculating the consolidation area, which resulted in a larger error, as well as by the small number of pediatric patients with consolidation, because the number of pediatric patients with the first phase of edema at such an early age significantly exceeds the number of pediatric patients with a second phase of edema.

The disadvantage of the model, which equation is presented in Table 7, is that it includes all control characteristics, with the exception of body weight and, in a less degree, the diameter of the pulmonary artery, and the period of variability in time is minutes/hours. At the same time, the period of change in the pronouncement of the controlled variable, which is the interstitial syndrome, is much longer (in days). This implies a high proportion of randomness in obtaining the values of the coefficients in such a combination. The model, which characteristics and coefficients of the equation are presented in Table 8, partly eliminates this disadvantage because the variability period of controlled and controlling variables are approximated to comparable quantities.

## CONCLUSIONS

1. Interstitial edema and alveolar consolidation, described in terms of transthoracic ultrasonography, should be used as markers of hemodynamic disorders of the pulmonary circuit in congenital malformations in children at an early age.
2. The characteristics of interstitial edema and alveolar consolidation are reliably associated with clinical, laboratory, and instrumental signs of the pulmonary circuit.

Therefore, additional studies are required to develop the decisive rules for differential diagnostics of various types and stages of hemodynamic disorders of the pulmonary circuit and to determine diagnostic errors when using transthoracic ultrasonography as well as the measurement of pressures within the heart cavities and large vessels.

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◆ Information about the authors

*Ahlam A. Mohammad* — Postgraduate Student, Department of Hospital Pediatrics. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, Saint Petersburg, Russia. E-mail: d.ahlam@mail.ru.

◆ Информация об авторах

*Ахлам Ахмад Мохаммад* — аспирант, кафедра госпитальной педиатрии. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: d.ahlam@mail.ru.

◆ Information about the authors

*Ivan I. Akinshin* — Postgraduate Student, Department of Radiology and Biomedical Imaging Faculty of Postgraduate Education. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, St Petersburg, Russia. E-mail: akinshinivan87@gmail.com.

*Elena V. Sinelnikova* — MD, PhD, Dr Med Sci, Professor, Head, Department of Radiology and Biomedical Imaging Faculty of Postgraduate Education. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, Saint Petersburg, Russia. E-mail: sinelnikavae@gmail.com.

*Alla Jur'evna Rotar* — Student, Department of Radiology and Biomedical Imaging Faculty of Postgraduate Education. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, St Petersburg, Russia. E-mail: a_lepenchuk@mail.ru.

*Vyacheslav G. Chasnyk* — MD, PhD, Dr Med Sci, Professor, Head, Department of Hospital Pediatrics. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, Saint Petersburg, Russia. E-mail: chasnyk@gmail.com.

*Irina V. Solodkova* — MD, Associate professor, Chair of Hospital Pediatrics. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, Saint Petersburg, Russia. E-mail: isolodkova@mail.ru.

*Elena V. Baryshek* — MD, Professor, Chair of Hospital Pediatrics. St Petersburg State Pediatric Medical University, Ministry of Healthcare of the Russian Federation, Saint Petersburg, Russia. E-mail: barishek@yandex.ru.

◆ Информация об авторах

*Иван Иванович Акиншин* — аспирант, кафедра лучевой диагностики и биомедицинской визуализации ФП и ДПО. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: akinshinivan87@gmail.com.

*Елена Владимировна Синельникова* — д-р мед. наук, профессор, заведующая кафедрой лучевой диагностики и биомедицинской визуализации ФП и ДПО. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: sinelnikavae@gmail.com.

*Алла Юрьевна Ротарь* — ординатор, кафедра лучевой диагностики и биомедицинской визуализации ФП и ДПО. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: a_lepenchuk@mail.ru.

*Вячеслав Григорьевич Часнык* — д-р мед. наук, профессор, заведующий, кафедра госпитальной педиатрии. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: chasnyk@gmail.com.

*Ирина Владимировна Солодкова* — канд. мед. наук, доцент кафедры госпитальной педиатрии. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: isolodkova@mail.ru.

*Елена Валентиновна Барышек* — канд. мед. наук, профессор кафедры госпитальной педиатрии. ФГБОУ ВО «Санкт-Петербургский государственный педиатрический медицинский университет» Минздрава России, Санкт-Петербург. E-mail: barishek@yandex.ru.