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Chest CT characterization of children with necrotizing pneumonia due to *Mycoplasma pneumoniae* infection

Jiapu Hou, Ruiyang Sun, Xue Zhang, Wanyu Jia, Peng Li & Chunlan Song

We summarize the chest CT manifestations and prognoses of children with *Mycoplasma pneumoniae* pneumonia combined with necrotizing pneumonia. We retrospectively analyzed the chest CT manifestations and prognoses of 155 cases of necrotizing pneumonia in children due to *Mycoplasma pneumoniae* infection and compared the differences in clinical features and laboratory indices between the group with unilateral monolobar necrosis of the lungs (Group A) and the group with unilateral multilobar and bilateral necrosis (Group B). The chest CT findings of the children in both groups revealed that the area of lung necrosis was confined to the unilateral monolobe in 124 children. The necrotic condition of the lungs included only hypodense shadows in 80 children (51.61%) and cystic cavities in the necrotic areas in 75 children (48.39%). Bronchoscopic manifestations: Endobronchitis was present in 135 children, ulcerative necrosis of the bronchi in 47, and occlusive bronchitis in four. A total of 101 children were followed up. A small percentage of patients have residual manifestations such as lobar atelectasis and bronchial wall changes. The number of days of fever and cases of respiratory distress were significantly greater in group B than in group A. Chest CT reveals pulmonary necrosis in children due to *Mycoplasma pneumoniae* infection: the area of pulmonary necrosis is mostly unilateral and unilobar, the lower lungs are predominant, and areas of reduced enhancement can be seen on enhanced CT. CT manifestations after clinical treatment may be approximately normal or leave a striped shadow, lung atelectasis, or pleural thickening.

Keywords *Mycoplasma pneumoniae*, *Mycoplasma pneumoniae* pneumonia, Necrotizing pneumonia, CT imaging

Abbreviations

MP *Mycoplasma pneumoniae*
MPP *Mycoplasma pneumoniae* pneumonia
NP Necrotizing pneumonia

Mycoplasma pneumoniae (MP) infection is usually considered a self-limiting disease, with clinical manifestations that are in most cases mild, similar to the respiratory symptoms caused by other pathogen infections, and lack specific manifestations¹. *Mycoplasma pneumoniae* pneumonia (MPP) is often not detected in time because of the lack of reliable immediate diagnosis¹. MP is one of the major pathogens that causes respiratory infections in humans. MP has now become one of the most common pathogens of community-acquired pneumonia in children, accounting for approximately 10–40% of community-acquired pneumonia cases². Some studies have shown that the positive detection rate of MP in Chinese children with community-acquired pneumonia reaches 10–30%³. The main clinical manifestations of children with MPP are fever and persistent dry cough. In addition to respiratory symptoms, MP infections can lead to a variety of serious intrapulmonary and extrapulmonary injuries, such as necrotizing pneumonia (NP), pulmonary embolism, central nervous system inflammation, acute myocardial injury, and thrombosis¹. NP in children is characterized by liquefaction necrosis of lung tissue and is a serious complication of community-acquired pneumonia in children, accounting for approximately 9.0% of community-acquired pneumonia in children⁴. In recent years, with the gradual increase in the incidence of MPP, the number of NPs caused by MP infections has also increased annually^{5,6}. Children with NP progress

Pediatric Emergency Department, Children's Hospital Affiliated to Zhengzhou University, No. 1, South University Road, Erqi District, Zhengzhou 450052, Henan, China. ✉email: 13526867323@163.com

rapidly and are associated with a greater risk of complications, such as sepsis, pneumothorax, and respiratory failure^{7,8}. Therefore, understanding the clinical features, imaging manifestations and laboratory tests of children with MPP combined with NP is important for clinicians to recognize NP at an early stage to improve the prognosis of these children. There are fewer relevant studies describing the CT manifestations of children with MP infection leading to NP. In this study, the clinical data of 155 children with MPP combined with NP were included, and their characteristics were analyzed to provide a reference for clinicians.

Materials and methods

Study population

In this study, we used 155 children with MPP combined with NP hospitalized at the Children's Hospital Affiliated with Zhengzhou University from January 2023 to May 2024 as the study population. They were divided into group A (124 patients) and group B (31 patients) according to the size of the area of distribution of lung necrosis.

Inclusion and exclusion criteria

The diagnostic criteria for MPP are as follows^{9,10}: (1) fever, cough, shortness of breath and abnormal breath sounds; (2) typical chest imaging changes such as interstitial infiltrates, segmental and lobar solid changes, and hilar lymph node enlargement; and (3) positive for MP-DNA or RNA. A diagnosis is made when the above conditions are met.

Assays for MP-DNA or RNA: The test specimens were derived from pharyngeal swabs and sent for testing within 12 h, and the DNA and RNA of MP were detected by fluorescent PCR, and detected by Mycoplasma pneumoniae Nucleic Acid and Resistance Mutation Site Detection Kit (Merle, Jiangsu, China).

The inclusion criteria were as follows: (1) age greater than 1 year and less than 18 years; (2) met the diagnostic criteria for MPP; and (3) multiple air-containing cystic cavities or thin-walled cavities without fluid-air flattening in the area of solid lung lesions on chest CT^{10,11}. Enhanced CT of the chest may reveal areas of hypodense necrosis.

The exclusion criteria were as follows: (1) children with cavitary lung disease, such as pulmonary tuberculosis or pulmonary abscess; (2) children with preexisting diseases of the blood system, cardiovascular system, bronchial asthma, recurrent respiratory infections, immune deficiency, etc.; and (3) patients whose clinical information was incomplete.

Criteria for grouping

The criteria for Group A patients were as follows: the area of lung necrosis was confined to a single lobe of the lung. The criteria for group B were as follows: areas of lung necrosis distributed in unilateral multilobar or bilateral areas of the lung.

Data collection

We collected clinical data related to two groups of children with MPP combined with NP through the medical record system, including (1) general information, age, sex, and days of hospitalization; (2) clinical manifestations such as chest pain, dyspnea, days of fever, and the occurrence of intrapulmonary complications such as pleural effusion, mixed infection, and pulmonary embolism; (3) imaging manifestations such as chest CT and bronchoscopic features; and (4) laboratory test indicators.

CT examination method

CT examination was performed via a Philips Brilliance CT 64-row spiral CT scanner with a scanning range from the lung apex to the lung base, a scanning interval of 8 mm and a layer thickness of 2 mm. During the scan, the child lies flat on the scanning bed; smaller children need to be accompanied or sedated by a parent and repositioned according to the radiographer's request for a more satisfactory image.

CT-enhanced scans were performed by injecting nonionic contrast agent (Omnipaque, iodine concentration 300 mg/mL) via a forearm vein at a dose of 2.0–2.5 mL/kg and a flow rate of 0.5–2.5 mL/s, and arterial-phase images were acquired 30 s after injection.

Image analysis

Two pediatric diagnostic imaging physicians with more than 10 years of experience read the films independently and negotiated a consensus conclusion in case of disagreement. The observations included the following: (1) lung necrosis (low-density shadow only, cystic cavity), areas of distribution of lung necrosis (unilateral unilobar, unilateral multilobar and bilateral distribution), areas of distribution of lung solidity (unilateral unilobar, unilateral multilobar and bilateral distribution), pulmonary atelectasis, and pulmonary embolism; and (2) other extrapulmonary lesions: whether the pleura is thickened, whether there is pleural effusion, and whether there is fluid pneumothorax.

Bronchoscopy

Bronchoscopy and alveolar lavage were performed in 145 children with MPP combined with NP.

Observations: bronchial wall alterations: presence of endobronchitis, sputum embolism, ulcerative necrosis, stenosis, occlusive bronchitis, and plastic bronchitis.

Statistical analyses

We used SPSS software (version 21.0) for the statistical analysis. Quantitative information that conformed to a normal distribution was expressed as the mean $\pm$ standard deviation and was compared between groups by an independent samples t test. Quantitative information that did not conform to a normal distribution was

expressed as the median P50 (P25, P75) and compared via the Mann–Whitney U test. Qualitative information is expressed as a percentage (%), and $p < 0.05$ was considered to indicate a statistically significant difference.

Results

Baseline characteristics and clinical presentation

There were 124 children in group A. The male to female ratio was 1:1, the median age was 7 years, and the number of days of hospitalization was 13 (10, 15) days. In group B, there were 31 children, 18 males and 13 females, with a median age of 6 years and 14 (10, 20) days of hospitalization. There was no statistically significant difference in the age or sex of the children between the two groups. The differences in the number of days of hospitalization and the number of cases of chest pain between the children in Group B and those in Group A were not statistically significant. The difference between the two groups of children in terms of mixed infections was not statistically significant. Mixed infections were present in 61 of the 155 children with MPP in this study. Of these, 17 were co-infected with *Streptococcus pneumoniae*, 15 with adenovirus, 10 with respiratory syncytial virus, 10 with EBV, and the remainder with other pathogens. The number of days of fever and cases of respiratory distress were significantly greater in group B than in group A Tables 1 and 2.

Chest CT, fiberoptic bronchoscopic manifestations and laboratory tests

The differences in necrotic lung conditions, pulmonary atelectasis, bronchoscopic changes, pleural effusion, fluid pneumothorax and pleural thickening were not statistically significant between the two groups. The differences in white blood cell count, C-reactive protein, D-dimer, procalcitonin, the erythrocyte sedimentation rate, lactate dehydrogenase, and ferritin between the two groups of children were not statistically significant (Table 1).

Treatment and short-term prognosis

In the present study children with MPP combined with NP, we routinely treated them with macrolide antibacterial drugs and after a course of 5–7 days, those who had poor efficacy were shifted to second line drugs such as tetracyclines and levofloxacin after requesting the pharmacy department and obtaining informed consent from the parents of the children. Based on chest imaging, Bronchoscopy and alveolar lavage was considered for children with severe disease and large pulmonary solid lesions who did not show significant improvement. NP due to MP infection was mostly treated with fiberoptic bronchoscopy, which was performed in 145 out of 155 children. The number of fiberoptic bronchoscopies performed in this study was 2 (1, 3), with a maximum of 5 fiberoptic bronchoscopies. Airway support, such as oxygen and mechanical ventilation, was given to 46 children, and closed chest drainage was performed in 13 children. Among these, lobectomy was performed in one child. There was no statistically significant difference in airway support or fiberoptic bronchoscopy treatment between the two groups. More children in Group B than in Group A underwent closed chest drainage. The difference was

	Group A	Group B	P
Sex Male	50.00%	58.10%	0.547
Age	7(6,9)	6(4,8)	0.093
Days of hospitalization	13.00(10.00,15.00)	14.00(10.00,20.00)	0.075
Number of fever days	11.00(9.25,15.00)	14.00(10.00,20.00)	0.034
Chest pain	22.60%	38.70%	0.108
Dyspnea	16.90%	35.50%	0.042
Mixed infection	38.70%	41.90%	0.902
Pulmonary embolism	44.40%	38.70%	0.715
Pulmonary hypotension	10.50%	9.70%	1.000
Bronchoscopic changes	91.10%	96.80%	0.499
Pleural effusion	39.50%	45.20%	0.713
Hydropneumothorax	1.60%	0.00%	1.000
Pleural thickening	27.40%	25.80%	1.000
Number of bronchoscopies	2.00(1.00,3.00)	2.00(1.00,2.00)	0.892
Airway support	26.60%	41.90%	0.147
Closed Chest Drainage	5.60%	19.40%	0.036
WBC	11.72(8.35,15.15)	14.17(8.97,16.73)	0.137
CRP	21.22(4.11,69.23)	36.45(2.00,57.92)	0.900
D-dimer	1.88(0.95,3.14)	2.57(1.33,3.95)	0.061
PCT	0.16(0.08,0.36)	0.16(0.09,0.59)	0.305
ESR	36.50(20.25,59.00)	45.00(30.00,64.00)	0.178
LDH	407.00(322.50,612.00)	466.00(293.00,751.00)	0.860
Ferritin	229.20(137.83,368.55)	239.45(163.05,530.40)	0.265

Table 1. Comparison between the two groups. WBC, White blood cell count; CRP, C-reactive protein; PCT, Procalcitonin; ESR, Erythrocyte sedimentation rate; LDH, Lactate dehydrogenase.

Sex Male	80	51.61%
Age	7(5,9)	
Pulmonary necrosis		
Low density shadow	80	51.61%
Cystic cavity	75	48.39%
Distribution of lung necrosis		
Unilateral single leaf	124	80.00%
Upper lobe of the right lung	16	
Middle lobe of the right lung	9	
Lower lobe of the right lung	45	
Upper lobe of the left lung	18	
Lower lobe of the left lung	36	
Unilateral many leaves	16	10.32%
Bilateral of the lungs	15	9.68%
Distribution of pulmonary solid lesions		
Unilateral single leaf	99	63.87%
Unilateral many leaves	18	11.61%
Bilateral of the lungs	23	14.84%
None	15	9.68%
Concomitant symptom		
Pulmonary hypotension	16	10.32%
Bronchoscopic changes	143	92.26%
Endobronchitis	135	
Sputum suppository	54	
Ulcers, necrosis	47	
Narrowness	1	
Occlusive bronchitis	4	
Plastic bronchitis	10	
Pleural effusion	63	40.65%
Hydropneumothorax	3	1.94%
Pleural thickening	42	27.10%
Follow-up visit	101	65.16%
Legacy Symptoms		
Pleural thickening	44	
Lobular atelectasis	11	
Striped shadow	7	
Bronchial wall changes	29	
Bronchial stenosis	15	
Bronchiectasis	14	
Number of bronchoscopies	2(1,3)	
Treatments		
Bronchoscopy and alveolar lavage	145	
Airway support	46	
Closed Chest Drainage	13	
Pulmonary lobectomy	1	

Table 2. Baseline characteristics, chest CT manifestations, accompanying symptoms, and legacy symptoms in children with MPP combined with NP.

statistically significant. Additionally, 101 of 155 children with MPP combined with NP were followed up after discharge. The follow-up time ranged from 1 month to 1 year. Pleural thickening was present in 44 patients, lobular atelectasis in 11 patients, striated shadows in 7 patients, bronchial stenosis in 15 patients, and bronchial dilatation in 14 patients (Fig. 1) (Table 2).

Discussion

Current research suggests that the age of children infected with MP is concentrated in the preschool years, but infections in school-aged children may progress severely². In the present study, both groups of children were 7 (5,9) years old and were preschool and school aged. Therefore, the age of children with MPP combined with NP

1, Legacy Symptoms

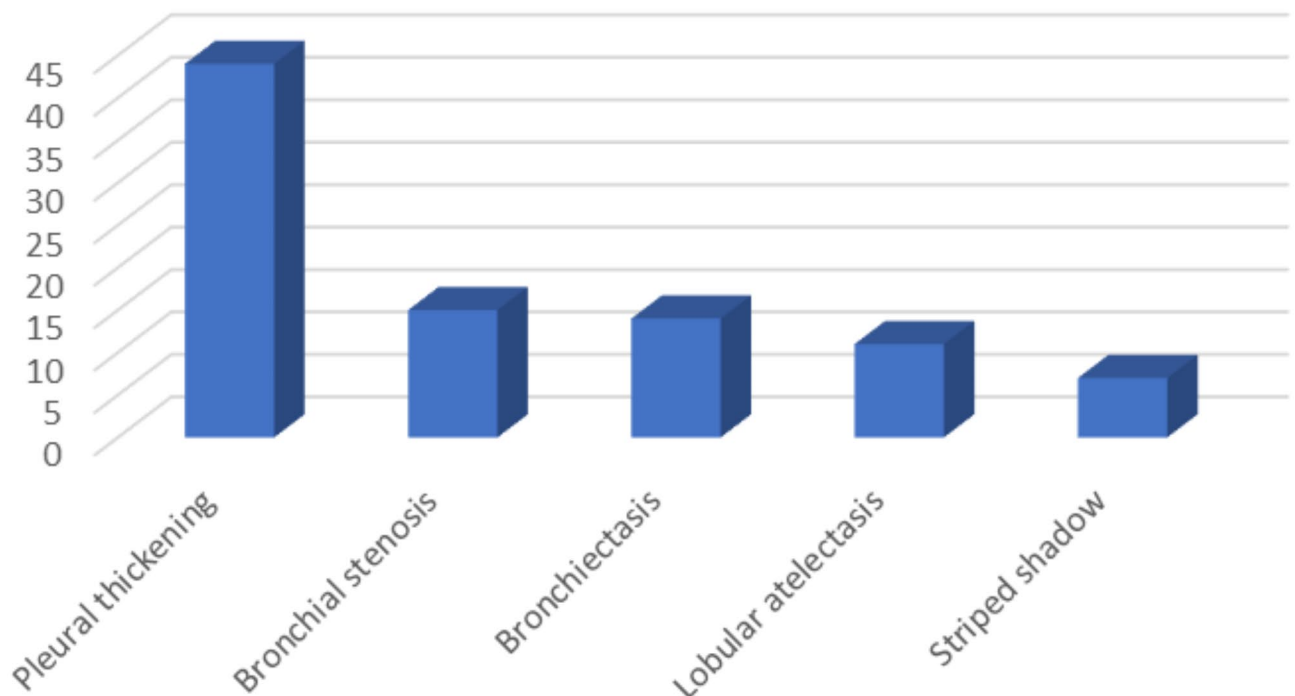


Fig. 1. Legacy symptoms.

is also concentrated in preschool-aged and school-aged children. We hypothesize that this may be related to the fact that bronchial development in preschool-aged and school-aged children is still imperfect and less resistant to pathogenic infections.

In this study, the number of days of fever was significantly greater in children in group B than in those in group A. Fever duration is a significant predictor in children with NP due to MP infection¹². The pathogenesis of MPP combined with NP is related not only to the direct injurious effects of MP and toxins on lung tissue but also to the secondary injurious effects caused by the large amount of inflammatory factors released by the body's immune-inflammatory response. It has also been hypothesized that the prolonged duration of fever may be related to further destruction of the solid areas of the lungs due to necrosis in children¹³. By combining the results of this study with the relevant literature, we hypothesize that the more extensive the lung necrosis is, the stronger the host immune-inflammatory response, which in turn is reflected in the prolonged duration of fever in the clinical manifestations.

In our study, the percentage of children in group A who experienced dyspnea was significantly lower than that in group B. Previous studies have shown that as necrotizing pneumonia progresses, the clinical manifestations of severe pneumonia, such as persistent high fever and respiratory distress, occur¹⁴. We consider that as the disease progresses more severely, the area of lung necrosis is more extensive, more lobes are involved, ventilation is more severely affected, and the child is more likely to develop dyspnea and other manifestations.

Summarizing and generalizing the chest CT manifestations and disease prognosis of children with NP due to MP infection will help clinicians deepen their understanding of this disease so that they can take appropriate therapeutic measures more immediately to improve the prognosis of these children and reduce the occurrence of complications. We summarized the chest imaging manifestations of 155 children and reported that the chest CT manifestations of this disease were dominated by the presence of necrosis in a single lobe of the lung, which accounted for 65.87% of the total cases, whereas areas of hypodensity were observed on enhanced CT (Fig. 2). Lung necrosis predominantly involves the lower lobes of the lungs, which is consistent with the findings of previous studies¹⁵. We believe that this finding is related to the anatomical structure of the lungs. As the disease progresses, a thin-walled cystic cavity shadow may appear in the area of necrosis. In the present study, 48.39% of the children presented with cystic cavities in the necrotic areas of the lungs. Previous studies have shown that the mechanism of lung parenchymal necrosis is an inflammatory reaction leading to thrombotic occlusion of pulmonary artery branches and alveolar capillaries, which in turn leads to ischemia and necrosis of the lung parenchyma, which manifests as an area of reduced enhancement on enhanced CT, which is in accordance with the findings of the present study¹⁵. Children with NP usually have severe and rapidly progressing disease, often accompanied by a variety of symptoms, such as pulmonary atelectasis, bronchoscopic changes, pleural effusion, fluid pneumothorax, and pleural thickening. In the present study, bronchoscopic changes occurred in 92.26% of the children. Most of the cases involved endobronchitis as well as bronchial sputum embolism caused by the MP infection itself. However,

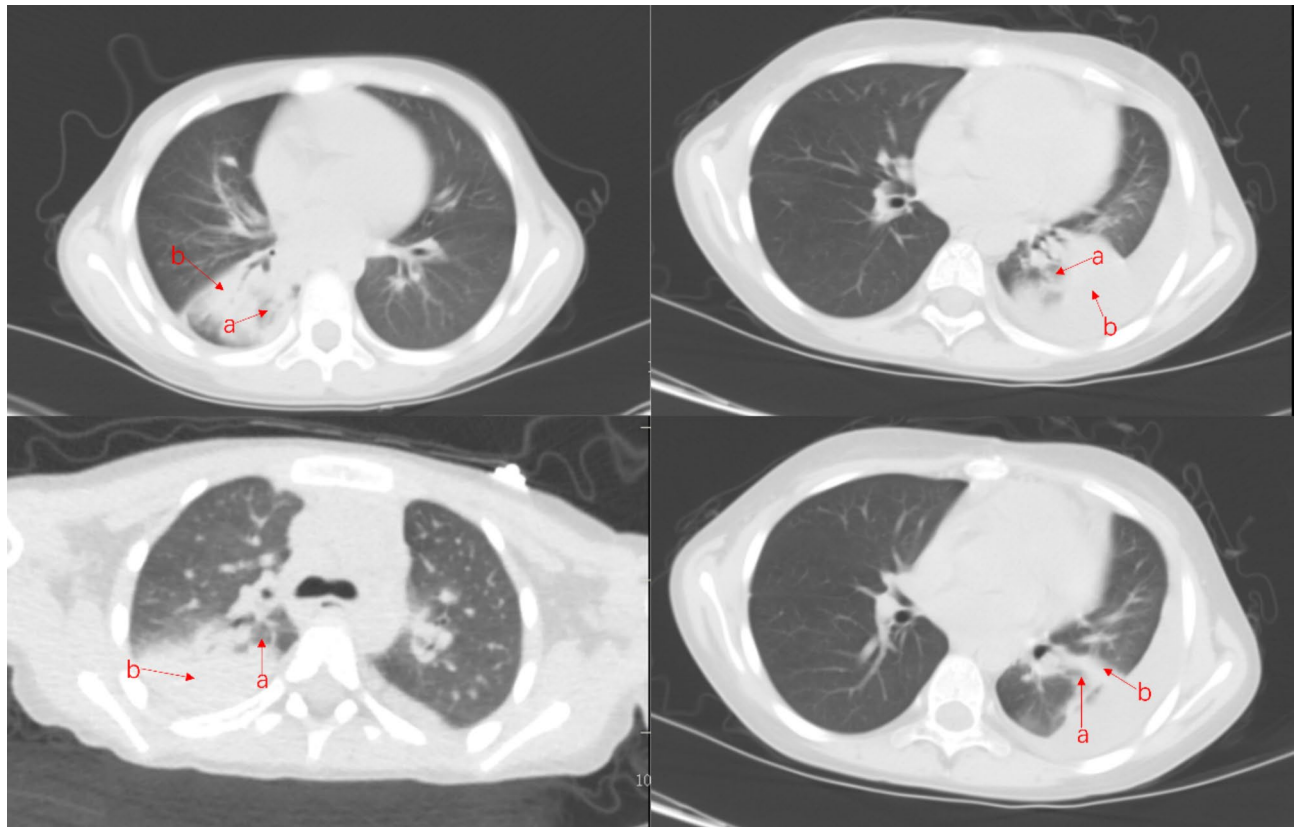


Fig. 2. CT manifestations of lung necrosis and solid lesions. The lower lobes of lungs showed large and patchy hyperdense shadows with blurred edges and bronchi fill with air and partial liquefaction and necrosis of the solid tissue in some of the shadows. (a) Arrows point to areas of necrotizing pneumonia. (b) Arrows point to areas of pulmonary solid lesions.

four of these children still developed occlusive bronchiolitis. Occlusive bronchiolitis obliterans (BO) is characterized by peripheral inflammation and fibrosis involving the small airways, leading to narrowing or complete obstruction of the airways¹⁶. The clinical presentation of patients with BO is irreversible airway obstruction. Although the occurrence of BO is very rare, it needs to be taken seriously by clinicians because of its irreversibility and the severity of the condition in most children, which manifests as severe bronchial obstruction and hypoxemia^{17,18}. In a study by Wang et al.¹⁹ most NPs caused by refractory *Mycoplasma pneumoniae* were accompanied by pleural effusion. In the present study, 40.65% of the children presented with pleural effusion, which is broadly in line with the findings of previous studies. Imaging of children with MPP combined with NP is generally complex and varied, and current diagnostic criteria for children with NP are still based on chest CT features²⁰. Therefore, understanding the chest CT manifestations of a child will help clinicians better recognize and diagnose them.

Fiberoptic bronchoscopy and alveolar lavage techniques are important tools in the diagnosis and management of children with NP. Pei et al. reported that the bronchoscopic alveolar lavage technique helps reduce local pathogenic microorganisms, promotes the excretion of inflammatory mediators from the lungs, removes sputum and mucus plugs at an early stage, reduces the incidence of luminal stenosis and occlusion, improves the lung ventilation function of children and promotes pulmonary reexpansion²¹. In the present study, 145 children were treated with bronchoscopic alveolar lavage, while the median number of bronchoscopic alveolar lavages was two. Previous studies have proposed that children with NP are often accompanied by severe bronchopathy and usually require 2 or more lavages, which is consistent with our findings²². In our study, more children in group B than children in group A underwent closed chest drainage, and the difference was statistically significant. Among the children with MPP combined with NP, 13 were treated with closed thoracic drainage, 8 of which were accompanied by pleural effusion. We hypothesize that children with large areas of pulmonary necrosis develop more severe pleural effusions, which often lead to respiratory distress and usually require closed thoracic drainage therapy to relieve compression. In this study, only one child with MPP combined with an NP underwent lobectomy, but there was no follow-up for this patient. Currently, with the increased understanding of the NP, in recent retrospective studies, the percentage of children with the NP undergoing lobectomy has decreased²³. Notably, the Guidelines for the Management of Childhood Mycoplasma Pneumonia (2023 Edition) also state that the majority of children with NP have favorable outcomes and do not require surgical resection of the lobes of the lungs¹⁰. However, there are still some children with MPP combined with NP who have poor outcomes and prolonged disease after anti-infective treatment and still undergo lobectomy. There is a lack of comparative studies on the efficacy of surgical treatment in children with MPP combined with NP, and prospective studies with large samples are needed to provide further

evidence-based support. Recovery after treatment in children with MPP combined with NP is related to the degree and extent of lung necrosis. Previous studies have indicated that although children with NP have a rapid and severe onset and a prolonged course of illness relative to common pneumonia, the majority of children with NP recover better than adults with NP do^{11,24}. Overall, most of the children in the two groups in this study improved clinically after active clinical treatment, and only some of them had residual abnormalities on lung imaging. NP caused by MP infection does not result in any residual cystic cavity in the lesion on chest CT review after treatment because of the small extent of necrosis and the cystic cavity, and a fibrous streak shadow remains in the necrotic area in only some cases. A small percentage of patients also have residual manifestations such as lobar atelectasis and bronchial wall changes such as bronchiectasis and bronchial stenosis.

This study has several limitations. First, the study had a small sample size and enrolled patients from a single center; thus, the results need to be further validated in larger samples and multicenter studies. Second, this was a retrospective study, and there may have been some bias in the selection of cases. Finally, fewer patients were followed up. In summary, chest CT in children with NP due to MP infection is characterized by necrosis of one or both lobes of the lungs and, in this study, mainly a single lobe. Areas of hypodensity are observed on enhanced CT. In severe cases, a thin-walled cystic cavity may develop in the necrotic area. Children tend to experience rapid progression, long disease duration, and slow absorption of lesions, often resulting in symptoms such as striated shadows, pleural thickening, lung atelectasis, and bronchial wall changes. Therefore, summarizing and generalizing the imaging characteristics of children with MPP combined with NP will help clinicians take corresponding measures in a more timely manner and improve the prognosis of these children.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Received: 18 November 2024; Accepted: 28 January 2025

Published online: 04 February 2025

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Author contributions

Jiapu Hou conceptualized the study, drafted the original manuscript, and reviewed and revised it. Ruiyang Sun provided medical records and participated in the revision of the manuscript. Xue Zhang provided medical records and participated in the revision of the manuscript. Wanyu Jia provided medical record information and reviewed and revised the manuscript. Peng Li provided medical records and participated in the revision of the manuscript. Chunlan Song conceptualized the study and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agreed to be responsible for all aspects of the work.

Funding

Provincial-Ministerial Joint Project of Medical Science and Technology Tackling Program in Henan Province (SB201903028). The Henan Provincial Science and Technology Research Project (LHGJ20240545).

Declarations

Competing interests

The authors declare no competing interests.

Ethics declarations

The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of Henan Children's Hospital (2022-K-L046) and individual consent for this retrospective analysis was waived.

Consent to publish

Informed consent was waived due to its retrospective nature. (Children's Hospital Affiliated to Zhengzhou University).

Additional information

Correspondence and requests for materials should be addressed to C.S.

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