

The multispiral computed tomography in the early diagnosis of pneumonia caused by SARS-CoV-2

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Abstract

The high informative value of chest computed tomography in the diagnosis of pneumonia caused by SARS-CoV-2 is generally recognized, but there is no enough data on the diagnostic capabilities of this method within 5 first days of the clinical manifestations of the disease. The paper presents the results of chest multispiral (multislice) computed tomography (MSCT) of 56 patients with COVID-19 pneumonia in the early days of the disease. **The aim** of the study was to analyze the semiotics of pathological changes in the lungs in the first days of the onset of clinical symptoms of COVID-19 and to clarify the methodology for conducting MSCT. **Methods.** The data of chest MSCT of 56 patients with clinical symptoms of a new coronavirus infection SARS-CoV-2 were analyzed. MSCT was carried out in the first 4 – 5 days of the disease. **Results.** Five variants for the development of the disease were revealed, including atypical, characterized by the prevalence and CT semiotics of lung damage and apparently due to the different response of the patients to SARS-CoV-2 infection. The leading signs of COVID-19 pneumonia in the early stages of the disease were foci of ground glass opacification (GGO), multifocal lesions of the lungs, edema of the interalveolar pulmonary interstitium, which distinguishes it from pneumonia of another etiology. **Conclusion.** Comparison of MSCT data and the clinical picture of the disease during the first 5 days suggests with high confidence the pneumonia associated with COVID-19. A prerequisite for conducting MSCT in case of suspicion of this type of pneumonia is the implementation of thin 0.5 – 1.5 mm sections, MSCT performance at suspended full inspiration, post-processing of unenhanced tomogram data in MinIP mode.

Key words: multispiral computed tomography, semiotics, pneumonia, SARS-CoV-2, COVID-19 pneumonia.

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Мультиспиральная компьютерная томография в ранней диагностике пневмонии, вызванной SARS-CoV-2

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Резюме

Высокая информативность компьютерной томографии (КТ) органов грудной клетки (ОГК) в диагностике COVID-19-ассоциированной пневмонии общепризнанна, однако данные о диагностических возможностях и особенностях выполнения этого метода в первые 5 суток клинических проявлений заболевания отсутствуют. В работе представлены результаты мультиспиральной КТ (МСКТ) ОГК пациентов ($n = 56$) с COVID-19-ассоциированной пневмонией в первые 4–5 суток развития симптомов болезни. **Целью** исследования явилось изучение семиотики патологических изменений в легких в первые дни появления клинических симптомов COVID-19 и описание особенностей методики проведения МСКТ. **Материалы и методы.** Проанализированы данные МСКТ ОГК пациентов с клинической симптоматикой новой коронавирусной инфекции SARS-CoV-2. МСКТ выполнялась в первые 4–5 суток заболевания. **Результаты.** Выявлено 5 вариантов развития заболевания, включая атипичный, различавшихся распространенностью и КТ-семиотикой поражения легких и обусловленных, по-видимому, различной реакцией организма пациентов на инфекцию SARS-CoV-2. Ведущими признаками COVID-19-ассоциированной пневмонии в ранние сроки заболевания являлись очаги «матового стекла», мультифокальность поражения легких, отек межалвеолярного легочного интерстиция, в чем и состояли отличия COVID-19-ассоциированной пневмонии от таковой другой этиологии. **Заключение.** Сопоставление данных МСКТ и клинической картины заболевания в течение первых 5 суток заболевания позволяет с высокой достоверностью предположить наличие пневмонии, ассоциированной с COVID-19. Необходимым условием проведения МСКТ при подозрении на пневмонию данного типа является выполнение тонких (0,5–1,5 мм) срезов, контроль за полной вдохом пациента, постпроцессинговая обработка данных нативной томограммы в MinIP-режиме.

Ключевые слова: мультиспиральная компьютерная томография, семиотика, пневмония, SARS-CoV-2, COVID-19-ассоциированная пневмония.

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On January 26, 2020, the National Health Commission of the People's Republic of China registered a total of 2,744 confirmed cases of pneumonia caused by the novel SARS-CoV-2 (2019-nCoV) coronavirus infection from 30 provinces (districts and cities), including 461 severe cases and 80 deaths. Despite the unprecedented measures to limit the spread of infection that were taken by the Chinese and International sanitary authorities, the World Health Organization has announced the COVID-19 pandemic on March 11, 2020. As of July 7, 2020, over 11.4 million cases in over 188 countries and territories were registered, resulting in more than 535,000 deaths; over 5.14 million people recovered [1–5]. Studies have demonstrated the high diagnostic efficiency of multispiral computed tomography (MSCT) of the chest in pneumonia caused by SARS-CoV-2 [6–9]. Although this conclusion was questioned in some publications [10]. However, most publications are devoted to the MSCT semiotics of lung tissue damage, assessment of the extent of the process, and its development. The diagnostic significance of MSCT at the early stage of COVID-19, recognition and correct interpretation of lung damage within the first 3 days from the onset of the symptoms have been studied insufficiently.

The aim of the study was to analyze the MSCT semiotics of pathological changes in the lungs in the first days of COVID-19 clinical symptoms and to clarify the methodology of MSCT in patients with suspected SARS-CoV-2 pneumonia.

Materials and methods

The single-center, non-randomized prospective study included patients ($n = 56$) with clinical symptoms of the novel coronavirus infection SARS-CoV-2, who had chest

MSCT for diagnostic purposes during the first 4 – 5 days of the disease. 29 (51.8%) patients complained of nasal congestion, sore throat, increased fatigue, low-grade fever. 27 (48.2%) patients experienced an increase in body temperature up to 38 – 39 degrees during the first two days. Subsequently, the diagnosis of COVID-19 was confirmed by laboratory tests in all examined patients.

MSCT was performed on days 1 to 5 after the onset of clinical symptoms. The scan was performed twice with an interval of 2 – 3 days in 18 (32.1%) patients. The MSCT data were evaluated for typical signs of viral pneumonia (Cov19Typ), according to the classification in the Expert Consensus Statement of Radiological Society of North America [11]. The MSCT findings of lung damage were compared with the severity of clinical symptoms (fever, dry cough, nasal congestion, weakness, and others). 2 (3.6%) patients had no clinical signs or symptoms at the time of MSCT but still showed CT findings of COVID-19 pneumonia and had SARS-CoV-2 confirmed by PCR.

Data analysis

The study results demonstrated there are several rules to be followed during MSCT in the case of suspected COVID-19, such as ensuring that the scan is performed at the complete inhalation. This approach will help avoid false positives in the form of pseudo ground areas (gravity-dependent atelectasis) associated with an incomplete inhalation or exhalation of the patient. The scanning should use thin sections of no more than 1.5 mm. Post-processing in the mode of minimum image intensity (MinIP) followed the previously described method [12]. The main goal of the post-processing is to improve the visual assessment of the native CT data. The MinIP



Figure 1. Multispiral computed tomography of the chest (1 mm slices) on the 2nd day of clinical onset of COVID-19 pneumonia: A, Axial slice. A ground glass opacity in the left lingular segment; B, Sagittal reconstruction in MinIP mode provides clearer visualization of the findings

Рис. 1. Мультиспиральная компьютерная томография органов грудной клетки (срез 1 мм) на 2-й день клинических проявлений COVID-19-ассоциированной пневмонии: А — аксиальный срез — очаг «матового стекла» в язычковом сегменте левого легкого; В — сагиттальная реконструкция в MinIP-режиме — более четкая визуализация изменений

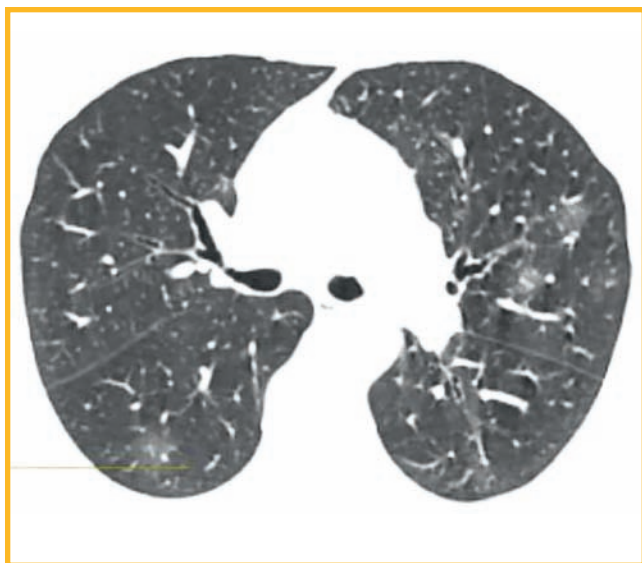


Figure 2. Multispiral computed tomography of the chest (1 mm slices) on the 3rd day of clinical onset of COVID-19 pneumonia; Axial slice – polisegment two-side micro ground glass opacities

Рис. 2. Мультиспиральная компьютерная томография органов грудной клетки (срез 1 мм) на 3-й день клинических проявлений COVID-19-ассоциированной пневмонии, аксиальный срез: полисегментарная двусторонняя локализация мелкоочаговых изменений по типу «матового стекла»

program isolates the elements of the air-filled structures of the lung. This improves the detectability of the ground glass opacities and allows to assess the state of the bronchi. It is an expert method for proving the presence or absence of ground glass findings, especially with low intensity, in borderline cases. Comparative analysis of the native MSCT data and the data obtained with a contrast enhancement demonstrated that contrast enhancement does not improve visualization of COVID-19 pneumonia. A contrast agent is optional unless the patient has other indications for it.

The data analysis identified various early CT signs of viral pneumonia caused by SARS-CoV-2.

Pneumonia with focal lesions and a limited extent of damage was detected in the first days of the disease in 17 (30.4%) patients. MSCT showed one or more small ground-glass opacities (up to 30 mm) in I – III segments of one or, less often, both lungs. The lesions had unclear outer edges and were localized mainly at the periphery (Figure 1, 2). Some ground-glass opacities included clearly distinguishable areas of high density (Figure 3). 7 out of 17 (41.2%) patients had increased pulmonary vascularity with a reticular consolidation of the interstitium at the periphery of the lesions. 2 out of 17 (11.8%) patients with single ground-glass opacities had no clinical signs of COVID-19 at the time of CT scan (the scan was conducted at the request of the patient due to the illness of a family member). 3 out of 17 (17.6%) patients had MSCT performed on the 3rd day of clinical symptoms of COVID-19, and the scan did not reveal the typical findings in the lungs. However, MSCT was repeated on the 5th day (2 days after the initial examination) in one patient after a rapid deterioration. The scan revealed signs of COVID-19 pneumonia in the lung tissue. One of these cases is described below:

Clinical case

Patient G., 53 years old, reported pain, sore throat, dry cough, and subfebrile temperature up to 37.4 °C on April 04, 2020. Chest MSCT was performed on April 06, 2020. The scan showed no significant pathological findings in the lungs and mediastinum. On April 07, 2020, the patient's condition worsened. The body temperature rose to 39.5 °C in the evening, and the patient reported weakness, headache, myalgia, and intensified cough. The chest MSCT was repeated on April 08, 2020. Both pulmonary fields showed multifocal ground-glass opacities, mostly round, in all segments as compared to the scan on April 06 (Figure 4). No fluid in the pleural cavity and intrathoracic lymphadenopathy were confirmed. Conclusion: The patient's status worsened as compared to the scan on April 06, 2020. MSCT signs of COVID-19 viral pneumonia.

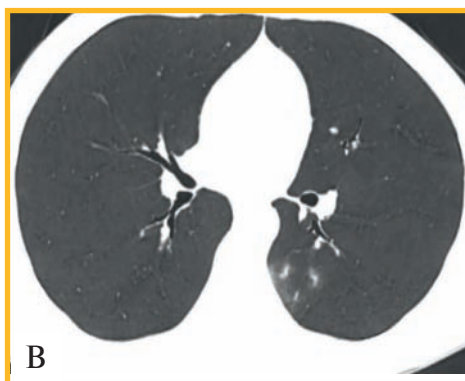
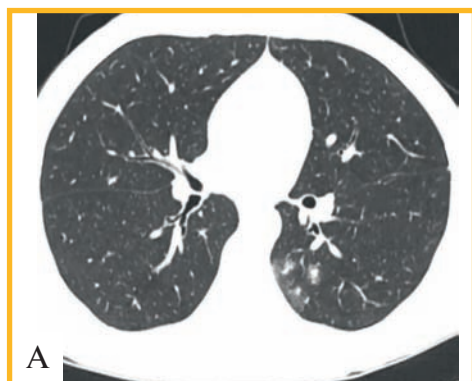


Figure 3. Multispiral computed tomography of the chest (1 mm slices) on the 2nd day of clinical onset of COVID-19 pneumonia: A, Axial slice. The pathological ground glass opacities with high density focal findings cover the whole left IV segment; B, C, Axial projection and sagittal reconstruction of the findings in MinIP mode

Рис. 3. Мультиспиральная компьютерная томография органов грудной клетки (срез 1 мм) на 2-й день клинических проявлений COVID-19-ассоциированной пневмонии: А – аксиальный срез – патологические изменения «матового стекла» полностью охватывают IV сегмент левого легкого, на фоне которого выделяются очажки высокой плотности; В, С – аксиальная проекция и сагиттальная реконструкция зоны изменений в MinIP-режиме

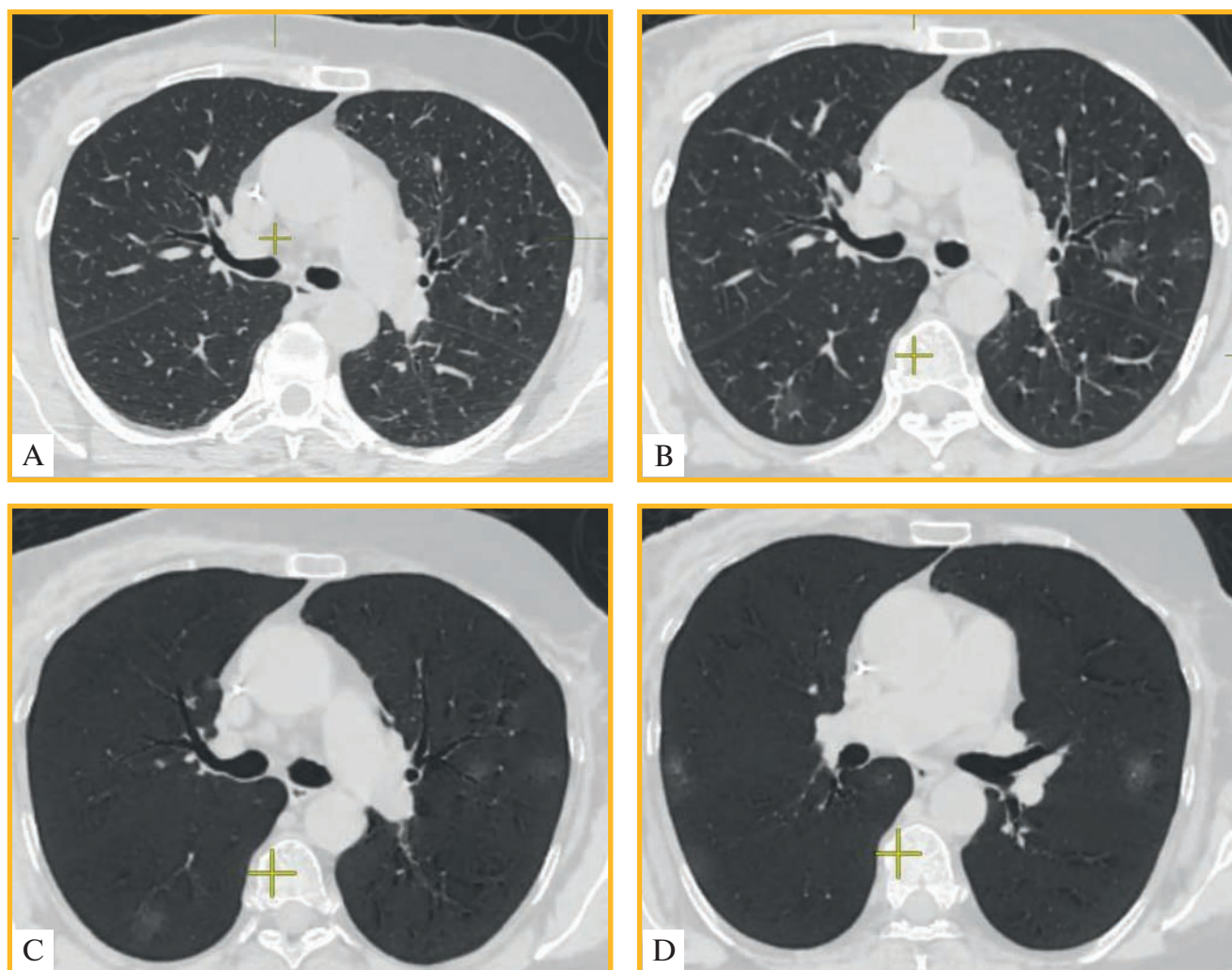


Figure 4. Chest multispiral computed tomography, 1 mm axial slices: A, Day 2 of COVID-19 clinical symptoms, no findings that suggest pneumonia; B, The same patient on day 4 of COVID-19 clinical symptoms. The ground glass opacities appeared in both lungs; C, D, A clearer visualization of the findings in MinIP mode. COVID-19 pneumonia

Рис. 4. Мультиспиральная компьютерная томография органов грудной клетки, аксиальные срезы 1 мм: А – 2-й день клинических проявлений COVID-19, данных за наличие пневмонии не получено; В – та же пациентка, 4-й день клинических проявлений COVID-19 – появление в левом и правом легких очагов «матового стекла»; С, D – более четкая визуализация изменений в MinIP-режиме – COVID-19-ассоциированная пневмония

Multifocal bilateral ground glass opacities up to 30 – 45 mm in size in 3 to 5 lung segments were found in 15 (26.8%) patients. These lesions had unclear, blurred outer edges with a pericissuritis type reaction of pleura and thickening of the interstitium along the periphery of the foci. This group of patients differed from the previous one both by the variable macrostructure of the lesions and by the chaotic distribution of areas of the affected lung tissue. In total, the findings were observed in all parts of the lungs, both subpleurally, in the middle and hilar zones of the lungs, and in the mediastinal pleura. 2 out of 15 (13.3%) patients showed extensive bilateral findings with polysegmental ground-glass opacities. Areas of swollen alveolar tissue were visualized against the opacities (Figure 5).

Polysegmental bilateral lung lesions with a predominant peribronchial localization were observed in 13 (23.2%) patients. Several segments (possibly in different lobes) of the lungs were involved in the process. The entire segment or part of it was affected. High-density infiltration

was observed against the ground glass opacities in the central zone. Other findings included air bronchogram sign, crazy paving sign, honeycombing of the interalveolar and pulmonary interstitium, mediastinal lymphadenopathy, limited pleural effusion in some cases, and dilatation of the pulmonary veins of the affected area. In contrast to the previous group, these patients showed predominantly peribronchial localization of the pathological findings, dilatation, and thickening of the bronchial walls, the air bronchogram sign, and mediastinal lymphadenopathy. Some patients showed local pleural effusion, areas of cobblestone-like increased pulmonary interstitial pattern, rough, cord-like consolidation of the interstitium and interlobar pleura. The dense infiltrate was larger in the central part of the focal ground-glass opacities. Individual groups of alveoli were “swelled”. Probably, the respiratory bronchioles were damaged, and inflammation led to the ball-valve ventilation of individual groups of alveoli.

7 (12.5%) patients had **infiltrative lobar lesions** along with focal changes. The pneumonia was localized in

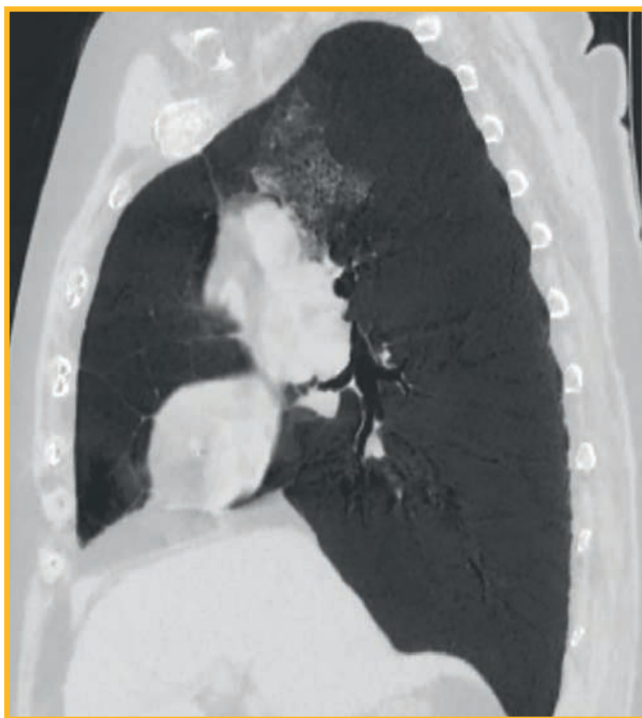


Figure 5. Multispiral computed tomography of the chest (1 mm slices) on the 1st day of clinical symptoms of COVID-19 pneumonia. The sagittal reconstruction in MinIP mode showed extensive lesions in the left upper lobe and the low intensity ground glass opacities in the upper and lower lobes of the right lung

Рис. 5. Мультиспиральная компьютерная томография органов грудной клетки (срез 1 мм) на 1-й день клинических проявлений COVID-19-ассоциированной пневмонии. При сагиттальной реконструкции в MinIP-режиме выявлены обширные изменения в верхней доле левого легкого, «матовое стекло» низкой интенсивности в нижней и верхней долях правого легкого

II – V lobes of the lungs. The focal ground-glass opacities, dense infiltrations in the central zone, polysegmental infiltrations, air bronchogram sign, thickening of the bronchial wall, cobblestone sign in the interstitium, reticular consolidation of the interstitium, pleural reactions in the form of pleural effusion and thickening, mediastinal lymphadenopathy, and dilatation of the peripheral pulmonary veins within the lesions (Figure 6) were also found.

4 (7.1%) patients had **atypical findings** in the lungs. 3 (75.0%) patients had increased pulmonary vascularity due to diffuse consolidation of the interstitium with damage to both lungs and thickening of the bronchial walls. No ground-glass opacities were found. 1 (25.0%) patient had a bilateral lesion. Single ground-glass opacities associated with a pronounced infiltration of the left lower lobe, thickening of the bronchial walls and interstitial tissue, and dilatation of the pulmonary veins were found.

Discussion

Analysis of the data of patients with suspected COVID-19 pneumonia showed that MSCT is a highly sensitive diagnostic method that reveals pathological findings in lung tissue in the first days of the disease.

The most common signs of pneumonia are variable ground-glass opacities (infiltration in the central zone, unclear or blurred outer edges). The pulmonary vascularity is intensified due to the cord-type interstitial edema, a reticular macrostructure, up to the cobblestone appearance. If the lesion is subpleural, the pleura is consolidated. The most likely reason for the cobblestone sign in the first days of the disease is the pronounced edema of the interlobular interstitium associated with the ground-glass opacities. The findings could be localized in any part of the lung. The disease affected the alveolar tissue and caused a reaction of the interalveolar and pulmonary interstitium. We observed these CT signs of pneumonia in the early days of COVID-19 in 32 (55.6%) patients.

13 (23.2%) patients had extensive infiltrations along with the ground-glass opacities. The changes were mainly peribronchial, the bronchial walls were thickened due to edema, and mediastinal lymphadenopathy developed. Our data coincide with the opinion of most researchers [1–11]. Only one publication did not confirm lymphadenopathy in patients with SARS-CoV-2 pneumonia [6].

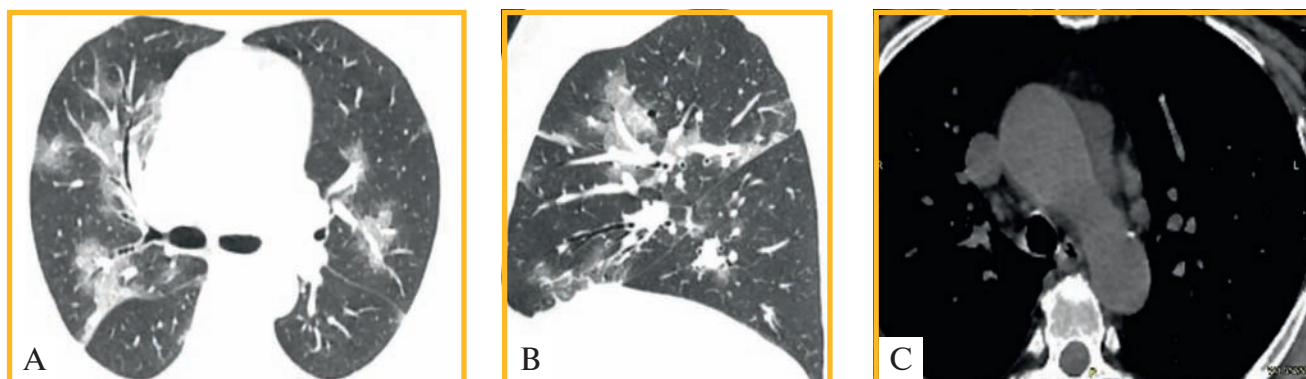


Figure 6. Multispiral computed tomography of the chest (1 mm slices) on the 4th day of clinical symptoms of COVID-19 pneumonia: A, B, Axial slices. The sagittal reconstruction shows multilobar polysegmental lung damage, pericarditis, high density lesions associated with the ground glass opacities, air bronchogram symptom; C, Indurated and enlarged lymph nodes in the aortic window in the region of aortic arch

Рис. 6. Мультиспиральная компьютерная томография органов грудной клетки (срез 1 мм) на 4-й день клинических проявлений COVID-19-ассоциированной пневмонии: А, В — аксиальный срез. Сагиттальная реконструкция — многодолевое полисегментарное поражение легких, перицистит, участки высокой плотности на фоне «матового стекла», симптом «воздушной бронхограммы»; С — уплотненные, увеличенные лимфатические узлы в аортальном окне, области дуги аорты

7 (12.5%) patients had infiltrative lobar changes along with the focal findings. These cases of severe pneumonia were characterized by extensive damage to the lung tissue and polymorphic MSCT findings in the lung parenchyma, bronchial wall, interstitium, pleura (in the form of pleural effusion and thickening), mediastinal lymph nodes, and peripheral pulmonary veins within the affected area.

Also, 4 (7.1%) patients with COVID-19 had atypical MSCT findings in the lungs. These findings have not been described in COVID-19 patients before and included a pronounced increase in the pulmonary vascularity caused by an interstitial consolidation (edema) and dilation of the peripheral pulmonary veins along with the ground-glass opacities.

The variable prevalence and inter-patient semiotics of COVID-19 pneumonia indicate a variable response to the infection. All authors emphasize the need to comply with specific methodological requirements when performing MSCT in patients with suspected pneumonia caused by SARS-CoV-2. In particular, the scan should be performed with thin slices, since the ground glass can be skipped in slices of more than 5 mm [12]. However, we did not find any references to the need for post-processing of native MSCT data in the mode of minimum image intensity in the available literature.

Note that MSCT signs of COVID-19 pneumonia can appear earlier or later than the clinical symptoms. Several authors report that the pathomorphological changes in the lungs in the first days of pneumonia associated with SARS-CoV-2 infection are mediated by dilatation and congestion in the alveolar capillaries, exudation of fluid into the alveolar cavity, and edema of the interlobular interstitium. These processes are seen in the MSCT scan as single or multiple ground-glass opacities, reticular consolidation of the interstitium, fusing of the lesions, and the appearance of high-density foci against the ground glass opacities [5–9].

Special attention should be paid to the differentiation between pneumonia caused by SARS-CoV-2 and pneumonia of a different etiology. COVID-19 pneumonia should be distinguished from pneumonia associated with influenza, parainfluenza, adenovirus, human metapneumovirus, respiratory syncytial virus, as well as bacterial and atypical pneumonias (mycoplasma, chlamydia, and others). Some non-infectious diseases (vasculitis, dermatomyositis, and organizing pneumonia) can cause changes in the lung tissue similar to the ones caused by COVID-19 pneumonia [13–17]. An important differential diagnostic sign of COVID-19 pneumonia, as opposed to the above-mentioned diseases, is that the typical findings can be located in any part of the lungs, the changes are multifocal, and the ground glass symptom can be combined with infiltrative changes and interstitial edema. The breakdown of lung tissue in COVID-19 pneumonia does not lead to the formation of cavities. The changes that are associated with viral pneumonia of a different etiology, mycoplasma or chlamydial infection are localized mainly in the basal or hilar parts of the lungs. Bacterial pneumonia is usually associated with infiltrative changes in the alveolar tissue in specific segments or lobes. The infiltrations are often prone to decay and are typically complicated by exudative pleurisy.

Bacterial pneumonia is not associated with the ground-glass opacities [18].

In our opinion, pneumonia caused by SARS-CoV-2 can be suggested after the comparison of MSCT data with the clinical picture and after MSCT monitoring.

Conclusion

- MSCT at the early stages of COVID-19 pneumonia shows a specific macrostructure that allows for a conclusion about the causative agent.
- Thin-section MSCT is a highly effective method for diagnosing COVID-19 pneumonia and can be used when patients show clinical signs of the disease or for monitoring of persons who had contact with an infected patient.
- Post-processing of the native MSCT data in the mode of minimum intensity projection provides additional information about the macrostructure of the findings and the state of the bronchi.
- MSCT is necessary for patients with suspected COVID-19 pneumonia, especially in hospitals with different specialization.

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