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Original Article

Pulmonary Invasive Fungal Disease: Ultrasound and Computed Tomography Scan Findings

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Abstract

OBJECTIVE: The importance of ultrasound in diagnosing pulmonary invasive fungal diseases (IFD) has yet to be assessed. Thus, this study aimed to evaluate the frequency of sonographic findings in patients suspected of an invasive pulmonary fungal infection.

MATERIAL AND METHODS: This prospective longitudinal study examined all patients with lung lesions in imaging modalities and suspected IFDs referred to Dr. Sheikh and Akbar pediatric hospitals from 2019 to 2022. Considered variables were the halo sign in the computed tomography (CT) scan; the target sign in the ultrasound and contrast-enhanced CT scan; the cavity; wedge-shaped consolidation; and pleuritis and extrapulmonary invasion to the chest wall or subdiaphragmatic invasion in both modalities. All patients who underwent lung CT scans and ultrasounds until the final diagnosis were followed up. The degree of agreement between ultrasound and CT scan findings and the sensitivity, specificity, and diagnostic accuracy of these signs were assessed.

RESULTS: This study involved 40 patients with an average age of 7.16 ± 4.23 years. Acute leukemia was the commonest underlying disease detected in 17 (42.5%) cases. The target sign in ultrasound (61.9%) and the halo sign in CT scan (71.4%) had the highest frequency among the variables in patients with IFD. Cohen's kappa coefficient agreement in both modalities was 0.5 for the cavity, with significant relation ($P = .02$). The Cohen's kappa was less than .17 for other findings ($P > .05$). The diagnostic criteria in the simultaneous examination of the fungus target in ultrasound and halo in CT scan showed a sensitivity of 82.4% and specificity of 76.5%, respectively.

CONCLUSION: Combining the characteristic findings of ultrasound and CT-scan provides a higher value in diagnosing pulmonary invasive fungal disease.

KEYWORDS: Diagnostic methods, pediatric lung disease, respiratory infections, invasive fungal disease
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INTRODUCTION

Invasive fungal disease (IFD) is one of the major causes of death in immune-compromised children, such as cancer patients and those treated by hematopoietic stem cell transplants.[1,2] The people who live in areas where mycoses are persistently endemic are also at high risk of IFD.[3] However, diagnosis is supposed to be difficult in the mentioned populations, although it is critical for disease management and outcome improvement.[4,5] The early diagnosis of patients with fungal pneumonia is of utmost importance since treatment outcome highly depends on early interventions. On the other hand, delayed diagnosis is associated with high mortality, for example, >70% mortality rate for *Aspergillus* respiratory infections.[4]

Diagnosis of IFD based only on history and clinical examination is unreliable due to low sensitivity and specificity[6,7] and lack of determining the etiology of infection.[8] Although culturing the biopsy or bronchoalveolar lavage is the gold standard diagnosis of IFD, these methods are time-consuming and have complications.[9,10] Therefore, radiological imaging for quick assessment and diagnosis plays an important role. Imaging in children can help determine the spread of the infection from its primary origin and help antifungal treatment follow-up.[11]

Ultrasound has always been interesting of all radiological imaging modalities due to its greater availability, lower cost, and less ionizing side effects. Chest ultrasound (transthoracic ultrasound or TTUS) is well-known for diagnosing pleural effusion, pneumonia, and lung masses.[12,13] However, there are few case reports on the role of ultrasound in diagnosing invasive fungal infections of the lung.[14,15] In this regard, the present study was designed to determine the frequency of lung ultrasound findings in patients suspected of pulmonary IFD and compare the diagnostic accuracy of this modality with a lung computed tomography (CT) scan in the diagnosis of IFD.

MATERIAL AND METHODS

Study Design and Participants

This prospective longitudinal study examined all patients with lung opacity in imaging modalities and suspected IFD referred to 2 children's hospitals in Mashhad University of Medical Science from 2019 to 2022.

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Before participating in this research, all required exams were described to the parents of the participants, and informed consent was obtained. First, the immune-compromised patients under 18 years of age were suspected of having a fungal infection with a history of cough and sputum production, fever, pleuritic chest pain, shortness of breath, and physical examination indicating pneumonia (body temperature >38°C or <36°C, respiratory rate above 22/min, heart rate >90/min, and auscultation rales on chest examination) were subjected to a chest x-ray (CXR). In cases where the CXR was consistent with the diagnosis of pneumonia, patients who had responded to pneumonia treatment were excluded from our study. However, additional examinations were performed by thoracic ultrasound and CT scan in cases of lack of response to treatment and suspicion of fungal infections. Then, the patients were followed up until the final diagnosis.

Diagnostic Method

An experienced pediatric radiologist performed the ultrasound examination (Figure 1). In lung ultrasound, 10 chest regions were examined, including 5 regions in each hemithorax: 2 anterior, 2 laterals, and 1 posterior region on each side. The anterior chest wall is defined from the parasternal line to the anterior axillary line. This area was divided into 2 upper and lower areas to align with the nipple landmark. The lateral area was defined from the anterior axillary line to the posterior axillary line, divided into upper and lower halves. The posterior region was defined from the posterior axillary line to the paravertebral line.

In ultrasound, a healthy lung has pleural sliding, A-line (repetitive lines parallel to the pleural line), and B-line (that is defined as long vertical hyperechoic reverberation artifacts originating from the interlobular septa that extend down the screen and that move and fade simultaneously with the pleural sliding). However, in interstitial lung abnormalities, there are multiple B lines (more than 3 lines in 1 area). The presence of focal interstitial abnormalities is considered early evidence of pneumonia. Ultrasonic diagnosis of pneumonia depends on lung consolidation with a tissue-like pattern (due to reduced alveolar ventilation and increased liquid content). On real-time ultrasound, consolidations may contain air bronchograms or multiple branching echogenic spots. A pleural effusion is an anechoic space between the parietal and visceral pleura with the respiratory movement of the lung inside the effusion.

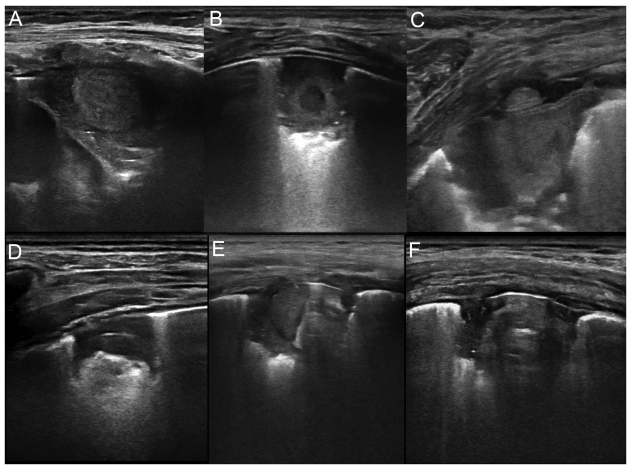

Figure 1. Ultrasound images of some patients with invasive pulmonary fungal infections. (A) The hyperechoic nodule (fungus ball) within the consolidation. (B) Target lesions as a hypoechoic center with a hyperechoic rim. (C) A wedge-shaped lesion associated with pleuritis and invasion on the chest wall. (D) Hyperechoic fungus ball with peripheral hypoechoic rim and reactive pleuritis. (E) Hyperechoic fungus ball with cavitation and air crescent sign. (F) A wedge-shaped consolidation with cavitation.

The IFD in the transthoracic ultrasound has 4 characteristic appearances: the target lesion (as a hyperechoic central nodule with a hypoechoic rim or as a hypoechoic center with a hyperechoic rim), the cavitary lesions (U-shaped consolidation), wedge-shaped consolidation, and pleuritis and extrapulmonary invasion to the chest wall or diaphragm. Computed tomography scan findings of the IFD are a nodule with halo sign, reverse halo sign, crescent sign, wedge-shaped opacity, and cavitary consolidation. The extrapulmonary invasion has been defined in ultrasound as the passage of the lesion along the pleura and in CT scan as a focal pleural thickening or periosteal reaction. The target sign in high-resolution computed tomography (HRCT) has been defined as the lesions with the hypodense center with a hyperdense rim in the mediastinal window of contrast-enhanced slices.

Diagnostic methods of IFD were paranasal sinuses debridement (5 cases), core needle biopsy (3 cases), surgery (4 cases), galactomannan test (2 cases), simultaneous target lesions in liver or spleen ultrasound (1 case), specific signs such as halo (14 cases) and crescent sign (6 cases) in lung CT scan, appropriate response to start of antifungal treatment (13 cases), and past medical history (7 cases).

Statistical Analysis

The data related to ultrasound and CT scan of the patients, their outcome, and general information were all collected and categorized. Sampling was done in a full census manner. The demographic data and general characteristics of the study population were described in tables using descriptive statistics methods, including central tendency indices, dispersion indices, and frequency distribution.

MAIN POINTS

- The characteristic ultrasound appearances of invasive fungal disease (IFD) included the target sign, the cavity, wedge-shaped consolidation, and pleuritis and extrapulmonary invasion to the chest wall or subdiaphragm.
- The characteristic computed tomography (CT) scan appearances of IFD included the halo sign and the crescent sign, the target signs in contrast-enhanced CT; wedge-shaped consolidation; and extrapulmonary invasion.
- There is a slight-to-moderate degree of agreement between the related findings in thoracic ultrasound and CT scan.
- The simultaneous use of contrast-enhanced CT scan and targeted ultrasound has a higher diagnostic value in diagnosing pulmonary fungal infections.

The Statistical Package for the Social Sciences, version 25.0, (IBM Corp.; Armonk, NY, USA) was used for statistical analysis, and tables were created in Microsoft Word 2016. The Cohen's kappa (κ) coefficient of agreement was used to evaluate the agreement of the results of different imaging modalities. A Cohen's κ value 0 was considered no agreement, .1-.2 as slight agreement, .21-.4 as fair agreement, .41-.6 as moderate agreement, .61-.8 as substantial agreement, .81-.99 as near-perfect agreement, and 1 as perfect agreement. Correlations were also analyzed between the 2 modalities, and a $P < .05$ was considered statistically significant. Also, the sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy of the imaging variables in ultrasound and CT scan were calculated.

Ethics Committee Approval

This study was registered with the Organizational Ethics Committee of the Faculty/Region of Mashhad University of Medical Sciences on January 20, 2021, and approved with code IR.MUMS.MEDICAL.REC.1399.730 and the number 981267.

RESULTS

This study involved 40 patients, 24 male (60%) and 16 female (40%). The average age of the patients was 7.41 ± 4.23 years, and the average size of the masses was 28.48 ± 16.23 mm. The underlying diseases were leukemia (17), Wilms' tumor (1), anaplastic anemia (3), immune deficiency (4), coronavirus disease 2019 (1), and diabetes mellitus (1). There was not a known underlying disease in 13 patients. Seventy percent of lesions were multiple and 52.5% were bilateral. Opacity in CXR was seen in 47.1% of patients, and others had normal CXR. The final diagnoses of lung lesions in the examined patients were IFD (21), chronic granulomatosis disease (4), round pneumonia (4), oil aspiration (3), chloroma (2), tuberculoma (2), abscess (1), tumor (1), inflammation (1), and hydatid cyst (1). Table 1 shows the demographic and diagnostic characteristics of suspected IFD patients.

Table 1. Demographic and Diagnostic Characteristics of Patients with Suspected IFD

Variables	Number
Age (mean)	7.41 ± 4.23 (years)
Male/female	24/16
Underlying disease	
• Leukemia	17
• Unknown	13
• Known immune deficiency	4
• Anaplastic anemia	3
• Others	3
Diagnostic methods	
• Specific CT scan findings	14
• Response to treatment	13
• Past medical history	7
• Sinus debridement	5
• Surgery	3
• Core needle biopsy	3
• Galactomannan test	2
Final diagnosis	
• IFD	21
• Chronic granulomatosis disease	4
• Round pneumonia	4
• Oil aspiration	3
• Chloroma	2
• Tuberculoma	2
• Others	4

CT, computed tomography; IFD, invasive fungal disease.

The most common ultrasound finding (60%) was a nonspecific mass. The diagnosis agreement based on the ultrasound variables was the same as the final diagnosis in 33 people (82.5%), but it was different in 7 people (28.5%).

Finally, the frequency of the ultrasound and CT-scan findings of the IFD (21 cases), including fungus ball, target sign, wedge-shaped lesions, cavity, and pleuritis and extrapulmonary invasion, was investigated. The target sign was the most common ultrasound finding (61.9%) and the central hyperechoic nodule (fungus ball) was seen in 28.6% of cases (Figure 2). However, the target sign in ultrasound is occasionally seen in other diseases, such as necrotizing pneumonia.

The most common findings were the cavity and the halo sign in the CT scan, with 30% and 71.4%, respectively. Contrast-enhanced HRCT was done in a few patients; the lesions with the hyperdense center with hypodense rim (target sign) were seen in the mediastinal window (Figure 2).

Although in the CT scan, the focal pleural reaction was observed in the adjacent fungal lesions in most patients

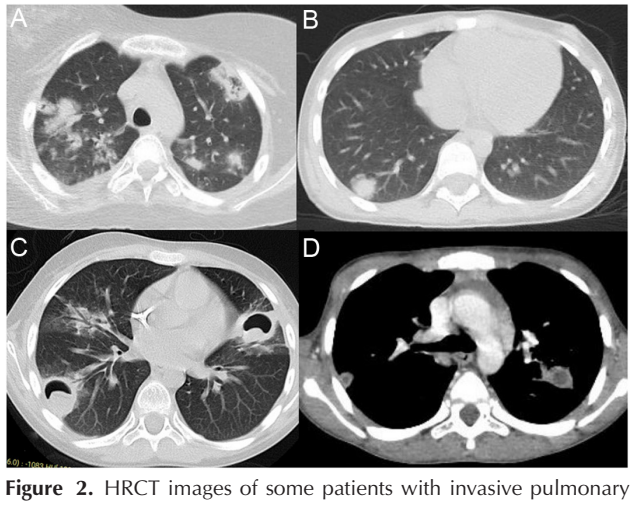

Figure 2. HRCT images of some patients with invasive pulmonary fungal infections. (A) Multiple opacity with peripheral or central ground glass (halo sign and reverse halo sign). (B) Nodular lesion with ground-glass opacity (halo sign). (C) The cavitary lesions with fungus ball and air crescent sign. (D) The hypodense center with a hyperdense rim (target sign) lesions in the mediastinal window of contrast-enhanced slices.

Table 2. Agreement Between CT Scan and Ultrasound Parameters in 21 Patients with Pulmonary IFD

		CT Scan Variable Crescent Sign		Cohen's Kappa Coefficient	*P*
Ultrasound Variable		**Negative (%)**	**Positive (%)**		
Fungus ball	Negative (%)	7 (63.6%)	4 (36.4%)	−.03	.90
	Positive (%)	4 (66.7%)	2 (33.3%)		
Target sign		Halo sign		.05	.81
	Negative (%)	1 (20%)	4 (80%)		
	Positive (%)	2 (15.4%)	11 (84.6%)		
		Target sign in contrast-enhanced CT			
		–	2		
Wedge-shaped consolidation		Wedge-shaped opacity		.08	.71
	Negative (%)	9 (69.2%)	4 (30.8%)		
	Positive (%)	3 (60%)	2 (40%)		
Cavity		Cavity		.50	.02
	Negative (%)	10 (76.9%)	3 (32.1%)		
	Positive (%)	1 (20%)	4 (80%)		
Extrapulmonary invasion		Extrapulmonary invasion		.17	.20
	Negative (%)	7 (100%)	0		
	Positive (%)	8 (80%)	2 (20%)		

CT, computed tomography; IFD, invasive fungal disease.

(9 cases), the clear invasion was seen in only 2 patients. However, ultrasound reliably showed extrapulmonary invasion in many patients (11 cases).

Cohen's κ statistical test was used to evaluate the agreement of ultrasound with CT-scan results in IFD. As presented in Table 2, the moderate agreement in both modalities and significant relation is due to the cavity (Cohen's $\kappa = .5$; $P = .02$). However, there was a slight degree of agreement (Cohen's $\kappa = -.03$; $P = .90$) between the fungus ball in ultrasound and the crescent sign in the CT scan and the target sign in the ultrasound and halo sign in the CT scan (Cohen's $\kappa = .05$; $P = .81$). Similarly, wedge-shaped lesions and extrapulmonary invasion in both modalities had a slight degree of agreement (Cohen's $\kappa = .08$ and .17; $P = .71$ and .20, respectively) that was nonsignificant.

In IFD patients, the sensitivity, specificity, and accuracy of the target sign in ultrasound were 56.25%, 81.25%, and 68.75%, that of the halo sign in CT scan were 70.58%, 88.23%, and 79.41%, and that of the simultaneous target sign in the ultrasound and halo sign in CT scan were 82.35%, 76.47%, respectively.

DISCUSSION

As a result of a recent meta-analysis, the role of lung ultrasound in diagnosing pediatric pulmonary infections is undeniable due to its high sensitivity and specificity, given the sensitivity of ultrasound to the natural determination of lung masses is higher than that of CT scan.[16,17] Due to the advantages that ultrasound has over invasive methods or other diagnostic devices with ionizing rays, there are always many efforts in clinical and even basic sciences (such as artificial intelligence and deep learning strategies) in order to enhance our knowledge and understanding of the cause and origin of artifacts in this diagnosis modality.[18,19]

Invasive pulmonary fungal infections are one of the important causes of death, especially in immunocompromised people, and early diagnosis has a key role in improving the prognosis of the disease in the mentioned people.[2,5] *Aspergillus*, *Candida*, and mucormycosis are 3 major causes of opportunistic fungal infections in immunocompromised patients with airway or angioinvasive features.[16,20]

In addition, IFD is becoming more common in premature and low-birth-weight infants, leading to decreased survival rate. In line with diagnostic problems of pulmonary infections in children and to clarify the diagnostic role of ultrasound modality, Jing Liu et al[21] investigated 7 cases of pulmonary fungal infections in newborns. They found that ultrasound features (including lung consolidations, irregular margins, shred signs, lung pulse, pleural line abnormalities, and different types of B-lines in nonconsolidated areas that show different degrees of edema) can help diagnose these patients. Similar avascular findings were reported in a case report by Grabala et al.[22]

In a prospective pilot study, Raffaella et al[23] studied 10 hematologic patients who underwent hematopoietic stem cell transplants and developed invasive fungal infections. In this study, patients were evaluated once at the beginning of the study and 10 days after the start of antifungal treatment using a CT scan and chest ultrasound. Chest ultrasound showed consolidations and hypoechoic areas with inhomogeneous

echoes and unclear margins in 40% of patients. The researchers concluded that ultrasound is highly sensitive to fungal pneumonia lesions and their follow-ups. However, these findings are nonspecific and can be seen in other conditions causing pneumonia.

Studies that show more specific findings of fungal infections are few; Rodrigues-Pinto et al[14] published a case report that endoscopic ultrasound showed an ill-defined hypoechoic paraesophageal lesion with a central annular image without vascular flow in a patient with acute myeloid leukemia. The ultrasound-guided fine-needle aspiration of the lesion revealed *Aspergillus*.[14] Alamdaran et al[15] reported some characteristic signs of invasive pulmonary fungal infections in 6 leukemia patients; they report 4 types of sonographic findings in transthoracic ultrasonography: the target sign, the cavity, wedge-shaped consolidation, and extrapulmonary invasion to the chest wall or subdiaphragmatic invasion. The target lesions have some features: a central hyperechoic nodule with a hypoechoic rim, a hypoechoic center with a hyperechoic rim, a hypoechoic nodule in the center of consolidation, and a hyperechoic nodule in the center of consolidation. The cavitary lesions are seen as an air crescent adjacent to the central hyperechoic or as a U-shaped consolidation, in which the air crescent is at the center of it. The central hyperechoic nodule is due to a fungus ball, as during cavitation, air envelopes it as a crescent sign. The extrapulmonary invasion to the pleura (focal pleuritis) and the chest wall, or to the subdiaphragmatic area, was seen in some of the subpleural lesions. Subsegmental consolidation is wedge shaped, probably due to airway or vessel invasion. We have found target signs in ultrasound frequently (61.9%) in cases where the final diagnosis was a fungal infection.

Some characteristic features of pulmonary fungal infection on x-ray or CT scan are reported; the halo sign and the "reverse-halo" sign are more specific findings of invasive pulmonary fungal infections on CT-scan images. The halo sign is a ground-glass opacity surrounding a rounded consolidation area, probably due to angioinvasion. The "reverse-halo" sign is defined by central ground-glass opacity with peripheral consolidation, probably due to necrotic or cavitary consolidation. The air crescent sign is due to central cavitation surrounding the fungus ball.[24]

In the current research, we investigated the diagnostic value of ultrasound and CT-scan findings. Our results showed that there is a different degree of agreement between variables. The target sign in ultrasound and the halo sign in CT scan and the cavity in both modalities have a significant moderate degree of agreement. These correlations suggest that we can rely on variables such as cavities and especially target signs for diagnosing invasive pulmonary fungal infection by ultrasound.

There was a slight agreement between the fungus ball in ultrasound and the crescent sign in CT scan and between wedge-shaped lesions in both modalities that were not statically significant. These 2 are probably due to the limitation of the ultrasound window after cavitation and air lung, which does not allow visualization of the fungus ball and the wedge-shaped appearance. However, this indicates the complementary role of ultrasound and CT scan in diagnosing fungal lung infections.

The low degree of agreement between the parameters of CT scan and ultrasound in pulmonary IFD emphasizes the complementary role of these 2 methods in diagnosing this disease.

Pulmonary fungal infection diagnosis based on simultaneous examination of the target sign in ultrasound and the halo sign in CT scan showed a sensitivity of 82.35%, specificity of 76.47%, and positive and negative predictive values of 77.77% and 81.25%, respectively. As a result, ultrasound and CT scan can provide more precise diagnostic accuracy in these patients.

It should be noted that although ultrasound is valuable in evaluating peripheral lung opacity, it has limitations in diagnosing central intraparenchymal parenchymal lesions. In this study, which is one of the few studies in this field, there are some limitations. The limitations of this study include the small sample size (due to the overall low prevalence of fungal lung infections), and it was impossible to match the ultrasound appearance with the pathologic appearance. We have tried to reduce this error to a minimum with careful data accumulation and using statistical methods. However, further studies need to be designed prospectively with a larger sample size and control of confounding factors to investigate this issue more precisely.

CONCLUSION

There are 4 characteristic ultrasound appearances of IFD: the target sign, the cavity, wedge-shaped consolidation, and extrapulmonary invasion to the chest wall or subdiaphragmatic invasion. Although there is a slight-to-moderate degree of agreement between the number of the related findings in thoracic ultrasound and CT scan, this research shows that the simultaneous use of both modalities has a higher value in diagnosing fungal infections.

Ethics Committee Approval: This study was approved by Ethics Committee of Mashhad University of Medical Science (Approval No: IR.MUMS.MEDICAL.REC.1399.730, Date: 12 - 10 - 2022).

Informed Consent: Written informed consent was obtained from the parents of the patients who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – A.S.A.; Design – A.S.A., B.E.; Supervision – A.S.A., G.A.; Materials – G.A.; Data Collection and/or Processing – B.R., B.E.; Analysis and/or Interpretation – B.E., B.R.; Literature Search – B.R., D.S.F.; Writing – D.S.F.; Critical Review – A.S.A., G.A.

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REFERENCES

1. Barnes RA. Early diagnosis of fungal infection in immunocompromised patients. *J Antimicrob Chemother*. 2008;61(suppl 1):i3-i6. [CrossRef]
2. Ozsevik SN, Sensoy G, Karli A, et al. Invasive fungal infections in children with hematologic and malignant diseases. *J Pediatr Hematol Oncol*. 2015;37(2):e69-e72. [CrossRef]
3. Chu JH, Feudtner C, Heydon K, Walsh TJ, Zaoutis TE. Hospitalizations for endemic mycoses: a population-based national study. *Clin Infect Dis*. 2006;42(6):822-825. [CrossRef]
4. Von Eiff M, Roos N, Schulten R, Hesse M, Zühlsdorf M, Van de Loo J. Pulmonary aspergillosis: early diagnosis improves survival. *Respiration*. 1995;62(6):341-347. [CrossRef]
5. Caillot D, Mannone L, Cuisenier B, Couaillier JF. Role of early diagnosis and aggressive surgery in the management of invasive pulmonary aspergillosis in neutropenic patients. *Clin Microbiol Infect*. 2001;7(suppl 2):54-61. [CrossRef]
6. Gereige RS, Laufer PM. Pneumonia. *Pediatr Rev*. 2013;34(10): 438-456; quiz 455. [CrossRef]
7. Pereda MA, Chavez MA, Hooper-Miele CC, et al. Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis. *Pediatrics*. 2015;135(4):714-722. [CrossRef]
8. Shah SN, Bachur RG, Simel DL, Neuman MI. Does this child have pneumonia? the rational clinical examination systematic review. *JAMA*. 2017;318(5):462-471. [CrossRef]
9. Stefanutti D, Morais L, Fournet JC, et al. Value of open lung biopsy in immunocompromised children. *J Pediatr*. 2000;137(2): 165-171. [CrossRef]
10. Jain S, Self WH, Wunderink RG, et al. Community-acquired pneumonia requiring hospitalization among US adults. *N Engl J Med*. 2015;373(5):415-427. [CrossRef]
11. Chamilos G, Marom EM, Lewis RE, Lionakis MS, Kontoyiannis DP. Predictors of pulmonary Zygomycosis versus invasive pulmonary aspergillosis in patients with cancer. *Clin Infect Dis*. 2005;41(1):60-66. [CrossRef]
12. Alamdaran SA, Estilaee S, Farrokh D, Morovatdar N. Thoracic mass nature determination; what modality is better in pediatric age? *Int J Pediatr*. 2019;7(8):9921-9928.
13. Reissig A, Kroegel C. Sonographic diagnosis and follow-up of pneumonia: a prospective study. *Respiration*. 2007;74(5):537-547. [CrossRef]
14. Rodrigues-Pinto E, Lopes S, Principe F, Costa J, Macedo G. Pulmonary aspergillosis diagnosed by endoscopic ultrasound fine-needle aspiration. *Endosc Ultrasound*. 2016;5(1):58-60. [CrossRef]
15. Alamdaran SA, Heidarzadeh H, Zavvar SN, Badiee Z, Jaberi M, Ghasemi A. Presentation of sonographic features of pulmonary invasive fungal disease in six children with leukemia. *Int J Pediatr*. 2020;9(2):13203-13211.
16. Najgrodzka P, Buda N, Zamojska A, Marciniewicz E, Lewandowicz-Uszyńska A. Lung ultrasonography in the diagnosis of pneumonia in children—a metaanalysis and a review of pediatric lung imaging. *Ultrasound Q*. 2019;35(2):157-163. [CrossRef]
17. Lameh A, Seyedi SJ, Farrokh D, Lavasani S, Alamdaran SA. Diagnostic value of ultrasound in detecting causes of pediatric chest X-ray opacity. *Turk Thorac J*. 2019;20(3):175-181. [CrossRef]
18. Demi M, Prediletto R, Soldati G, Demi L. Physical mechanisms providing clinical information from ultrasound lung images: hypotheses and early confirmations. *IEEE Trans Ultrason Ferroelectr Freq Control*. 2020;67(3):612-623. [CrossRef]
19. van Sloun RJG, Demi L. Localizing B-Lines in lung ultrasonography by weakly supervised deep learning, in-vivo results. *IEEE J Biomed Health Inform*. 2020;24(4):957-964. [CrossRef]
20. Panse P, Smith M, Cummings K, Jensen E, Gotway M, Jokerst C. The many faces of pulmonary aspergillosis: imaging findings with pathologic correlation. *Rad Infect Dis*. 2016;3(4): 192-200. [CrossRef]
21. Liu J, Ma HR, Fu W. Lung ultrasound to diagnose pneumonia in neonates with fungal infection. *Diagnostics (Basel)*. 2022; 12(8):1776. [CrossRef]
22. Grabala J, Grabala M, Onichimowski D, Grabala P. Possibilities of using ultrasound for diagnosis of invasive pulmonary mucormycosis–A case study. *Pol Ann Med*. 2017;24(2):224-227. [CrossRef]
23. Raffaella G, Lorenzo L, Elisabetta X, et al. Lung ultrasound to evaluate invasive fungal diseases after allogeneic hematopoietic stem cell transplantation. *Infect Chemother*. 2019;51(4):386-392. [CrossRef]
24. Choo JY, Park CM, Lee HJ, Lee CH, Goo JM, Im JG. Sequential morphological changes in follow-up CT of pulmonary mucormycosis. *Diagn Interv Radiol*. 2014;20(1):42-46. [CrossRef]