



## Original Research

Chest imaging classification in *Mycoplasma pneumoniae* pneumonia is associated with its clinical features and outcomes

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## ABSTRACT

**Background:** The imaging findings of *Mycoplasma pneumoniae* pneumonia (MPP) vary; however, few studies have focused on the relationship of imaging classification with clinical manifestations and outcomes.

**Objective:** To prospectively investigate whether chest imaging classification in *Mycoplasma pneumoniae* pneumonia (MPP) is associated with its clinical features and outcomes.

**Methods:** A total of 1,401 hospitalized children with MPP were enrolled from January 2019 to December 2021. Imaging findings were categorized as bronchopneumonia and consolidation/atelectasis according to X-ray, and bronchopneumonia, consolidation/atelectasis, bronchiolitis, and mosaic pattern according to computed tomography (CT). Clinical characteristics and outcomes of patients with different imaging classifications were prospectively analyzed based on electronic medical records.

**Results:** Bronchopneumonia was the most common finding (59.6%), while consolidation/atelectasis was the most severe group. Clinical manifestations and laboratory indicators for the consolidation/atelectasis group included serious abnormalities. Further, outcomes of the patients were worse, including having longer total durations of fever and hospitalization, greater hospitalization expenses, and a higher likelihood of developing refractory MPP, necrotizing pneumonia, and bronchiolitis obliterans (BO) in this group. The incidence of bronchiolitis, a disease characterized by a high prevalence of fever, moist rales, and an atopic constitution, tended to increase after the coronavirus disease pandemic and predisposed patients to BO. A mosaic pattern occurred in allergic and young individuals, with wheezing as the main manifestation, with patients having relatively mild symptoms and good outcomes.

**Conclusion:** Different imaging classifications have different clinical features and clinical outcomes; thus, formulating an imaging-based classification system is of great clinical value.

## 1. Introduction

*Mycoplasma pneumoniae* (MP) is one of the most common pathogens of community acquired pneumonia (CAP) in children, accounting for 32.4% of cases of CAP in children aged 6 months to 14 years in China [1]. Although MP pneumonia (MPP) is generally considered a

self-limiting disease, it could trigger both internal and external pulmonary complications, progressing to refractory MPP (RMPP), necrotizing pneumonia (NP), bronchiolitis obliterans (BO), and even fatal pneumonia [2–5]. Early identification and treatment of these patients is important for preventing the development of poor prognosis.

Chest X-ray is the preferred imaging method for assessing CAP;

**Abbreviations:** ALT, alanine aminotransferase; APTT, activated partial thrombin time; BO, bronchiolitis obliterans; CAP, community-acquired pneumonia; CT, Computed tomography; CRP, C-reactive protein; ICU, intensive care unit; LDH, lactate dehydrogenase; MP, *Mycoplasma pneumoniae*; MPP, *Mycoplasma pneumoniae* pneumonia; NLR, neutrophil-to-lymphocyte ratio; NP, necrotizing pneumonia; PT, prothrombin time; RMPP, refractory *Mycoplasma pneumoniae* pneumonia; WBC, white blood cell.

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however, chest X-ray findings of MPP are not characteristic. Computed tomography (CT) allows visualization of pathologic changes in the lung parenchyma and interstitium, which could reveal diseased bronchioles with dilated lumen (more than 2 mm in diameter) or thickened walls, and correlates well with pathological findings [6,7]. Currently, MP-related BO has increasingly been reported; moreover, CT examination may be of value for assessing MPP.

Imaging findings of MPP vary and have been studied extensively [8–10]; however, few studies have focused on the relationship of imaging classification with clinical manifestations and outcomes. Few small sample studies have suggested the existence of a good correlation between the imaging classification and clinical features [11–13]. Homogeneous lobar consolidation and parapneumonic effusion were associated with fever duration of  $\geq 7$  days following the initiation of macrolides [11]. Consolidative lesions were frequently observed in older children and associated with more severe clinical features [12]. Leng et al. [13] analyzed the clinical information of 71 children with MPP, and found the severity of CT manifestations to be related to the pulmonary ventilation function in school children. However, these were retrospective studies with small sample sizes and did not consider outcomes, such as MPP-related BO or NP.

Therefore, we probed whether the chest imaging classification in MPP was associated with its clinical features and outcomes. Our study aimed to prospectively investigate the clinical characteristics and outcomes of different imaging classifications in children with MPP in a 3-year study cohort.

## 2. Methods

### 2.1. Study population

Patients with MPP who were hospitalized at the Department of Respiratory Medicine of Children's Hospital of Nanjing Medical University from January 1, 2019, to December 31, 2021, were enrolled in this cohort study. We prospectively collected information concerning the demographic information clinical features, chest imaging findings, laboratory findings, and clinical outcomes from electronic medical records. The study was approved by the research ethics committee of our institution (Approval number: 201812257-1) and the parents of all participating children provided written informed consent prior to inclusion in the study.

### 2.2. Inclusion and exclusion criteria

The following inclusion criteria were applied: (1) age  $\geq 28$  days and  $< 18$  years, (2) accompanied by fever and respiratory symptoms, (3) chest X-ray confirmed pneumonia, and (4) positive serologic test results (positive serum MP IgM, or seroconversion in paired sera) and positive MP polymerase chain reaction (DNA expansion increments  $\geq 1 \times 10^3$  copies/ml) results for nasopharyngeal extractions/sputum.

Patients meeting the following criteria were excluded: (1) patients with bronchopulmonary dysplasia, congenital heart diseases, immunodeficiency, or heredity neurological disorders; (2) patients with respiratory diseases, such as tuberculosis and bronchial asthma; (3) evidence of coinfection with other pathogens determined by virus testing, sputum culture, blood, alveolar lavage fluid, and pleural effusion culture; (4) patients with a disease course  $\geq 4$  weeks preadmission; (5) or incomplete clinical data.

### 2.3. Diagnostic tests for MP infection

Nasopharyngeal extractions/sputum aspirates were obtained within 24 h of admission. A quantitative MP DNA diagnostic kit (DaAn Gene, Guangzhou, China) was used to measure MP load. Chemiluminescence immunoassay kits (YHLO Biotech, Shenzhen, China) were used to identify serum IgM and IgG antibodies.

### 2.4. Data collection

All children underwent routine screening within 24h of admission, including peripheral white blood cell (WBC) count, neutrophil/lymphocyte ratio (NLR), C-reactive protein (CRP), nasopharyngeal extractions/sputum culture, MP DNA, nasopharyngeal extractions/sputum and blood respiratory etiology examination, levels of serum D-dimer, lactate dehydrogenase (LDH), alanine transaminase, aspartate aminotransferase. The age, sex, clinical symptoms, and signs, extrapulmonary complications, preadmission fever duration, total fever duration, allergic history, hospitalization days, and hospitalization expenses were recorded. A history of allergic diseases diagnosed and prescribed by a physician, including atopic dermatitis, drug and food allergies, allergic rhinitis, allergic dermatitis, and allergic conjunctivitis. Erythema was evaluated as any form of rash from onset to discharge.

CT was recommended when at least one of the following criteria was met: (1) the clinical manifestations were inconsistent with the chest radiography, (2) airway and lung malformations were suspected, (3) serious complications were associated with pneumonia, and (4) patients who failed to respond to treatment or had other diseases necessitating exclusion, such as interstitial lung disease and pulmonary tuberculosis [5,14,15].

Liver function damage was defined as an increase in alanine transaminase of more than double the usual level [5]. RMPP can be considered as MPP in patients treated with macrolides antibiotics for 7 days or more and have aggravated clinical signs and aggravated pulmonary imaging findings [5]. Diagnostic criteria for necrotizing pneumonia were as follows: multiple low-density areas, cystic bubbles, and air or liquid cavities were observed on chest CT, which fused into large cavities, and enhanced chest CT showing a reduced enhancement area, thin-walled cavity, and no edge enhancement [2,3]. BO diagnostic criteria were as follows: persistent or recurrent cough, wheezing, tachypnea, and decreased exercise intolerance for at least 6 weeks after MPP; extensive wheezing and moist crackles in both lungs; CT showing mosaic perfusion patterns, bronchiectasis or thickening of the bronchial wall; and lung function tests showing irreversible or fixed air obstruction. Patients with other diseases that causing chronic wheezing, such as cystic fibrosis and bronchopulmonary dysplasia were excluded [4].

### 2.5. Chest imaging classification

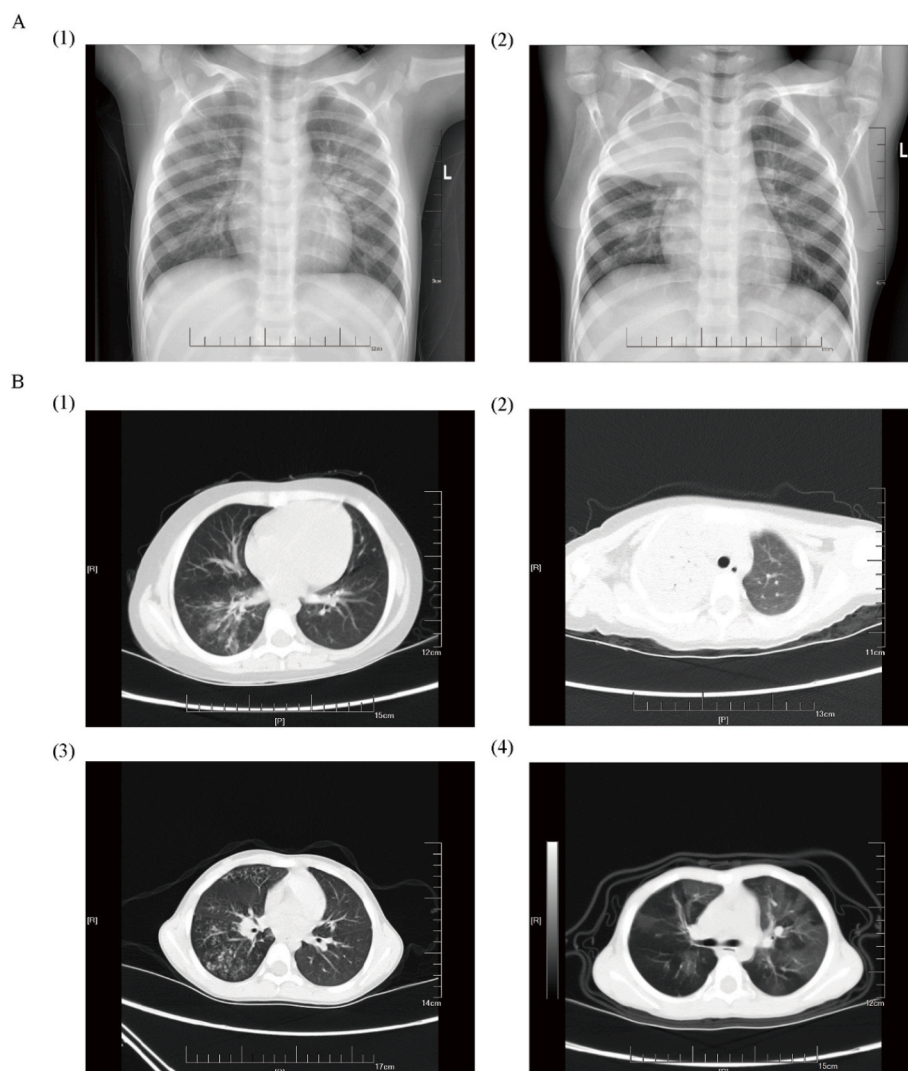
The chest imaging findings with the most serious manifestations were obtained 48 h before or after admission, and classified by two radiologists who reached a consensus before findings were finally categorized. For patients with multiple findings in a single chest image, the most dominant finding was selected for classification.

Classification based on X-ray findings was performed as described previously, with slight modifications [12]: bronchopneumonia and consolidation/atelectasis (Fig. 1A). Bronchopneumonia was defined as scattered localized patches with unclear boundaries in one lobe or both lungs. Consolidation/atelectasis was defined as homogenous dense opacity in at least one lobe, with or without an air-bronchogram in the lesion [12].

Based on features of CT images, patients were divided into the following four groups: bronchopneumonia, consolidation/atelectasis, bronchiolitis, and mosaic pattern (Fig. 1B). Typical imaging findings of bronchiolitis included centrilobular nodules, branching linear opacities (tree-in-bud pattern), and bronchiolar wall thickening. The mosaic pattern was characterized by mosaic-like regional air-trapping [7].

### 2.6. Clinical outcomes

All children were followed up until June 1, 2022. Data of outpatient and inpatient visits of children throughout follow-up were collected from electronic medical records. Follow-up data included the following: (1) short-term outcomes (total fever duration, whether oxygen was



**Fig. 1. Classification of X-ray and computed tomography (CT) findings of *Mycoplasma pneumoniae pneumonia* (MPP).** A. X-ray classification. (1) Bronchopneumonia: scattered localized patches with unclear boundaries in one lobe or both lungs. (2) Consolidation/atelectasis: homogenous dense opacity in at least one lobe, with or without an air-bronchogram in the lesion. B. CT classification. (1) Bronchopneumonia: scattered localized patches with unclear boundaries in one lobe or both lungs. (2) Consolidation/atelectasis: homogenous dense opacity in at least one lobe, with or without an air-bronchogram in the lesion. (3) Bronchiolitis: centrilobular nodules, branching linear opacities (tree-in-bud pattern), and bronchiolar wall thickening. (4) Mosaic pattern: multiple areas of mosaic-like regional air-trapping (hypoattenuation).

administered during admission, whether the patient was transferred to intensive care unit (ICU), length of stay, and hospitalization expenses; (2) long-term outcomes (clinical manifestations, lung signs, lung function, and chest CT showing the development of BO or NP).

## 2.7. Statistical analysis

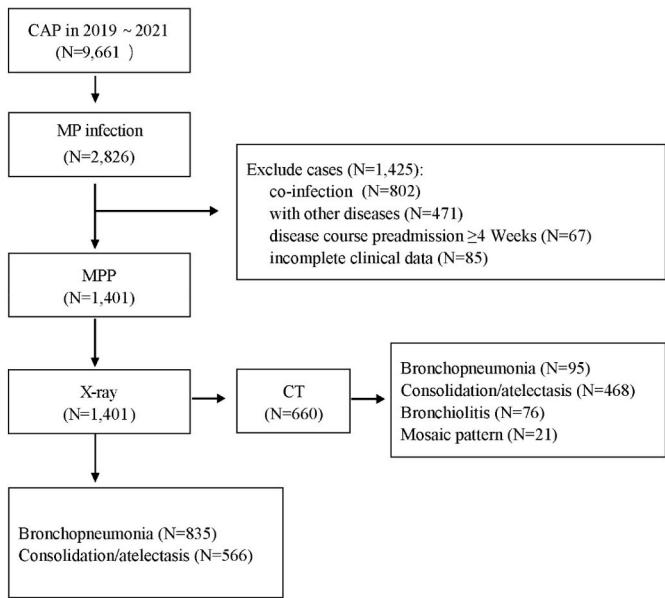
Statistical analyses were performed using SPSS 26.0 software. Normally distributed data are reported as mean  $\pm$  standard deviation. Data with a skewed distribution are presented as median values (25th–75th interquartile ranges). Groups were compared using a two-sample *t*-test, Mann-Whitney *U* test, or Kruskal-Wallis test. Categorical variables are expressed as frequencies and percentages. Chi-square, Fisher's exact tests, or the Bonferroni method were used to compare groups. Values of  $P < 0.05$  were considered significant for all tests.

## 3. Result

### 3.1. Participants and clinical characteristics

A total of 9,661 patients with CAP were included in the study, with 2,826 (29.3%) MP-DNA positive, and 1,401 patients with MPP were included in the final analysis. All the enrolled patients underwent X-ray examination, and 660 underwent chest CT examination. All the patients were classified according to the imaging findings. Both X-ray and CT were performed in 660 cases at different points in time and we analyzed the match between CT and x-ray (See [Supplementary Table 1](#)). A total of 203 cases were diagnosed as bronchopneumonia by X-ray. Due to the progression of the disease or the improvement of the resolution, of which 44.2% were later CT diagnosis of consolidation/atelectasis, bronchiolitis or mosaic pattern ([Supplementary Table 1](#)). A study flow chart is provided in [Fig. 2](#).

Demographic and baseline clinical characteristics of the 1,401 included patients are shown in [Table 1](#). The median age of patients with MPP was 5.3 years, and 817 (58.3%) were males. The number of CAP and MPP cases in 2020 and 2021 decreased as compared to 2019. The



**Fig. 2. Flowchart of the study.** CAP: community acquired pneumonia, MP: Mycoplasma pneumoniae, MPP: Mycoplasma pneumoniae pneumonia, CT: computed tomography.

**Table 1**  
Demographic and baseline clinical characteristics of the MPP cases.

Characteristics	MPP (N = 1,401)
Age (years)	5.3 (3.3–7.2)
Male/female	817/584
Year [Cases of MPP(MPP/CAP%)]	
2019	1,049 (23.5)
2020	102 (4.6)
2021	250 (8.4)
Fever, n (%)	1,230 (87.8)
Preadmission fever duration (d)	7.0 (5.0–9.0)
Erythema, n (%)	94 (6.7)
History of allergy, n (%)	193 (13.8)
Moist rale, n (%)	602 (43.0)
Wheeze, n (%)	273 (19.5)
CRP ≥ 10 mg/L	574 (41.0)
WBC ( × 10 <sup>9</sup> /L)	8.2 (6.6–10.6)
NLR	2.0 (1.3–3.2)
Hemoglobin (g/L)	125.0 (119.0–131.0)
Platelets ( × 10 <sup>9</sup> /L)	270.0 (207.0–341.0)
Liver function damage, n (%)	51 (3.7)
LDH (U/L)	333.0 (287.0–413.0)
PT (s)	12.3 (11.6–13.0)
APTT (s)	31.6 (28.7–34.4)
D-dimer (ng/ml)	236.0 (144.0–542.0)
Fibrinogen (g/L)	3.5 (3.0–4.0)
Pleural effusion, n (%)	205 (14.6)

Data with a skewed distribution are presented as median (interquartile range). Categorical variables are expressed as n (%) (N = 1,401). Abbreviations: MPP, *Mycoplasma pneumoniae* pneumonia; CRP, C-reactive protein; WBC, white blood cell; NLR, neutrophil-to-lymphocyte ratio; LDH, lactate dehydrogenase; PT, prothrombin time; APTT, activated partial thrombin time.

highest annual MPP/CAP rate was 23.5% in 2019, while the rate dropped to 4.6% in 2020 and 8.4% in 2021. Fever was the main symptom of MPP, with 87.8% of the children experiencing fever. The median time of preadmission fever duration was 7 days. The proportion of pulmonary signs, such as moist rales and wheezing, were 43.0% and 19.5%, respectively. Some patients had a history of allergic disease (13.8%) and extrapulmonary complications, such as erythema (6.7%), liver function damage (3.7%), and pleural effusion (14.6%).

3.2. Evaluation of chest X-ray image classification

3.2.1. Comparison of the clinical features

Based on X-ray findings, bronchopneumonia was most common (59.6%) based on the X-ray findings. Patients in the consolidation/atelectasis group were older than those in the bronchopneumonia group and had less moist rales and wheezing (39.6% vs. 45.3% and 11.5% vs. 24.9%, respectively), a lower proportion of allergic disease history (11.5% vs. 15.3%), higher rates of erythema and fever, and a longer preadmission fever duration (7 days vs. 6 days). Further, symptoms of patients in the bronchopneumonia group were more frequently accompanied by pleural effusion (32.5% vs. 2.5%) (all  $P < 0.05$ ). No significant sex distribution-based differences between groups were observed ( $P = 0.149$ ) (Table 2).

Median CRP, NLR, and LDH levels in the consolidation/atelectasis group were significantly higher than those in the bronchopneumonia group (all  $P < 0.05$ ). Meanwhile, the incidence of extrapulmonary complications, such as liver function damage, and higher levels of D-dimer, a marker of hypercoagulability, were increased in the consolidation/atelectasis group (all  $P < 0.05$ ) (Table 2).

3.2.2. Distribution of X-ray image classifications according to age

Of the 1,401 MPP cases considered, 72.5% were aged  $\geq 6$  years. An age-based distribution of X-ray image classifications is shown in Fig. 3A. Consolidation/atelectasis was more frequently observed in school-aged and preschool groups versus the infant group (55% vs. 39.6% vs. 22.1%, respectively,  $P < 0.001$ ).

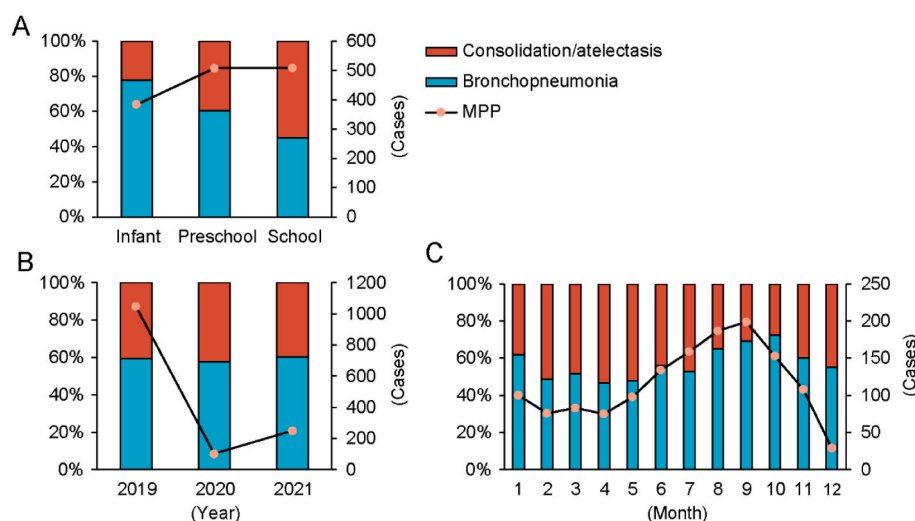
3.2.3. Distribution of X-ray image classifications according to year

Bronchopneumonia was the main X-ray manifestation observed during all years considered (59.6% in 2019, 57.8% in 2020, and 60.4%

**Table 2**  
Demographic and baseline clinical characteristics of the MPP cases with different X-ray image classifications.

Characteristics	Bronchopneumonia (N = 835)	Consolidation/atelectasis (N = 566)	P
Age (years)	4.4 (2.8–6.6)	6.1 (4.3–7.6)	<0.001
Male/female	500/335	317/239	0.149
Fever, n (%)	686 (82.2)	544 (96.1)	<0.001
Preadmission fever duration (d)	6.0 (4.0–7.0)	7.0 (5.3–10.0)	<0.001
Erythema, n (%)	40 (4.8)	54 (9.5)	<0.001
History of allergies, n (%)	128 (15.3)	65 (11.5)	0.040
Moist rale, n (%)	378 (45.3)	224 (39.6)	0.035
Wheeze, n (%)	208 (24.9)	65 (11.5)	<0.001
CRP ≥ 10 mg/L	250 (29.9)	324 (57.2)	<0.001
WBC ( × 10 <sup>9</sup> /L)	8.1 (6.6–10.2)	8.4 (6.6–11.0)	0.445
NLR	1.6 (1.1–2.5)	2.5 (1.6–4.1)	<0.001
Hemoglobin (g/L)	125.0 (119.0–132.0)	123.0 (117.0–130.0)	<0.001
Platelets ( × 10 <sup>9</sup> /L)	267.0 (208.0–334.0)	275.0 (206.0–347.5)	0.680
LDH (U/L)	320.0 (281.0–374.0)	360.5 (292.0–496.3)	<0.001
PT (s)	12.1 (11.5–12.8)	12.5 (11.7–13.3)	<0.001
APTT (s)	32.2 (29.5–35.0)	30.9 (27.9–33.8)	<0.001
D-dimer (ng/ml)	179.0 (122.0–267.0)	422.5 (192.3–1,135.0)	<0.001
Fibrinogen (g/L)	3.4 (2.9–3.9)	3.5 (3.0–4.0)	0.003
Liver function damage, n (%)	14 (1.7)	37 (6.6)	<0.001
Pleural effusion, n (%)	21 (2.5)	184 (32.5)	<0.001

Data are presented as median (interquartile range) or n (%) (N = 1,401). Mann-Whitney  $U$  test was used to compare nonnormally distributed continuous variables and Chi-square test was used to compare categorical variables between the two groups. Abbreviations: MPP, *Mycoplasma pneumoniae* pneumonia; CRP, C-reactive protein; WBC, white blood cell; NLR, neutrophil-to-lymphocyte ratio; LDH, lactate dehydrogenase; PT, prothrombin time; APTT, activated partial thrombin time.



**Fig. 3.** The distribution of X-ray image classifications of MPP according to age, year, and month ( $N = 1,401$ ). A. The distribution of X-ray image classifications according to age. Infant:  $< 3$  years old, preschool age:  $\leq 3 \sim < 6$  years old, school age:  $\geq 6$  years old. B. The distribution of X-ray image classifications according to the year ( $P = 0.906$ ). C. The distribution of X-ray image classifications according to the month ( $P < 0.001$ ). MPP: Mycoplasma pneumoniae pneumonia. Chi-square test was used to compare categorical variables between the two groups.

in 2021). There were no significant differences in chest X-ray image classifications among MPP cases ( $P = 0.906$ ) (Fig. 3B).

### 3.2.4. Distribution of X-ray image classifications according to month

The number cases of MPP peaked from July to October, accounting for 49.8% of the total MPP cases considered; however, consolidation/atelectasis was most frequently observed from December to May (Fig. 3C).

### 3.2.5. Clinical outcomes of X-ray classifications

In contrast to bronchopneumonia, the consolidation/atelectasis group had a higher proportion of refractory cases, ICU admissions, and patients undergoing oxygen therapy; significantly longer total fever duration and hospital stay; greater hospital expenses; and was more prone to NP (all  $P < 0.001$ ). No differences were observed between the X-ray classification groups regarding the development of BO ( $P = 0.309$ ) (Table 3).

## 3.3. Evaluation of chest CT image classifications

A total of 660 (47.1%) patients underwent chest CT examination, including 381 males and 279 females. The median age of all patients undergoing chest CT was 5.8 years. Consolidation/atelectasis was the most common finding (70.9%), followed by bronchopneumonia (14.4%), bronchiolitis (11.5%), and mosaic pattern (3.2%).

### 3.3.1. Comparison of clinical features

Patients in the consolidation/atelectasis group were the oldest compared to those in the other groups (median age: 6 years) and had the highest proportion of fever, longest preadmission fever duration, and least wheezing and moist rales (all  $P < 0.05$ ). Higher CRP, NLR, and LDH levels and more complications, including erythema, liver damage, pleural effusion, and hypercoagulability, were observed in the consolidation/atelectasis group versus other groups (Table 4). The bronchiolitis group was characterized by a high proportion of fever (90.8%) and long preadmission fever duration (6.5 days), second only to the consolidation/atelectasis group. Higher proportions of allergic disease history and moist rales were observed in this group compared to those in the consolidation/atelectasis group (27.6% vs. 11.3%,  $P < 0.05$ ; 86.6% vs. 38.9%,  $P < 0.05$ , respectively). Patients in the mosaic pattern group were the oldest compared to those in the other groups (median age: 2.3 years) and had the highest proportion of wheezing (66.7%) and allergic disease history (38.1%), the smallest proportion of fever (61.9%), and the shortest preadmission fever duration (4.5 days) versus those in other groups (Table 4).

### 3.3.2. Distribution of CT image classifications according to age

Consolidation/atelectasis was observed more frequently in the preschool and school age groups than in the infant group (73.5% vs. 46.5%,  $P < 0.05$ ; 80.7% vs. 46.5%, respectively,  $P < 0.05$ , respectively); however, there was no significant difference between the preschool and

**Table 3**  
Outcomes of the MPP cases with different X-ray image classifications.

Characteristics	Total ( $N = 1,401$ )	Bronchopneumonia ( $N = 835$ )	Consolidation/atelectasis ( $N = 566$ )	$P$
RMPP, n (%)	370 (26.4)	58 (6.9)	312 (55.1)	$<0.001$
ICU, n (%)	18 (1.3)	3 (0.4)	15 (2.7)	$<0.001$
Oxygen therapy, n (%)	58 (4.1)	17 (2.0)	41 (7.2)	$<0.001$
Total fever duration (d)	7 (5–10)	6 (4–8)	9 (6–10)	$<0.001$
Length of hospital stay (d)	7 (6–9)	7 (6–8)	8 (7–10)	$<0.001$
Hospitalization expenses (CNY)	7,382.9(7,382.9–10,706.7)	6541.5 (5,423.6–8,126.5)	9979.1 (7,294.0–13,638.9)	$<0.001$
NP, n (%)	30 (2.1)	1 (0.1)	29 (5.1)	$<0.001$
BO, n (%)	4 (0.3)	1 (0.1)	3 (0.5)	0.309

Data are presented as median (interquartile range) or n (%).

Mann-Whitney  $U$  test was used to compare nonnormally distributed continuous variables and Chi-square test or Fisher's exact tests was used to compare categorical variables between the two groups.

Abbreviations: MPP, *Mycoplasma pneumoniae* pneumonia; RMPP, refractory *Mycoplasma pneumoniae* pneumonia; ICU, intensive care unit; CNY, China Yuan; NP, necrotizing pneumonia; BO, bronchiolitis obliterans.

**Table 4**  
Demographic and baseline clinical characteristics of the MPP cases with different CT image classifications.

Characteristics	Bronchopneumonia N = 95	Consolidation/atelectasis N = 468	Bronchiolitis N = 76	Mosaic pattern N = 21	P
Age (years)	4.5 (2.6–6.6) <sup>bcd</sup>	6.0 (4.2–7.6) <sup>acd</sup>	4.7 (2.9–7.3) <sup>abd</sup>	2.3 (1.8–3.1) <sup>a b c</sup>	<0.001
Male/female	56/39	262/206	47/29	16/5	0.252
Fever, n (%)	68 (71.6) <sup>b c</sup>	450 (96.2) <sup>ad</sup>	69 (90.8) <sup>ad</sup>	13 (61.9) <sup>bc</sup>	<0.001
Preadmission fever duration(d)	6 (2–7) <sup>b c</sup>	7 (6–10) <sup>a c d</sup>	6.5 (4–9) <sup>a b d</sup>	4.5 (0–8) <sup>b c</sup>	<0.001
Erythema, n (%)	3 (3.2)	49 (10.5)	3 (3.9)	1 (4.8)	0.038
History of allergies, n (%)	14 (14.7)	53 (11.3) <sup>cd</sup>	21 (27.6) <sup>b</sup>	8 (38.1) <sup>b</sup>	0.002
Moist rale, n (%)	38 (40.0) <sup>c</sup>	182 (38.9) <sup>c</sup>	66 (86.8) <sup>ab</sup>	13 (61.9)	<0.001
Wheeze, n (%)	32 (33.7) <sup>bd</sup>	46 (9.8) <sup>a c d</sup>	20 (26.3) <sup>bd</sup>	14 (66.7) <sup>a b c</sup>	<0.001
CRP≥10 mg/L	28 (29.5) <sup>b</sup>	257 (54.9) <sup>ad</sup>	31 (40.8)	4 (19.0) <sup>b</sup>	<0.001
WBC (× 10 <sup>9</sup> /L)	8.2 (6.7–10.7)	8.5 (6.6–11.3)	8.1 (6.3–9.1)	9.6 (6.9–14.8)	0.483
NLR	1.6 (1.1–2.5) <sup>b c</sup>	2.6 (1.6–4.3) <sup>a c d</sup>	1.9 (1.2–3.3) <sup>abd</sup>	1.4 (1.2–1.7) <sup>bc</sup>	<0.001
Hemoglobin (g/L)	124.0 (117.0–133.0)	123.0 (116.0–129.0)	126.0 (117.8–132.5)	125.0 (119.5–132.5)	0.053
Platelets (× 10 <sup>3</sup> /L)	268.5 (209.8–329.3)	279.5 (212.0–357.0)	249.0 (186.5–318.5)	320.0 (236.0–421.3)	0.108
LDH (U/L)	320.0 (287.8–362.3) <sup>b</sup>	374.5 (292.0–521.0) <sup>ac</sup>	326.0 (295.5–389.3) <sup>b</sup>	343.0 (293.8–374.8)	<0.001
PT (s)	12.2 (11.2–12.9)	12.4 (11.6,13.2)	12.5 (11.7,13.2)	11.8 (11.4,12.4)	0.256
APTT (s)	32.0 (29.9–34.2) <sup>bd</sup>	30.7 (27.5–33.9) <sup>acd</sup>	32.6 (29.8–35.8) <sup>bd</sup>	29.1 (26.3–30.2) <sup>abc</sup>	<0.001
D-dimer (ng/ml)	177 (130.0–265.3) <sup>b</sup>	481 (207.5–1,271.3) <sup>acd</sup>	232.5 (150–354) <sup>b</sup>	185.5 (134–254) <sup>b</sup>	<0.001
Fibrinogen (g/L)	3.4 (3.0–3.9)	3.5 (2.9–4.0)	3.6 (3.1–3.9)	3.6 (2.5–4.1)	0.795
Liver function damage, n (%)	0 <sup>b</sup>	36 (7.7) <sup>a</sup>	1 (1.3)	0	0.002
Pleural effusion, n (%)	0 <sup>b</sup>	169 (36.1) <sup>a</sup>	0 <sup>b</sup>	0 <sup>b</sup>	<0.001

Data are presented as median (interquartile range) or n (%) (N = 660). Mann-Whitney *U* test, or Kruskal-Wallis test was used to compare nonnormally distributed continuous variables and Chi-square, Fisher’s exact test, or the Bonferroni method was used to compare categorical variables between the groups. Abbreviations: MPP, *Mycoplasma pneumoniae* pneumonia; CRP, C-reactive protein; WBC, white blood cell; NLR, neutrophil-to-lymphocyte ratio; LDH, lactate dehydrogenase; PT, prothrombin time; APTT, activated partial thrombin time. <sup>a</sup> compared with bronchopneumonia group, *P* < 0.05, <sup>b</sup> compared with consolidation/atelectasis group, *P* < 0.05, <sup>c</sup> compared with bronchiolitis group, *P* < 0.05, <sup>d</sup> compared with mosaic pattern group, *P* < 0.05.

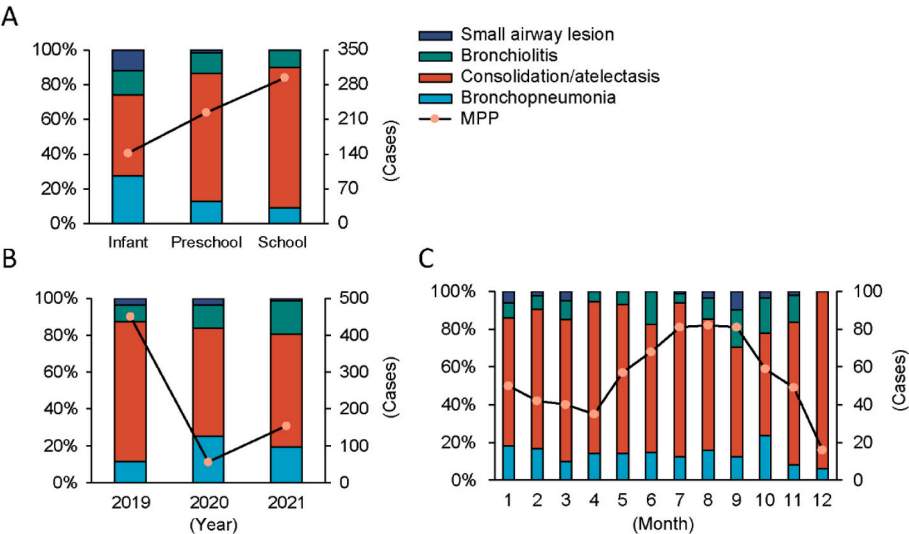
school age groups. No significant difference in the distribution of bronchiolitis was observed among the groups considered (*P* ≥ 0.05). The proportion of mosaic pattern in the infant group was higher than that in the other two groups, and gradually decreased as age increased (12.0% vs. 1.8% vs. 0, respectively, all *P* < 0.05) (Fig. 4A).

**3.3.3. Distribution of CT image classifications according to year**  
The proportion of consolidation/atelectasis in 2020 and 2021 were lower than that of 2019 (73.5% vs. 46.5%, *P* < 0.05; 80.7% vs. 46.5%, respectively, *P* < 0.05), while bronchiolitis showed an increasing trend from 2019 to 2021, and the number of cases in 2021 was double that in 2019 (18.2% vs. 9.1%, respectively, *P* < 0.05). There was no significant

difference in the proportion of patients with mosaic patterns observed among the three years considered (*P* ≥ 0.05) (Fig. 4B).

**3.3.4. Distribution of CT image classifications according to month**  
Consistent with the X-ray findings, more MPP cases were observed in summer and autumn than other months (July to October); however, a higher proportion of consolidation/atelectasis was observed in winter and spring (December to May) (Fig. 4C).

**3.3.5. Clinical outcomes of the CT classifications**  
As compared with other groups, the consolidation/atelectasis group had the highest proportion of RMPP, NP, and BO, longest total fever



**Fig. 4.** The distribution of CT image classifications of MPP according to age, year, and month (N = 660). A. The distribution of CT image classifications according to age. Infant: < 3 years old, preschool age: ≤ 3 ~ < 6 years old, school age: ≥ 6 years old. B. The distribution of CT image classifications according to the year (*P* = 0.906). C. The distribution of CT image classifications according to the month (*P* < 0.001). MPP: *Mycoplasma pneumoniae* pneumonia. Chi-square was used to compare categorical variables between the groups.

time, and greatest hospital expenses. Bronchiolitis may also progress to BO (Table 5). Representative cases are shown in Supplementary Figure 1 and Supplementary Figure 2. The bronchopneumonia and mosaic pattern groups had a relatively good prognosis than consolidation/atelectasis and bronchiolitis groups.

#### 4. Discussion

In the present study, we prospectively investigated the association of the chest imaging findings with the clinical features and outcomes in 1,401 patients with MPP who were hospitalized in our department from 2019 to 2021. Imaging findings were categorized as bronchopneumonia and consolidation/atelectasis according to X-ray, and bronchopneumonia, consolidation/atelectasis, bronchiolitis, and mosaic pattern according to CT. Of all the imaging classifications, bronchopneumonia was the most common findings, while consolidation/atelectasis was the most severe group, which was prone to RMPP, NP, and BO, followed by bronchiolitis. Moreover, bronchiolitis incidence showed an increasing trend after the coronavirus disease (COVID-19) outbreak.

MPP occurs endemically worldwide in many different climates and tends to be most common in summer or early fall [16,17]. Consistent with this finding, the detection rate of MP in our study was 29.3% and peaked from July to October. However, consolidation/atelectasis was more frequent in winter and spring; thus, more severe cases were observed in these months. Nevertheless, there was a substantial decrease in incidence since 2020, which was maintained at a relatively low level afterwards; this was consistent with findings of a global multi-center study and several native multi-center studies [17–19]. This finding could be partly attributable to the COVID-19 pandemic, which effectively controlled the transmission of MP [17]. Therefore, as the COVID-19 progresses, MPP may reveal new epidemiological characteristics and manifest as specific imaging changes.

Consolidation/atelectasis was most severe, with persistent fever, multiple internal and external pulmonary complications, and high inflammatory indicators, such as high CRP, NLR, and LDH levels, representative of a stronger systemic inflammatory response in this group [5, 16,20,21]. Children in this group were older than those in other groups, which may indicate that older children had a stronger systemic immune inflammatory response than younger children [20,21]. Serum D-dimer, as a specific marker of fibrinolysis, reflected the capacity to dissolve fibrin, with increasing evidence suggesting that the coagulation function was closely related to the inflammatory response [20,22]. High D-dimer levels may be an independent risk factor for RMPP and NP [20,23]. Collectively, these findings suggest that an excessive host immune response plays an important role in the pathogenesis of consolidation/atelectasis; thus, glucocorticoid administration could be an

effective treatment option for this group [21].

Although the X-ray-based bronchopneumonia group included patients with relatively good clinical presentations and outcomes, confirmation of bronchopneumonia or bronchiolitis using chest X-ray was challenging. MP bronchiolitis has been increasingly reported, and may develop BO [24,25]. Of the 660 patients with MPP who required CT examination, 11.5% presented with bronchiolitis changes. Children in this group presented with allergic history, persistent fever, and lung moist rales, and were prone to hypoxia. Zhao et al. [25] retrospectively reviewed 17 patients with BO following MP infection revealing that all patients had acute bronchiolitis prior to BO. Most of the patients had positive allergen test results and personal and/or family histories of atopic disease, findings with which those of our study are consistent. Therefore, MP bronchiolitis might be associated with an atopic constitution [24,25]. Considering the significantly elevated inflammatory indicators in this group, we assume that airway epithelial injury caused by an excessive inflammatory response may also play an important role in bronchiolitis; therefore, glucocorticoid administration may also benefit these patients. Therefore, early chest CT examination and early treatment with glucocorticoids may be considered in some children with persistent fever, moist rales, an atopic constitution, and an oxygen therapy requirement. However, the potential risks of radiation should be carefully evaluated.

Mosaic pattern secondary to air trapping is also a manifestations of small airway lesions but is not specific to this condition. Extensive air trapping may also be observed in hypersensitivity pneumonitis as well as interstitial lung diseases [7,26,27]. In our study, the clinical features and outcomes of this group were significantly different from those in the bronchiolitis group. The children in this group were younger (median age: 2.3 years), with a low incidence of fever, a short duration of fever, had wheezing as the main manifestation, low levels of inflammatory indicators, and an uneventful course. Therefore, we speculated that this could be related to the tapering of the airway lumen owing to bronchiolar wall edema and increased secretions and cellular debris, which was similar to the pathogenesis of acute bronchiolitis induced by viral infection [28]. With the removal of secretions and regression of wall edema, the symptoms improved and fewer sequelae were observed. In a prospective study of 100 adult survivors of COVID-19, mosaic pattern was quantified on expiratory chest CT images and correlated with the lung volume measurements [29]. However, the acquisition of expiratory CT images and quantification of the mosaic pattern were challenging owing to the inability to maintain exhalation in children. Therefore, further research is warranted to explore the long-term effects of the mosaic pattern on pulmonary function in children.

**Table 5**  
Outcomes of the MPP cases with different CT image classifications.

	Bronchopneumonia N = 95	Consolidation/atelectasis N = 468	Bronchiolitis N = 76	Mosaic pattern N = 21	P
RMPP, n (%)	10 (10.5) <sup>bc</sup>	287 (61.3) <sup>acd</sup>	23 (30.3) <sup>ab</sup>	3 (14.3) <sup>b</sup>	<0.001
ICU, n (%)	0	16 (3.4)	2 (2.6)	0	0.309
Oxygen therapy, n (%)	4 (4.2)	39 (8.3)	9 (11.8)	1 (4.8)	0.306
Total fever duration (d)	6.0 (2.0–8.0) <sup>bc</sup>	9.0 (6.0–10.8) <sup>acd</sup>	7.0 (5.0–9.3) <sup>abd</sup>	4.5 (0–8.3) <sup>bc</sup>	<0.001
Length of hospital stay (d)	7.0 (6.0–9.0) <sup>bc</sup>	8.0 (7.0–11.0) <sup>a d</sup>	8.5 (7.0–10.0) <sup>a d</sup>	7.0 (6.0–9.0) <sup>bc</sup>	<0.001
Hospitalization expenses (CNY)	7,108.7 (5,960.6–9,308.5) <sup>bc</sup>	10,941.7 (7,680.1–14,502.6) <sup>acd</sup>	8,729.3 (7,125.9–12,839.2) <sup>abd</sup>	7,682.8 (5,666.7–11,488.3) <sup>bc</sup>	<0.001
NP, n (%)	0	30 (6.4)	0	0	0.002
BO, n (%)	0	3 (0.6)	1 (1.3)	0	0.717

Data are presented as median (interquartile range) or n (%) (N = 660).

Mann-Whitney U test, or Kruskal-Wallis test was used to compare nonnormally distributed continuous variables and Chi-square, Fisher's exact test, or the Bonferroni method was used to compare categorical variables between the groups.

Abbreviations: MPP, *Mycoplasma pneumoniae* pneumonia; RMPP, refractory *Mycoplasma pneumoniae* pneumonia; ICU, intensive care unit; CNY, China Yuan; NP, necrotizing pneumonia; BO, bronchiolitis obliterans.

<sup>a</sup> compared with bronchopneumonia group,  $P < 0.05$ , <sup>b</sup> compared with consolidation/atelectasis group,  $P < 0.05$ , <sup>c</sup> compared with bronchiolitis group,  $P < 0.05$ ,

<sup>d</sup> compared with mosaic pattern group,  $P < 0.05$ .

## 5. Conclusions

In conclusion, chest X-ray and CT findings can be considered important reference indicators for the diagnosis and prognosis of MPP. Each chest imaging classification has distinct clinical characteristics, and associated short- and long-term prognoses are relatively poor in consolidation/atelectasis, followed by bronchiolitis. Different imaging classifications have different clinical features and clinical outcomes; thus, formulating an imaging-based classification is of great clinical value.

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## Data availability statement

The raw data is available upon reasonable request from the corresponding authors.

## CRediT authorship contribution statement

**Xia Huang:** Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **Haiyan Gu:** Data curation, Formal analysis, Funding acquisition, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Ruxi Wu:** Data curation, Investigation. **Lei Chen:** Data curation, Investigation. **Tian Lv:** Data curation, Investigation. **Xinyi Jiang:** Data curation, Investigation. **Huili Li:** Data curation, Investigation. **Bin Guo:** Investigation, Methodology. **Jie Liu:** Investigation, Methodology. **Dan Li:** Data curation. **Deyu Zhao:** Conceptualization, Funding acquisition, Supervision. **Feng Liu:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

## Declaration of competing interest

None.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.rmed.2023.107480>.

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