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Factors Associated with Missed Detection of Tracheobronchial Foreign Bodies on Computed Tomography in Children: A Retrospective Study of Bronchoscopically Confirmed Cases

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Abstract

Background: Tracheobronchial foreign body (TFB) is a common and life-threatening pediatric emergency. Computed tomography (CT) is widely used in children with suspected tracheobronchial foreign body (TFB), yet some cases with bronchoscopically confirmed TFB still show negative CT findings. This study aimed to investigate factors associated with missed CT detection of TFB in children with bronchoscopically confirmed cases.

Methods: We retrospectively analyzed 951 children with bronchoscopically confirmed TFB. CT detection versus missed detection was defined based on original radiology reports. Data on age, sex, foreign body location, duration of aspiration, definite aspiration history, presence of granulation tissue on bronchoscopy, and concomitant imaging findings were collected. Three independent multivariable binary logistic regression models with different codings of concomitant imaging findings (presence/absence, number, pathological mechanism type) were constructed. Collinearity was assessed using variance inflation factor, and bootstrap internal validation was performed.

Results: The missed detection rate was 8.6% (82/951). Absence of a definite aspiration history was the most robust independent factor (odds ratio [OR] range 2.70–2.87 across three models, all $P \leq 0.001$). The highest risk of missed detection was observed in children aged 3-6 years (mean OR 4.76), followed by foreign body location in the trachea/carina/glottis (mean OR 4.19), right bronchus (OR≈2.0), and age 1-3 years (mean OR 1.95). Concomitant imaging findings showed heterogeneous associations: mixed-type findings (OR= 4.27, $P=0.018$) and a single type of finding (OR=2.62, $P=0.021$) significantly increased the risk, whereas purely obstructive/masking findings or the presence of two or more types did not. Duration of aspiration and granulation tissue on bronchoscopy were not independently associated with missed detection.

Conclusions: Absence of a definite aspiration history, age 3-6 years or 1-3 years, and foreign body location in the trachea/carina/glottis or right bronchus are independent risk factors for missed CT detection of TFB in children. Mixed or solitary concomitant imaging findings also increase missed detection risk, whereas purely obstructive changes or multiple findings do not. For children with these characteristics but negative CT findings, high clinical suspicion should be maintained, and timely bronchoscopy should be considered.

I. Introduction

Tracheobronchial foreign body (TFB) is a common acute and critical condition in children and one of the important causes of death related to pediatric accidental injuries. Timely and accurate diagnosis and removal of the foreign body are crucial for reducing the incidence of complications and mortality[1]. Computed tomography (CT), with its high spatial resolution and powerful image post-processing capabilities, has become an important non-invasive imaging adjunct when TFB is highly suspected clinically. CT not only clearly displays the location, size, and secondary pulmonary changes of the foreign body but also presents its shape and anatomical relationship with the airway from multiple angles through three-dimensional reconstruction, providing important guidance for bronchoscopic surgical approaches and thereby improving the efficiency and safety of the procedure [2,3].

Multiple studies have confirmed that CT has excellent diagnostic performance for suspected TFB, with sensitivity of 91%-100%, specificity of 92%-100%, and both positive and negative predictive values at high levels[4-6]. However, even among children with bronchoscopically confirmed TFB, some still have false-negative preoperative CT findings, i.e., missed detection. A meta-analysis by Goodarzy et al[7]. further pointed out that significant heterogeneity exists among existing studies, and factors such as absence of a history of foreign body aspiration, differences in radiologists' experience, and different CT scanning protocols are important sources affecting diagnostic accuracy.

Nevertheless, the specific key factors leading to missed detection on CT have not been systematically elucidated. In addition, the available literature suggests that prolonged duration of aspiration, coexisting extensive pulmonary infection, and the material and shape of the foreign body may be associated with missed CT detection[2]; however, most of these are single-factor analyses lacking systematic exploration. Critically, previous studies have not simultaneously evaluated the interactions among clinical characteristics (e.g., aspiration history), foreign body properties (e.g., location), and imaging findings (e.g., complication types), nor have they employed multi-model cross-validation, thus providing limited clinical guidance.

International guidelines have reached a consensus on the imaging pathway for suspected TFB in children: the American College of Radiology (ACR) Appropriateness Criteria state that chest radiography is the initial screening tool, low-dose chest CT is indicated when chest radiography is negative but clinical suspicion remains high, and bronchoscopy remains the diagnostic gold standard[8]. The European Society of Paediatric Radiology (ESPR) emphasizes that CT in children should strictly follow the ALARA principle using low-dose protocols[9]. However, these guidelines do not identify the key risk factors for missed CT detection in bronchoscopically confirmed populations, nor do they provide mechanism-based classification or risk stratification of concomitant imaging findings. Consequently, there is still a lack of evidence-based guidance for the identification and management of patients at high risk of missed diagnosis on CT. Based on this, the present study retrospectively analyzed clinical data from 951 children with bronchoscopically confirmed TFB. With strictly defined criteria for CT detection versus missed detection, three binary logistic regression models with different definitions of concomitant imaging findings were constructed to systematically evaluate factors associated with missed CT detection in bronchoscopically confirmed cases. The aim is to provide evidence-based support for optimizing CT diagnostic strategies, improving the targeted interpretation of imaging results, and offering a reference for identifying cases at high risk of missed detection.

2. Materials and Methods

2.1 Study design and setting

This was a single-center, retrospective cohort study conducted at the Department of Pediatric Respiratory Medicine, Gansu Provincial Maternal and Child-care Hospital (Gansu Provincial Central Hospital), Lanzhou, China. The study aimed to investigate factors associated with missed detection of tracheobronchial foreign bodies (TFB) on computed tomography (CT) in children with bronchoscopically confirmed TFB.

2.2 Participants

We retrospectively collected clinical data of 951 children who attended our department between January 2017 and December 2021 and were diagnosed with TFB by bronchoscopy.

Inclusion criteria: (1) age ≤ 12 years; (2) bronchoscopic identification and successful removal of an airway foreign body; (3) low-dose CT scan covering from the larynx (glottic region) to the lung bases completed within 1 week before the procedure; (4) complete clinical data, imaging data, and bronchoscopy records.

Exclusion criteria: (1) failure to complete the specified range of CT scan before the procedure; (2) missing key variables such as duration of foreign body aspiration, definite history of aspiration, or concomitant imaging findings; (3) coexisting primary respiratory diseases that might interfere with CT interpretation, such as congenital airway malformations or pulmonary tumors.

2.3 Variable definitions and data collection

2.3.1 Grouping Criteria

Children were divided into a CT-detected group and a CT-missed group based on whether the preoperative original CT report showed direct signs of TFB. All CT reports were issued by radiologists in our hospital with at least 5 years of experience in pediatric chest imaging during routine clinical work. To minimize information extraction bias, two researchers with experience in pediatric clinical research (who did not participate in image interpretation and were blinded to bronchoscopy results when extracting CT report conclusions) independently extracted the CT report conclusions from the electronic medical record system. Disagreements were resolved through group discussion. Cases that still could not reach a consensus were excluded.

CT-detected group: The original CT report clearly described direct signs of a foreign body, such as"foreign body in the trachea/bronchus,""intraluminal hyperdense shadow," or "irregular space-occupying lesion."For reports with non-definitive descriptions such as "suspected foreign body" or "cannot rule out a foreign body," the research team made a post-hoc determination based on bronchoscopic findings: if bronchoscopy confirmed the presence of a foreign body in the corresponding location, the case was assigned to the CT-detected group; if no foreign body was confirmed, the case was excluded. This post-hoc classification may introduce verification bias, as detailed in the Limitations section of the Discussion.

CT-missed group

The original CT report did not mention any direct or suspicious signs related to a foreign body, but bronchoscopy subsequently confirmed the presence of an airway foreign body.

2.3.2 Variable Collection and Definitions

Data were independently extracted by two uniformly trained researchers who were blinded to CT grouping results during the extraction process. Disagreements were resolved through consultation within the research team.

(1) Demographic characteristics: Sex, age, season of onset, and place of residence were collected. Age groups: 0–1 year, 1–3 years, 3–6 years, 6–12 years. Seasons: spring (March-May), summer (June-August), autumn (September-November), winter (December-February). Residence: urban or rural.

(2) Clinical features:

 Type of foreign body: vegetative or non-vegetative.

 Location of foreign body: left bronchus, right bronchus, multiple sites (involving ≥ 2 airway anatomical segments), or trachea/carina/glottis.

 Definite history of aspiration: recorded as "yes" if the parent or an eyewitness could describe the aspiration process; otherwise "no".

 Granulation tissue on bronchoscopy: present or absent.

 Duration of aspiration: acute phase (≤ 1 day), subacute phase (1–7 days), chronic phase (> 7 days).

(3) Concomitant imaging findings:

These were defined as all pulmonary and airway abnormalities on CT other than direct signs of the foreign body, all extracted from the original CT reports. Classification was based on expert consensus[10]combined with pathological mechanisms:

 By presence: present or absent.

 By number: 0, 1, or ≥ 2 types of abnormalities.

 By type: no abnormality; obstructive/masking findings (atelectasis, consolidation, emphysema, obstructive pneumonia, and bronchial stenosis/occlusion); mixed findings (co-existence of obstructive/masking findings and secondary/non-obstructive findings such as pneumothorax, pneumomediastinum, subcutaneous emphysema, mediastinal shift/hernia, pleural effusion, and bullae).

All abnormalities in this study were based on obstructive/masking findings; no case with only secondary/non-obstructive findings was identified. The assignment of variables is shown in Table 2.

2.4 CT Technical Details

All children underwent spiral CT scanning from the glottic region to both lung bases. A low-dose protocol was used: tube voltage 80–100 kV, automatic tube current modulation, slice thickness 0.625 mm, and reconstruction thickness 1.0 mm. Coronal and sagittal multiplanar reconstructions were routinely performed. Children under 5 years of age received oral 10% chloral hydrate sedation (30–50 mg/kg) before the examination. During scanning, the thyroid and gonads were shielded with lead aprons, strictly following the ALARA principle[8].

2.5 Statistical Analysis

IBM SPSS Statistics 25.0 and R language were used for data analysis. Categorical data were expressed as frequencies (percentages) and compared between groups using theχ^2test; Fisher's exact test was used when the expected frequency was < 5.

Variable selection and model construction: Univariate analysis was performed for all independent variables. Variables with P < 0.10 in univariate analysis and clinically important variables were included in the candidate model. Three independent binary logistic regression models were constructed, differing only in the coding of concomitant imaging findings: Model A (presence/absence), Model B (number of types), and Model C (pathological mechanism type). All models used the Enter method to force inclusion of variables. Collinearity was diagnosed using variance inflation factor (VIF), with VIF < 5 indicating no significant multicollinearity.

Model fit and internal validation

Model fit was assessed using the Hosmer-Lemeshow test. Nagelkerke R^2 was calculated to estimate the explanatory power of each model. Bootstrap internal validation with 1000 resamples was performed to obtain bias-corrected and accelerated (BCa) 95% confidence intervals for odds ratios (ORs). All tests were two-sided, and a P-value < 0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics 25.0 and R language.

3. Results

3.1 Baseline Characteristics

A total of 951 children with bronchoscopically confirmed TFB were included in this study, including 638 males (67.1%) and 313 females (32.9%). Age ranged from 0.1 to 12 years, with a median age of 2.1 years. Age distribution: 0–1 year, 256 cases (26.9%); 1–3 years, 639 cases (67.2%); 3–6 years, 45 cases (4.7%); 6–12 years, 11 cases (1.2%).

Preoperative CT detected the foreign body in 869 cases (91.4%) and missed it in 82 cases (8.6%). It should be noted that the missed detection rate reported here is the proportion of CT-negative cases among bronchoscopically confirmed TFB patients, not the overall false-negative rate of CT in the clinically suspected TFB population.

3.2 Univariate Analysis

Based on whether CT missed the foreign body, differences in variable distributions between the two groups were compared. The results showed that there were no statistically significant differences between the two groups in sex, season of onset, residence, or foreign body type (all $P > 0.05$). Factors significantly associated with CT missed detection included age, foreign body location, duration of aspiration, definite aspiration history, and concomitant imaging findings (all $P < 0.05$). The association between granulation tissue on bronchoscopy and missed detection approached statistical significance ($P = 0.079$). Details are as follows (see Table 1 for detailed data):

 Age: The 3–6 years age group had the highest missed detection rate (20.0%), followed by the 1–3 years group (9.2%), the 6–12 years group (9.1%), and the 0–1 year group (5.1%). The overall difference was statistically significant ($\chi^2 = 11.780$, $P = 0.008$).

 Foreign body location: The trachea/carina/glottis had the highest missed detection rate (15.0%), followed by the right bronchus (10.8%) and multiple sites (6.9%), with the left bronchus having the lowest rate (6.0%). The difference was statistically significant ($\chi^2 = 8.615$, $P = 0.009$).

Duration of aspiration: The missed detection rate increased with longer duration: 5.2% for ≤ 1 day, 8.0% for 1–7 days, and 13.3% for > 7 days. The difference was statistically significant ($\chi^2 = 11.357$, $P = 0.003$).

Definite aspiration history: Children without a definite aspiration history had a significantly higher missed detection rate (19.7%) than those with a definite history (6.8%) ($\chi^2 = 23.859$, $P < 0.001$).

Concomitant imaging findings: Children with any concomitant finding had a higher missed detection rate than those without (9.9% vs. 3.9%, $P = 0.007$). By number, those with only one type of concomitant finding had a missed detection rate of 10.8%, and those with ≥ 2 types had a rate of 8.7%; the difference between groups was statistically significant ($P = 0.017$). By type, the missed detection rate was highest in the mixed findings group (18.8%), followed by the obstructive/masking only group (9.5%), both significantly higher than that in the no-abnormality group (3.9%) ($P = 0.005$).

Granulation tissue on bronchoscopy: The missed detection rate was 9.7% in children with granulation tissue and 6.3% in those without, with a difference approaching statistical significance ($\chi^2 = 3.089$, $P = 0.079$).

3.3 Multivariable Analysis

Age, sex, foreign body location, duration of aspiration, definite aspiration history, granulation tissue on bronchoscopy, and concomitant imaging findings were included as candidate independent variables in the multivariable logistic regression analysis. Multicollinearity diagnostics showed that the VIF for each variable ranged from 1.02 to 1.43, all below 5, indicating no significant multicollinearity among the variables and allowing subsequent regression analysis.

Table 1

Table 1. Baseline Characteristics of the Study Population and Univariate Analysis of Factors Associated with CT Missed Detection

Variable	Category	Total (N = 951)	CT Detected (n = 869)	CT Missed(n = 82)	Missed Detection Rate (%)	χ^2	*P*
Demographics							
Sex, n (%)	Male	638(67.1)	586(67.4)	52(63.4)	8.2	0.548	0.459
	Female	313(32.9)	283(32.6)	30(36.6)	9.6		
Age group, n (%)	0 ~ 1 year	256(26.9)	243(28.0)	13(15.9)	5.1		
	1 ~ 3years	639(67.2)	580(66.7)	59(72.0)	9.2	**11.780**	**0.008**
	3 ~ 6years	45(4.7)	36(4.1)	9(11.0)	20.0		
	6 ~ 12years	11(1.2)	10(1.2)	1(1.2)	9.1		
Season, n (%)	Spring	286(30.1)	261(30.0)	25(30.5)	8.7	2.309	0.511
	Summer	199(20.9)	178(20.5)	21(25.6)	10.6		
	autumn	222(23.3)	202(23.2)	20(24.4)	9.0		
	Winter	244(25.7)	228(26.2)	16(19.5)	6.6		
Residence, n (%)	Urban	287(30.2)	261(30.0)	26(31.7)	9.1	0.100	0.752
	Rural	664(69.8)	608(70.0)	56(68.3)	8.4		
Clinical Features							
Foreign body type, n (%)	Plant	887(93.3)	811(93.3)	76(92.7)	8.6	0.049	0.824
	Not-Plant	64(6.7)	58(6.7)	6(7.3)	9.4		
Foreign body location, n (%)	Left bronchus	418(44.0)	393(45.2)	25(30.5)	6.0	**8.615**	**0.035**
	Right bronchus	435(45.7)	388(44.6)	47(57.3)	10.8		
	Multiple sites	58(6.1)	54(6.2)	4(4.9)	6.9		
	Trachea/GlottisCarina	40(4.2)	34(3.9)	6(7.3)	15.0		
Duration of aspiration, n(%)	≤ 1 day	271(28.5)	257(29.6)	14(17.1)	5.2	**11.357**	**0.003**
	1 ~ 7 days	424(44.6)	390(44.9)	34(41.5)	8.0		
	>7 days	256(26.9)	222(25.5)	34(41.5)	13.3		
Definite inhalation history, n(%)	Yes	819(86.1)	763(87.8)	56(68.3)	6.8	**23.859**	**<0.001**
	No	132(13.9)	106(12.2)	26(31.7)	19.7		
Granulation tissue, n (%)	Yes	636(66.9)	574(66.1)	62(75.6)	9.7	**3.089**	**0.079**
	No	315(33.1)	295(33.9)	20(24.4)	6.3		
Concomitant Imaging Findings							

Variable	Category	Total (N = 951)	CT Detected (n = 869)	CT Missed(n = 82)	Missed Detection Rate (%)	χ^2	*P*
Demographics							
Presence of any finding, n (%)	Yes	748(78.7)	674(77.6)	74(90.2)	9.9	**7.179**	**0.007**
	No	203(21.3)	195(22.4)	8(9.8)	3.9		
Number of finding types, n (%)	0	203(21.3)	195(22.4)	8(9.8)	3.9	**8.171**	**0.017**
	1	437(46.0)	390(44.9)	47(57.3)	10.8		
	≥ 2	311(32.7)	284(32.7)	27(32.9)	8.7		
Type of imaging findings, n (%)	None	203(21.3)	195(22.4)	8(9.8)	3.9	**10.508**	**0.005**
	Obstructive/Masking	716(75.3)	648(74.6)	68(82.9)	9.5		
	Mixed	32(3.4)	26(3.0)	6(7.3)	18.8		

Table 2
Variable Assignment

Variable	Coding Method
gender	Male = 1,female = 2
Age	0 ~ 1 year = 1(Reference), 1 ~ 3 years = 2, 3 ~ 6 years = 3, 6 ~ 12 years = 4
Season	Spring = 1, Summer = 2, Autumn = 3, Winter = 4
Residence	Rural = 1, Urban = 2
Foreign Body Type	Plant = 1, Non-plant = 2
Foreign Body Location	Left bronchus = 1(Reference), Right bronchus = 2, Multiple sites = 3, Trachea/Carina/Glottis = 4
Duration of aspiration	≤ 1 day = 1(Reference), 1 ~ 7 days = 2, >7 days = 3
Definite inhalation history	No = 0,Yes = 1(Reference)
Granulation tissue	No = 0(Reference),Yes = 1
Presence of any finding	No = 0,Yes = 1
Number of finding types	0 = 0(Reference), 1 = 1, ≥ 2 = 2
Type of imaging findings	None = 0(Reference), Obstructive/Masking = 1, Mixed (Obstructive+Secondary/Non-obstructive) = 2

Three independent binary logistic regression models were constructed, each using a different definition of concomitant imaging findings (Model A: by presence/absence; Model B: by number; Model C: by type of findings). The candidate independent variables were consistent across all three models. All three models showed good fit (Hosmer-Lemeshow test, $P > 0.05$ for all), with Nagelkerke R^2values of 0.109 (Model A), 0.115 (Model B), and 0.112 (Model C), indicating stable explanatory power for the variance in CT missed detection.

Model C (by type of findings) showed (Table 3) that the factors most strongly associated with an increased risk of CT missed detection were age 3–6 years (OR = 4.597, 95% CI: 1.724–12.254, *P* = 0.002), followed by mixed imaging findings (OR = 4.270, 95% CI: 1.280-14.237, *P* = 0.018) and foreign body location in the trachea/carina/glottis (OR = 4.020, 95% CI: 1.371–11.782, *P* = 0.011). Absence of a definite aspiration history (OR = 2.725, 95% CI: 1.525–4.871, *P* = 0.001), foreign body location in the right bronchus (OR = 2.040, 95% CI: 1.211–3.436, *P* = 0.007), and age 1–3 years (OR = 1.921, 95% CI: 1.018–3.627, *P* = 0.044) were also significantly associated with missed detection. The association between purely obstructive/masking findings and missed detection did not reach statistical significance (OR = 2.172, 95% CI: 0.963–4.899, *P* = 0.062).

Model A (by presence/absence of concomitant findings) showed that age 3–6 years (OR = 4.834, 95% CI: 1.825–12.807, *P* = 0.002), age 1–3 years (OR = 1.958, 95% CI: 1.038–3.693, *P* = 0.038), foreign body location in the trachea/carina/glottis (OR = 4.292, 95% CI: 1.485–12.404, *P* = 0.007) or right bronchus (OR = 2.018, 95% CI: 1.199–3.394, *P* = 0.008), absence of a definite aspiration history (OR = 2.704, 95% CI: 1.516–4.823, *P* = 0.001), and the presence of any concomitant imaging finding (OR = 2.284, 95% CI: 1.016–5.133, *P* = 0.046) were all independent factors for CT missed detection.

Model B (by number of concomitant findings) showed that age 3–6 years (OR = 4.860, 95% CI: 1.832–12.896, *P* = 0.001), age 1–3 years (OR = 1.976, 95% CI: 1.048–3.728, *P* = 0.035), foreign body location in the trachea/carina/glottis (OR = 4.194, 95% CI: 1.456–12.084, *P* = 0.008) or right bronchus (OR = 2.002, 95% CI: 1.190–3.370, *P* = 0.009), absence of a definite aspiration history (OR = 2.871, 95% CI: 1.601–5.151, *P* < 0.001), and the presence of one type of concomitant finding (OR = 2.623, 95% CI: 1.156–5.951, *P* = 0.021) were significantly associated with missed detection, whereas the presence of two or more types of concomitant findings showed no significant association (OR = 1.647, 95% CI: 0.673–4.034, *P* = 0.275).

Common findings across the three models: Absence of a definite aspiration history was the most robust independent factor for CT missed detection (mean OR across three models approximately 2.79, range 2.704–2.871, all *P* ≤ 0.001). Age 3–6 years, age 1–3 years, and foreign body location in the trachea/carina/glottis or right bronchus were consistently identified as independent factors across all three models, with effect sizes in descending order: age 3–6 years (mean OR 4.76) > trachea/carina/glottis (mean OR 4.19) > absence of definite aspiration history (mean OR 2.79) > right bronchus (mean OR 2.02) > age 1–3 years (mean OR 1.95). The association between concomitant imaging findings and missed CT detection was markedly heterogeneous: the presence of any concomitant finding (Model A), the presence of one type of finding (Model B), or mixed findings (Model C) significantly increased the risk of missed detection, whereas purely obstructive/masking findings (Model C) or the presence of two or more types of findings (Model B) showed no independent association. Duration of aspiration and granulation tissue on bronchoscopy were not independently associated with CT missed detection in any of the models (*P* > 0.05 for all). The direction and ranking of effect sizes were highly consistent across the three models, and bootstrap internal validation indicated good robustness of the results.

4. Discussion

Based on 951 children with bronchoscopically confirmed TFB, this study systematically investigated factors associated with CT missed detection in bronchoscopically confirmed cases by defining strict criteria for CT detection versus missed detection, standardizing variable coding and reference group settings, constructing three independent binary logistic regression models, and confirming the robustness of the results through bootstrap internal validation. The main findings are as follows: absence of a definite aspiration history was the most robust independent factor associated with CT missed detection (OR range 2.704–2.871 across the three models, all *P* ≤ 0.001); the 3–6 years

age group had the largest effect size (mean OR 4.764), followed by foreign body location in the trachea/carina/glottis (mean OR 4.169); foreign body in the right bronchus (OR ≈ 2.0) and age 1–3 years (OR ≈ 1.95) were also independent factors. Concomitant imaging findings were important factors increasing the risk of missed detection, with effect sizes dependent on the definition used: mixed imaging findings had the highest effect size (OR = 4.270), and the presence of one type of imaging finding (OR = 2.623) or any concomitant imaging finding (OR = 2.284) was also associated with missed detection risk. This study provides an in-depth analysis of the clinical and imaging mechanisms underlying CT missed detection of TFB, interprets the clinical value and practical implications of the findings, and objectively analyzes the study limitations, thereby offering evidence-based support for optimizing CT diagnostic strategies for pediatric TFB and improving the identification and management of cases at high risk of missed detection. The above conclusions still need further validation in larger multicenter studies.

Table 3

Multivariable logistic regression analysis of factors associated with CT missed detection of tracheobronchial foreign bodies in children: three models with different definitions of concomitant imaging findings

Variable (Reference)	Model A (Presence/Absence)		Model B (Number of Findings)		Model C (Type of Findings)	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Age group (Reference: 0–1 years)						
1 ~ 3 years	1.958(1.038–3.693)	0.038	1.976(1.048–3.728)	0.035	1.921 (1.018–3.627)	0.044
3 ~ 6 years	4.834(1.825–12.807)	0.002	4.860 (1.832–12.896)	0.001	4.597 (1.724–12.254)	0.002
6-12years	1.829(0.198–16.895)	0.595	1.709(0.183–15.966)	0.638	1.838 (0.199–16.988)	0.591
Foreign body location (Reference: Left bronchus)						
Right bronchus	2.018(1.199–3.394)	0.008	2.002(1.190–3.370)	0.009	2.040(1.211–3.436)	0.007
Multiple sites	1.067(0.345–3.297)	0.910	1.110(0.360–3.425)	0.856	1.019(0.327–3.175)	0.974
Trachea, carina Glottis	4.292(1.485–12.404)	0.007	4.194(1.456–12.084)	0.008	4.020(1.371–11.782)	0.011
Definite inhalation history (Reference: Yes)						
No	2.704(1.516–4.823)	0.001	2.871(1.601–5.151)	<0.001	2.725(1.525–4.871)	0.001
Concomitant imaging finding (Reference: No)						
Presence	2.284(1.016–5.133)	0.046	—	—	—	—
Number (Reference: 0)						
1	—	—	2.623(1.156–5.951)	0.021	—	—
≥ 2	—	—	1.647(0.673–4.034)	0.275	—	—
Type (Reference: None)						
Obstructive/Masking	—	—	—	—	2.172(0.963–4.899)	0.062
Mixed	—	—	—	—	4.270(1.280-14.237)	0.018
Model performance						
Hosmer-Lemeshow test (χ^2, P)	χ^2 = 11.185, P = 0.191		χ^2=5.106, P = 0.746		χ^2 =9.948, P = 0.269	

Variable (Reference)	Model A (Presence/Absence)		Model B (Number of Findings)		Model C (Type of Findings)	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Age group (Reference: 0–1 years)						
Nagelkerke R^2	0.109		0.115		0.112	

4.1. Absence of a definite aspiration history: the most robust independent factor for CT missed detection

In this study, absence of a definite aspiration history was the independent factor with the most stable effect size and strongest statistical significance across all three models (OR range 2.704–2.871, all $P \leq 0.001$), with the smallest variation in OR values among the three models, indicating the highest robustness of the association between this factor and CT missed detection. This finding is highly consistent with previous clinical studies[2, 11]. Koca et al[12]. also pointed out that absence of a definite aspiration history is a key clinical factor leading to decreased diagnostic performance of CT for pediatric airway foreign bodies and a significantly increased false-negative rate, and that a high level of clinical suspicion should be maintained even when CT shows no definite direct signs of a foreign body[12]. The underlying mechanisms can be explained from two aspects. First, foreign body aspiration in children, especially younger children, is often a sudden accidental event that is difficult for the child to articulate clearly; most of these children present without a definite aspiration history and with non-specific respiratory symptoms such as chronic cough, recurrent pulmonary infections, or episodic wheezing as the main manifestations[8]. This leads clinicians to prioritize infectious diseases or congenital airway abnormalities, and radiologists also lack a clear diagnostic orientation toward“screening for a foreign body”when interpreting CT images[13]. Second, absence of a definite aspiration history is often accompanied by prolonged duration of aspiration, which creates conditions for the development of pulmonary complications that further mask the direct signs of the foreign body[14], forming a vicious cycle of “unclear history— prolonged duration—complications—increased risk of missed detection”. Of note, “duration of aspiration” did not enter the final model in the multivariable analysis, suggesting that its effect on missed detection may operate indirectly through “unclear aspiration history” and “induction of complications”; that is, duration of aspiration may act as a mediator between absence of a definite aspiration history and CT missed detection. This finding suggests that for children with negative CT findings but no definite aspiration history, clinicians should not easily rule out TFB but should make a comprehensive judgment based on symptoms, signs, and indirect imaging findings. When conventional treatment fails, bronchoscopy should be considered even if CT shows no direct signs of a foreign body, to avoid missed diagnosis and delay in treatment.

4.2. Age and foreign body location: effect size ranking reveals characteristics of high-risk populations

This study showed that the 3–6 years age group had the highest risk of CT missed detection (mean OR 4.764 across the three models), significantly higher than the 1–3 years group (mean OR 1.95), while the 0–1 year group had the lowest risk. This ranking of effect sizes clarifies the characteristics of populations strongly associated with CT missed detection. Unlike the conventional clinical understanding (younger children are the highest-incidence population for TFB), children aged 3–6 years, although not the highest-incidence age group for TFB, had the highest risk of CT missed detection, with a missed detection rate of 20.0% in this study, suggesting that clinicians should focus on this age group as a priority for CT missed detection. The underlying mechanisms can be explained from two

perspectives. Regarding age: children aged 3–6 years have greatly expanded activity ranges and autonomous mobility, making the scenarios of foreign body aspiration more concealed; caregivers are more likely to overlook relevant exposure histories, leading to incomplete clinical history collection and a lack of clear diagnostic orientation toward foreign body screening when radiologists interpret CT images. Additionally, the airways of children in this age group are relatively wider, making incomplete impaction of the foreign body more likely, which makes it difficult to form typical direct signs such as intraluminal filling defects or stenosis; moreover, the secondary indirect imaging changes are often mild and easily confused with signs of common respiratory infections, significantly increasing the difficulty of image interpretation.

Regarding foreign body location: the trachea/carina/glottis had the highest risk of missed detection (mean OR 4.192 across the three models), followed by the right bronchus (OR ≈ 2.0), with the left bronchus having the lowest risk (reference group). This ranking closely matches the anatomical structure of the airway and the difficulty of recognizing CT signs of foreign bodies at different locations. The trachea/carina/glottis is an anatomically complex region of the upper airway. Foreign bodies in this location are often small or thin, and are significantly affected by respiratory and swallowing movements, which can easily produce motion artifacts during scanning; even with thin-slice scanning, the subtle direct signs of the foreign body can be obscured or overlooked[15]. A 7-year study by Qiu et al[2]. showed that among children with missed CT detection of airway foreign bodies, 43.9% had thin or powdery foreign bodies; more than half of these children had a diagnostic delay of ≥ 2 weeks, with the longest delay reaching 2 years, and pulmonary infiltrates were easily confused with pneumonia, further exacerbating the missed diagnosis. A study by Wang et al. on deep learning-based automatic detection of airway foreign bodies on CT further confirmed that absence of a definite aspiration history and radiolucent foreign bodies (thin, powdery) are key factors contributing to a high false-negative rate of CT[16]. Furthermore, the active physiological movements in this region may cause mild luminal changes to be interpreted as physiological variations, further increasing the probability of missed detection[17].

The right bronchus, with its larger diameter and steeper course, is a common site for foreign body aspiration. Foreign bodies here are prone to movement or incomplete impaction, making it difficult to form characteristic filling defects, and are more likely to cause secondary indirect changes such as emphysema and localized obstructive inflammation, which often mask the direct signs of the foreign body and lead to diagnostic confusion. In contrast, the left bronchus has a smaller diameter and a tortuous course; foreign bodies are more likely to become completely impacted, forming typical direct signs such as luminal narrowing or filling defects. Moreover, the secondary indirect changes (e.g., atelectasis, consolidation) have a stronger anatomical correspondence with the foreign body location, making it easier for radiologists to trace back and identify the foreign body. Therefore, the left bronchus has the lowest degree of association with CT missed detection[9].

4.3. Concomitant imaging findings: complex effect characteristics and insufficient stability of association

In this study, three regression models with different variable coding strategies were used to systematically investigate the association between concomitant imaging findings and CT missed detection. The results showed that the effect characteristics of this factor varied markedly with the coding method, indicating a non-linear association. Its influence on CT missed detection exhibited clear classification dependence, jointly affected by the type, number, and clinical decision-making.

Model A (by presence/absence) showed that the presence of any concomitant imaging finding was significantly associated with an increased risk of missed detection (OR = 2.284, $P = 0.046$). This finding aligns with the basic logic

of imaging diagnosis: in cases of missed CT detection of pediatric TFB, the foreign body is often masked by concomitant pathological changes such as atelectasis, consolidation, and airway thickening. Any abnormal findings in the airways or lungs increase the difficulty of identifying direct signs of the foreign body, thereby increasing the likelihood of missed detection[18].

Model B (by number of findings) showed that the risk of missed detection was significantly increased when only one type of concomitant finding was present (OR = 2.623, *P* = 0.021), whereas the presence of two or more types of findings was not significantly associated (OR = 1.647, *P* = 0.275). This difference can be explained from two aspects. First, when multiple complications coexist, the clinical picture is more complex, and clinicians'suspicion of TFB is significantly heightened. They may actively use post-processing techniques such as multiplanar reconstruction and thin-slice reconstruction for detailed airway evaluation. Such targeted clinical interventions can effectively offset the risk of missed detection caused by imaging masking. Azzi et al.[18]pointed out that when CT shows multiple airway and pulmonary pathological findings, clinicians are more inclined to proceed with bronchoscopy, thereby optimizing diagnostic decisions and reducing missed detection. Second, a single concomitant finding is often a mild, localized abnormality (e.g., unilateral emphysema) that is easily attributed to a common respiratory infection, leading to low clinical vigilance; thus, its association with missed detection is significantly stronger.

Model C (by pathological mechanism type) showed that only mixed imaging findings were significantly associated with missed detection risk (OR = 4.270, *P* = 0.018, n = 32), whereas purely obstructive/masking findings showed a borderline association (OR = 2.172, *P* = 0.062). This is an important finding of this study: mixed findings include both obstructive changes and secondary changes (e.g., pneumothorax, pneumomediastinum). Such severe secondary complications may distract the radiologist's attention toward the latter, causing them to overlook careful observation of the bronchial lumen, making mixed findings the type of concomitant imaging finding with the highest degree of association with missed detection[9]. In contrast, purely obstructive/masking findings (e.g., atelectasis, consolidation) are both direct pathological consequences of foreign body impaction and key warning clues for radiologists to search for the foreign body. Their"sign-masking effect" and "clinical alerting effect"may counteract each other, which is why they did not show a significant independent association in the regression model.

In summary, the association between concomitant imaging findings and CT missed detection is complex and shows insufficient stability of effect. At present, it can only be concluded that under specific coding methods, mixed findings and a single type of finding are significantly associated with missed detection risk. The clinical value of this factor as an independent predictor of CT missed detection remains unclear, and its effect characteristics need further validation in future multicenter studies with larger sample sizes and uniform variable definitions.

4.4. Limitations

The core findings of this study (absence of a definite aspiration history, age, and foreign body location) remained stable and significant across all three models, and the following limitations did not substantially affect the conclusions. First, verification bias. Only children with bronchoscopically confirmed TFB were included, and true-negative cases were not enrolled, making it impossible to assess the overall diagnostic performance of CT. In addition, the use of post-hoc classification for reports with "suspected foreign body" may have overestimated the CT detection rate. Future multicenter prospective studies are needed for validation. Second, selection bias. This was a single-center retrospective study, and the generalizability of the conclusions is limited. Third, reading bias. Variables were extracted from routine CT reports without double-blinded independent re-reading of images, so subjective influence could not be completely excluded. Fourth, limited model explanatory power. The Nagelkerke R^2 values ranged from 0.109 to 0.115, suggesting that factors such as foreign body material, size, shape, radiologist experience, and respiratory motion artifacts were not included. Fifth, heterogeneity of concomitant imaging findings.

The sample size of some subgroups was small (e.g., mixed findings, n = 32), and the classification was exploratory; multicenter data are needed to clarify the true associations. Sixth, imaging technology factors not covered. The study did not analyze the impact of low-dose CT, iterative reconstruction, or AI-assisted diagnosis on reducing the missed detection rate, which represents an important direction for future research.

5. Conclusion

CT is an important non-invasive imaging modality for the diagnosis of TFB, but its diagnostic performance is influenced by multiple factors. This study demonstrates that absence of a definite aspiration history is the most robust independent factor associated with CT missed detection. Age 3–6 years and 1–3 years, as well as foreign body location in the trachea/carina/glottis or right bronchus, are significantly associated with CT missed detection, with effect sizes decreasing in that order. The association between concomitant imaging findings and CT missed detection is complex and lacks stability, and their independent predictive value requires further validation. Clinicians should pay close attention to children with the above characteristics. Even when CT shows no direct signs of a foreign body, a high level of suspicion should be maintained, and timely bronchoscopy should be performed when necessary to avoid delays in diagnosis and treatment. Future studies may combine thin-slice CT and artificial intelligence-assisted image interpretation to further optimize diagnostic strategies, reduce missed detection, and avoid unnecessary bronchoscopic procedures.

Declarations

Ethics approval and consent to participate

This retrospective study was reviewed and approved by the Ethics Committee of Gansu Provincial Maternal and Child-care Hospital, which granted a waiver of informed consent . The study involved no more than minimal risk to participants and used de-identified data only.

Consent for publication

All authors listed have approved the manuscript for publication and consent to its publication in this journal.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request. All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

WW and YW conceptualized and designed the study. WW, QZ, SP, WL, and SW collected and extracted the data. WW and QZ performed the statistical analysis. WW drafted the initial manuscript. YW supervised the study and critically

revised the manuscript. All authors read and approved the final manuscript.

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