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The role of 3D computed tomography (CT) imaging in the diagnosis of foreign body aspiration in children

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Abstract. – OBJECTIVE: The aim of this study was to improve the understanding of FBA in children and to decrease the rate of misdiagnosis, missed diagnosis and morbidity.

PATIENTS AND METHODS: We analyzed the clinical features and the three-dimensional reconstructed CT images of 590 children with foreign body aspiration (FBA) in the Xuzhou area of the Jiangsu province.

RESULTS: CT imaging revealed common complications of FBA including emphysema (n = 379), pneumonia (n = 174), and atelectasis (n = 26). The remaining 120 patients had no visible complications on the three-dimensional reconstructed CT images. Serious complications including pneumothorax, pneumomediastinum, subcutaneous emphysema, pneumatorrhachis could also be observed. The types of foreign bodies were diverse: the most common were peanuts and sunflower seeds. The diagnostic accuracy of the three-dimensional CT imaging was high, with a sensitivity and specificity of 99.83% and 99.89%, respectively.

CONCLUSIONS: 3D CT imaging is an accurate, non-invasive technique to evaluate children with suspected FBA that can help decrease the rate of misdiagnosis and eliminate a delay in treatment for this potentially life-threatening condition.

Key Words:
Pediatric, Foreign bodies, Three-dimensional CT, Complications.

Introduction

Foreign body aspiration (FBA) is a frequent and serious cause of respiratory problems in children, especially among those younger than 3 years of age[1,2]. FBA is potentially lethal and accounts for 40% of all accidental deaths in infants less than 1 year old[3]. FBA may result in either airway compromise and death, or severe complications such as recurrent pulmonary infections, emphysema and atelectasis. Therefore, it is of the utmost importance to identify a diagnostic method that can differentiate between FBA and conditions that mimic it to eliminate any delay in performing bronchoscopy when it is necessary. FBA is not easily diagnosed because the clinical history is often incomplete and its manifestation is atypical. This often causes the treatment of FBA to be delayed. In serious cases, FBA can result in sudden suffocation in children. This study retrospectively analyzed 1501 children with suspected FBA who were admitted to our hospital. Herein, we summarize the regularity of its pathogenesis, its clinical features, and our findings with CT imaging to decrease the rate of misdiagnosis and missed diagnosis, to explore effective measures for the prevention and treatment of FBA, and to provide a meaningful reference.

Patients and Methods

Patients

From January 2009 to July 2010, 1501 children (1040 boys, 461 girls) who were admitted to our hospital because of suspected FBA were included in this study. We included pediatric patients who had a history of foreign body aspiration and those who had a history suggestive of FBA. All of the pediatric patients underwent a

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three-dimensional CT scan. Fiberoptic bronchoscopy demonstrated 584 children with foreign bodies in their airways and 6 children coughed the foreign bodies out themselves. These 590 children (389 boys and 201 girls, mean age 18 months, range 50 days to 10 years) were the main research subjects in this study. Their clinical history was gathered and the locations and patterns of tracheobronchial obstruction and its complications on the three-dimensional reconstruction CT images were evaluated.

CT scan

CT examinations were performed with a 16-section multi-detector CT (MDCT) scanner (Lightspeed; GE Medical Systems, Waukesha, WI; or Somaton Emotion; Siemens Medical Systems, Shanghai, China). Patients were oriented in the supine position. MDCT was performed from the level of the larynx to the dome. Sedation was used during the examination. Scans were conducted during spontaneous breathing in all children under anesthetic. The following CT parameters were used to acquire all data. The parameters for the 16-MDCT Lightspeed instrument were: section thickness, 5.0 mm; pitch, 0.938-1.75; 120kVp; 100 mAs; DFOV, 130-250 mm. The parameters for the 16-MDCT Somaton Emotion instrument were: section thickness, 5.0 mm; pitch, 1; 120kVp; 100 mAs. The 3D reconstruction parameters were: convolution value, B70S; Window value, Lung. Images were reconstructed in the axial plane at a 1.3 mm section thickness with a reconstruction algorithm.

Image Processing

After scanning, data were sent and processed at an independent workstation (Advantage Windows 4.2; GE Medical Systems, Waukesha, WI, USA or Syngo mmwp VE31A; Siemens, Shanghai, China). Computer generation of the tracheobronchial images was accomplished in three successive steps as described below. First, we browsed through the original axial images, and then selected the multi-planar reconstruction (MPR) method in the lung window. We observed the lung and bronchus at all levels in the lung and soft tissue windows, and then converted to the "Navigation" method and regulated the image threshold with a range from –400 HU to –700 HU. We combined the coronal, axial, and sagittal plane images, adjusted the cursor position within the bronchial lumen, and observed different areas that we were interested in. We adjusted the angle and position of the trachea and bronchi, observed the inner cavity and the situation inside the trachea and bronchi. The aperture of the virtual camera could be adjusted between 0 and 170°. The endoscopic view began at the tracheal inlet, moved to the trachea, right main bronchus, left main bronchus, and upper lobes. We then moved to the middle lobe and lingula; and finally moved to the lower lobes. The radiologist had to pull the virtual endoscope back to the bifurcation before entering smaller branches. We next selected airstructure in the lung window, so that we could observe the gas distribution and the main tracheobronchial lumen. Post-processing time ranged from 15 to 20 minutes for each patient. The virtual images for each patient were saved as digital files. The axial images and three-dimensional CT images were saved on an independent workstation.

Image Analysis

CT images of children with or without foreign bodies were evaluated by two experienced radiologists. The radiologists reached a consensus about whether the foreign bodies existed, their locations, shapes, intensity and any complications arising due to their presence. The tracheobronchial system was carefully evaluated for the presence of foreign bodies. Additional parenchymal and mediastinal abnormalities were noted including emphysema, atelectasis, and pneumonia and so on. The axial CT images were interpreted first; then the three-dimensional CT post-processing images were evaluated in our studies. The three-dimensional reconstructed CT images indicated the presence of a foreign body by the high intensity in the lumen of the tracheobrochial tree. The complications due to FBA were indirect signs.

Statistical Analysis

The clinical data recorded included the pediatric patients' age and gender, the symptoms and signs, the duration of symptoms, the previous medical evaluation, and the types of foreign bodies. We noted the outcomes of the three-dimensional CT such as the presence or absence of FBA and its complications such as emphysema, atelectasis, pneumonia, pneumomediastinum, subcutaneous emphysema, and pneumorrhachis. The diagnostic accuracy of the three-dimensional reconstruction CT with reference to bron-

Table I. Age at incidence of FBA.

Age (years)	Positive (FBA)	Negative	Total	Morbidity (%)
<1	36	232	268	13.43
1-3	472	374	846	55.79
3-7	67	233	300	22.33
>7	15	72	87	17.24
Total	590	911	1501	39.31

choscopy was made using sensitivity, specificity, positive predictive value, and negative predictive value. Statistical analysis was performed with Stata software (version 10, Stata Institute, TX, USA). $p < 0.05$ was considered as statistically significant.

Results

Age at Incidence of FBA

FBA constitutes a common clinical entity encountered in the pediatric age group. In our study, foreign bodies were found in 590 of 1501 patients (39.31%). These 590 patients were the main subjects in this study. Among the 590 patients, 389 (65.93%) were boys while 201 (34.07%) were girls. The ratio of boys to girls was 1.94:1. The patients' age ranged from 50 days to 10 years old. The most common age group was 1-3 years, accounting for 80% of the cases with FBA ($p < 0.05$) (Table I).

Time Lapse Between Aspiration and Arrival at the Hospital

Almost half (46.95%) of the patients in our study went to the hospital more than 72 hours (3 days) after the FBA event. The patient who arrived at the hospital the earliest was 30 minutes following the FBA event while the longest took 6 months before consulting (Table II). The majority of the cases (342 cases, 57.97%) were admitted to the ear, nose and throat (ENT) department while the remaining 134 cases (22.71%) were admitted to the pediatric department.

Table II. Time lapse between aspiration and arrival at the hospital.

Duration (days)	N (%)
<1	148 (25.08)
1-3	165 (27.97)
3-7	107 (18.14)
8-15	97 (16.44)
16-30	45 (7.63)
>30	28 (4.75)

Symptoms of FBA

A definite history of foreign body aspiration was available in 312 cases (52.88%) while 278 cases (47.12%) presented without any history. These 278 patients in our study underwent the three-dimensional CT for their symptoms such as coughing, choking, sputum, dyspnea, fever, sudden onset of wheezing and so on. The breath sounds were often different in the children with foreign bodies. These signs and symptoms occurred alone more often than not, and they were related to the duration of foreign bodies and the degree of airway obstruction. A history of coughing was found in 363 patients (61.53%) with foreign body aspiration; however, it was also present in the group without any foreign bodies. Choking and wheezing, although frequent (28.28% of cases for wheezing), were symptoms that had poor predictive value of the presence of a foreign body in the airway.

Locations of the Foreign Body and Associated Complications

The locations of the foreign bodies identified in the tracheobronchial tree are described in Table III. The proportion of foreign bodies identified in the right main bronchus, left main bronchus and trachea were 26.95%, 33.39% and 12.54%, respectively. Parenchymal and mediastinal abnormalities were observed frequently in our study, occurring in 470 patients (79.66%) with FBA. Emphysema, pneumonia, atelectasis were the main complications of FBA (Table IV, see also Figures 1 and 2). There were 7 severe cases in our study, which presented with serious complications such as pneumothorax, pneumomediastinum, subcutaneous emphysema, and pneumatorrhachis (Figure 3).

Table III. The locations of foreign bodies in the airway.

Location	N (%)
Trachea	74 (12.54)
Right main bronchus	159 (26.95)
Right intermediate bronchus	49 (8.31)
Right upper bronchus	7 (1.19)
Right lower bronchus	17 (2.88)
Left main bronchus	197 (33.39)
Left upper bronchus	9 (1.53)
Left lower bronchus	15 (2.54)
Other types (combined)	62 (10.51)

Table IV. Complications arising due to FBA.

Complication	N (%)
Emphysema	379 (63.06)
Atelectasis	26 (4.33)
Pneumonia	174 (28.95)
Pneumothorax	3 (0.50)
Pneumomediastinum	14 (2.33)
Subcutaneous emphysema	3 (0.50)
Pneumorrhachis	2 (0.33)

Types of Foreign Bodies

Foreign bodies were successfully identified and removed by bronchoscopy in 584 patients, while in 6 cases they were spontaneously removed after coughing (1.02%). Although a wide variety of foreign bodies were retrieved, the most frequent were of vegetative origin (97.86%), with the most common being peanuts (57.63%). The remaining 2.14% of the foreign bodies included objects such as whistles, bone, candy, soil, plastic objects and others (Table V).

The Diagnostic Accuracy of the Three-Dimensional Reconstructed CT Images

The three-dimensional CT reconstructions evaluated the presence of a foreign body via the

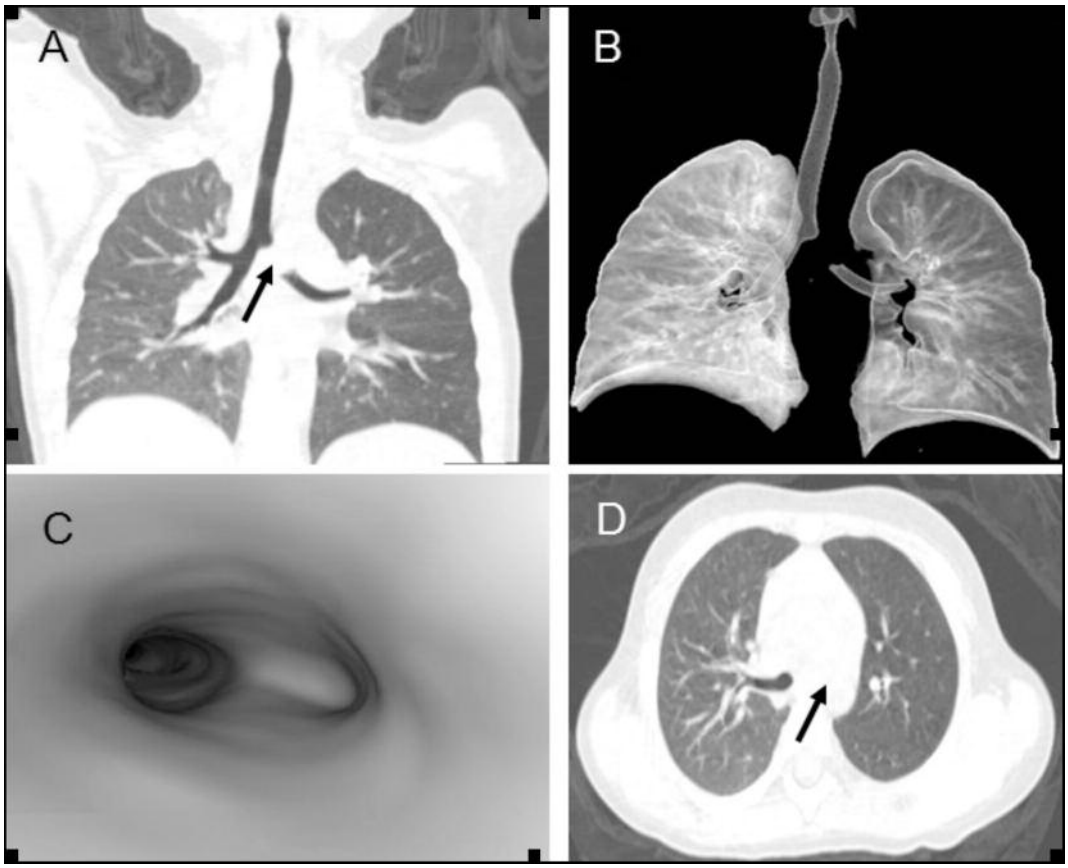

Figure 1. ***A,*** 2-year-old girl who aspired a peanut 24 hours prior to examination. ***(A)*** Multiplanar reconstruction (MPR) image. ***(B)*** Ray sum image. ***(C)*** CT virtual endoscopy (CTVE) image, and ***(C)*** An axial image revealed that the left main bronchus was completely blocked (black arrow in A and D). In ***A-D***, emphysema in the left lung can be observed and the mediastinum shifted to the right. Half a peanut was extracted from the location during the bronchoscopy examination.

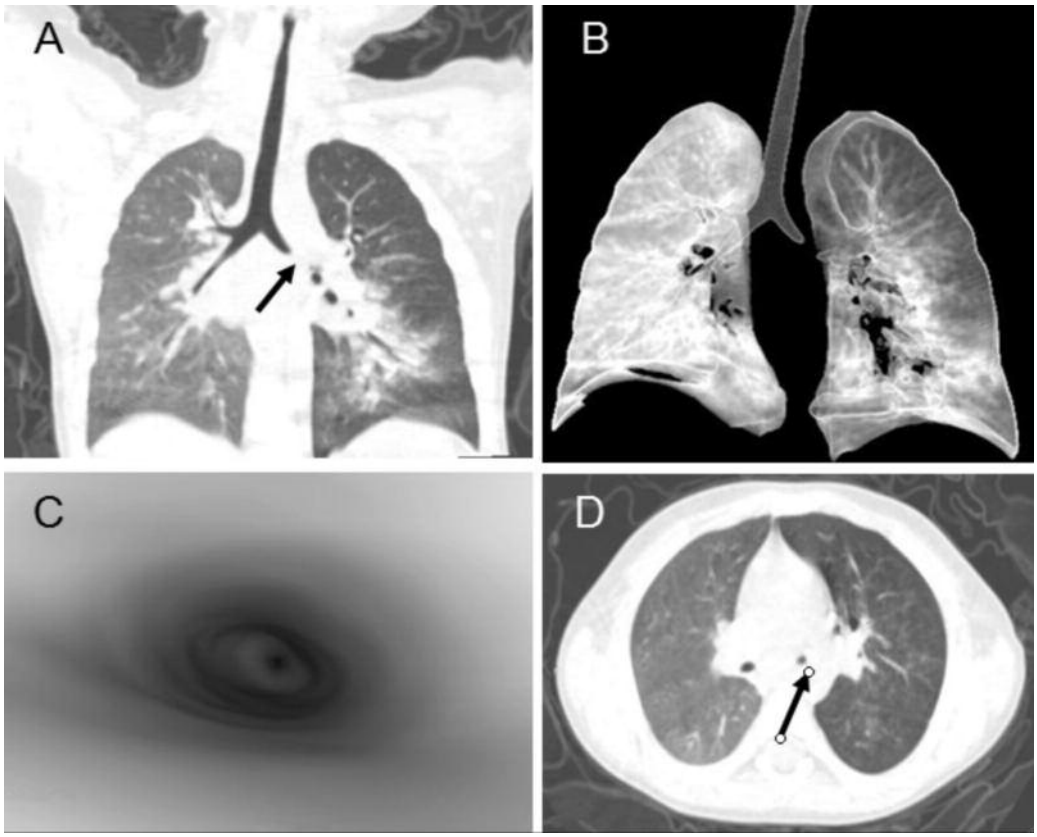

Figure 2. A 12-month-old boy who was admitted to the hospital for foreign body aspiration and who presented with harsh breath sounds and wheezing sounds. ***(A)*** Multiplanar reconstruction (MPR) image. ***(B)*** Ray sum image. ***(C)*** CT virtual endoscopy (CTVE) image, and ***(D)*** An axial image revealed that the left main bronchus was blocked (black arrow in A and D). In ***A, B-D***, pneumonia can be seen in the left lung, especially in the left lower lobe. Semen juglandis was extracted from the location during the bronchoscopy examination.

observation of a high intensity object in the lumen of the tracheobrochial tree. The indirect signs of FBA were the complications. It has been suggested that if the airway is blocked and complications are observed, we can assume that a foreign body is present. However, there was one false-positive case (Figure 4) and one false-negative case in our study. From the data shown in Table VI, we calculated the sensitivity, specificity, positive predictive value, and negative predictive value of the three-dimensional reconstructed CT images in evaluating the presence of a foreign body at 99.83%, 99.89%, 99.83% and 99.89%, respectively.

Table V. Type of foreign body.

Type	N (%)
Peanut	340 (57.63)
Sunflower seed	131 (22.20)
Watermelon seed	35 (5.93)
Semen juglandis	23 (3.90)
Soybean	9 (1.53)
Chinese chestnut	7 (1.19)
Fruits	8 (1.36)
Rice	7 (1.19)
Whistle	4 (0.68)
Chicken	2 (0.34)
Plastic object	2 (0.34)
Bone	2 (0.34)
Candy	2 (0.34)
Soil	1 (0.17)
Other objects	17 (2.88)

Table VI. Diagnostic accuracy of three-dimensional reconstructed CT images.

Three-dimensional CT examination	Clinical diagnosis	
	Presence	Absence
Positive	590	1
Negative	1	609

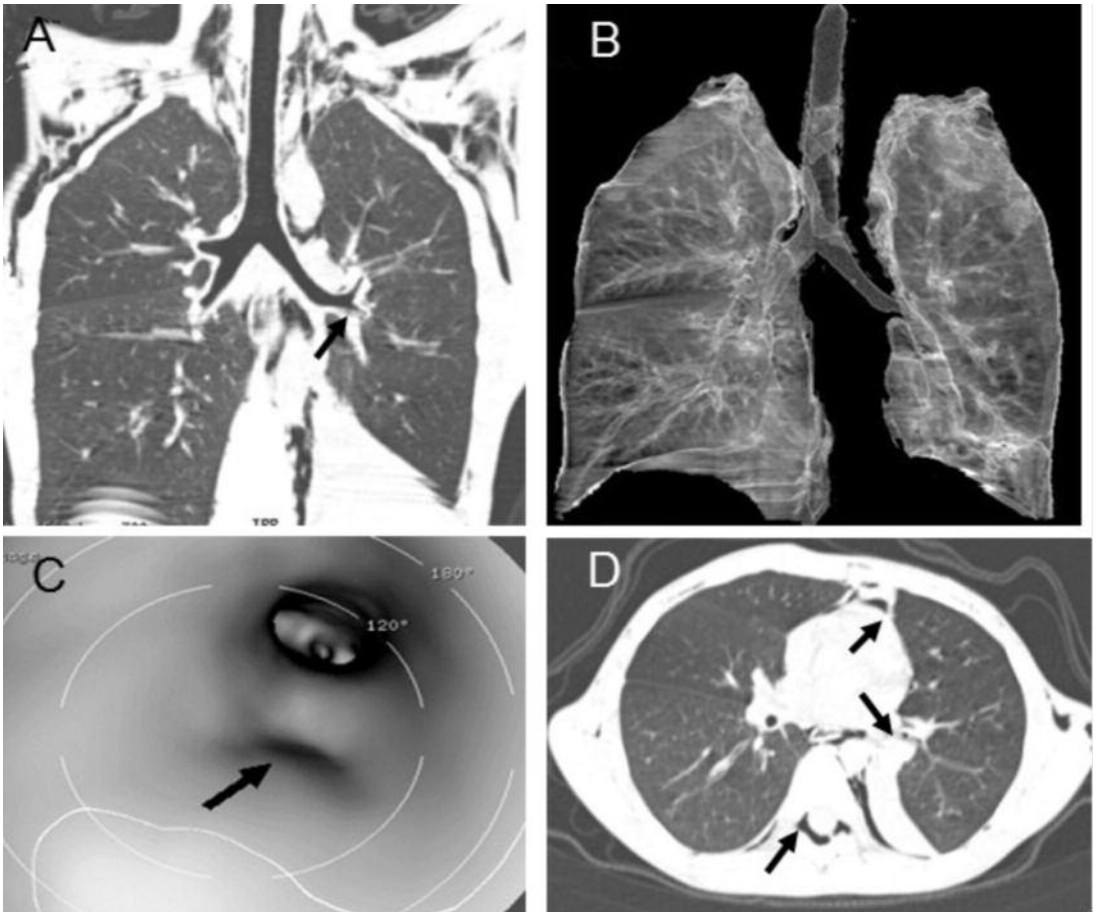

Figure 3. A 7-year-old boy who presented with coughing and wheezing for 3 days. ***(A)*** Multiplanar reconstruction (MPR) image. ***(B)*** Ray sum image. ***(C)*** CT virtual endoscopy (CTVE) image, and ***(D)*** An axial image revealed that the left lower bronchus was completely blocked (black arrows in ***A, C, D***). In ***A*** and ***D***, the left lower lobe shows atelectasis and serious complications including pneumomediastinum, subcutaneous emphysema, pneumatorrhachis. A peanut was extracted from the location during the bronchoscopy examination.

Discussion

Pediatric airway foreign body aspiration is associated with a high rate of airway distress, morbidity, and mortality, especially in children younger than 3 years of age. In 2006, there were 4100 deaths related to foreign body aspiration in the United States (1.4 per 100 000)[4]. The morbidity and mortality can be reduced by expedient diagnosis and treatment.

In this retrospective study, we analyzed 1501 cases of children who underwent three-dimensional CT imaging based on a suspicion of FBA, and 590 of them had foreign bodies in their airways. Eighty percent of all cases of FBA were in the 1-3 year age group. Young children are more prone to inhaling foreign bodies for several reasons. First, they have poor chewing ability due to a lack of posterior dentition (they lack cuspid molars necessary to grind food into a smooth bolus). Second, they have immature swallowing coordination and tend to be easily distracted when eating (e.g. laughing, playing or running)[5]. Third, young children explore their world by introducing objects into their mouth. Additionally, with their increased ambulation, there may be less adult supervision, and thus the likelihood of aspiration is higher.

The time lapse between aspiration and seeking treatment at the hospital ranged from 30 minutes to 6 months. Parental recall of a choking or gagging event followed by a cough is highly suspicious of foreign body aspiration. However, this initial event may be short lived and the child may be asymptomatic for one or more weeks, often leading the parents to forget about the episode. In

the absence of a choking or aspiration event, the diagnosis may be delayed for weeks to months. Sometimes symptoms are not easily understood. Persistent cough, recurrent fever, pneumonia, haemoptysis, malaise and failure to thrive are suspected signs of chronic FBA. Other studies also document long delays in seeking treatment following FBA[6].

In our investigation, we found that children were directly referred to the ENT department first in most cases. We also note that cases of FBA occurred more frequently in boys, which was consistent with other reports[7-9]. A history of a choking episode or coughing spell was usually obtained from the parents, but a definitive history of foreign body aspiration was available in only 52.88% of the cases in our study. This may be due in part to the ambulatory nature of children in the vulnerable 1-3 year age group who may have been out of parental view during the acute aspiration episode, thus there may not have been a witness to supply the incriminating clinical history. Many children underwent the three-dimensional CT based on their clinical symptoms alone. Thus, a very high degree of clinical suspicion is necessary in order to avoid any delay in the retrieval of the foreign body. The presenting symptoms of foreign body aspiration may vary depending on its location, size, and chronicity. The children may be comfortable and in no apparent distress or may present in extremis with impending airway failure. Coughing, choking, sputum, dyspnea, fever and sudden onset of wheezing were the main symptoms of FBA in our study, but these symptoms are not specific, and they could also indicate other respiratory diseases. Some children were treated for respiratory infections or asthma, which delayed the correct diagnosis, so if there is clinical suspicion of foreign body aspiration, a three-dimensional CT examination is necessary to avoid any delay in foreign body removal.

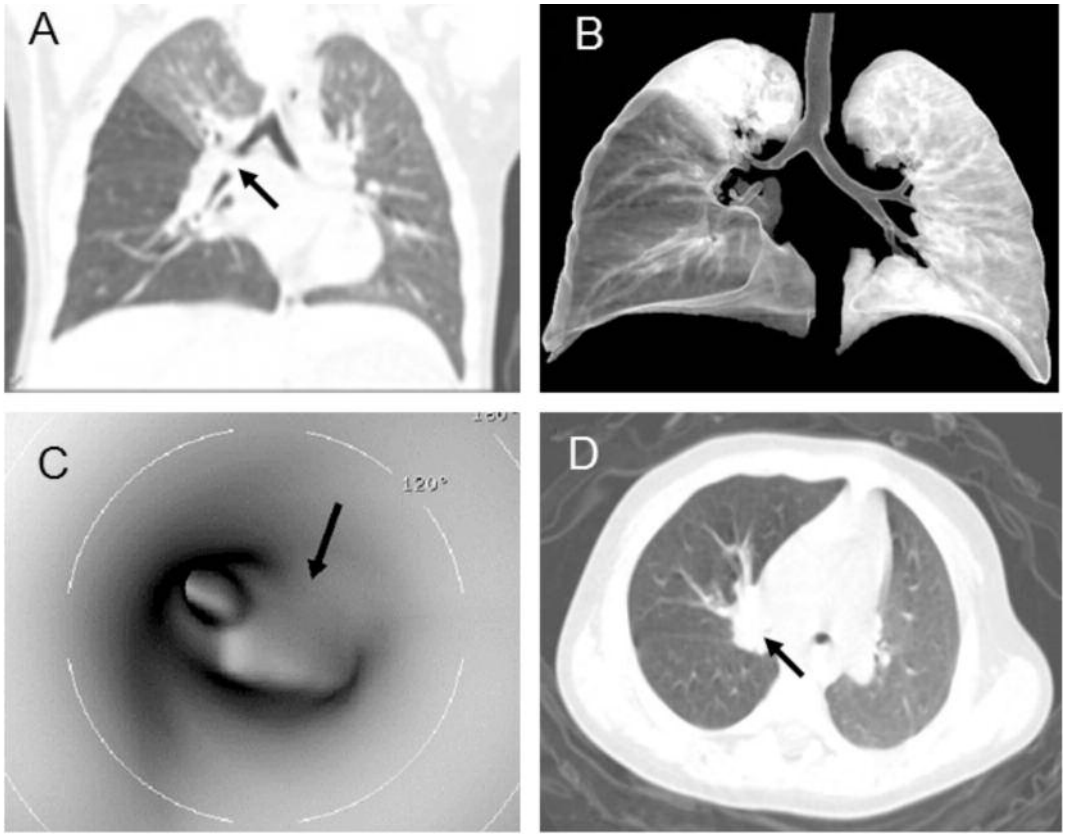

Figure 4. A 12-month-old boy was admitted to the hospital for rale in the pharynx for 20 days. He had a history of eating peanuts and sunflower seeds. ***(A)*** Multiplanar reconstruction (MPR) image. ***(B)*** Ray sum image. ***(C)*** CT virtual endoscopy (CTVE) image, and ***(D)*** An axial image revealed the right intermediate bronchus was blocked (*arrows* in A, C, D). In ***A, B*** and ***D,*** emphysema in the right middle and lower lobes can be observed, but no foreign body was found during the bronchoscopy examination.

There are several reasons why chest radiography and bronchoscopy examination should not be used as a first choice in children with suspected FBA. Chest radiography diagnosis of foreign body aspiration is challenging for several reasons. Although radiopaque foreign bodies are obvious, almost 90% of foreign bodies are radiolucent and 30% of chest radiographs show normal findings in children who aspirate foreign bodies. The sensitivity and specificity of chest radiography for foreign body detection have been reported to be only 68% and 67%, respectively[10]. Additionally, it is not easy to observe the exact locations and shapes of the foreign bodies with this technique. Moreover, the absence of positive radiological findings does not exclude the diagnosis of foreign body aspiration. Contrary to the general impression that bronchoscopy is simple and safe in pediatric patients, there are several complications associated with this procedure that is performed under general anesthesia in pediatric patients. In contrast, three-dimensional CT images could clearly differentiate the different shapes of aspirated foreign bodies, and almost all of foreign bodies showed high density in the CT images.

The three-dimensional reconstructed CT images, allowed us to not only observe the locations and the shapes of foreign bodies, but also the complications caused by FBA. Complications were more likely to occur if the foreign body was longstanding. Indeed if the FBA event occurred within 24 hours of diagnosis, complications were rarely observed. We also found that if the foreign bodies were located in the trachea, only 14.30% of patients had complications. This may be due to the increased width of the trachea, which is difficult to obstruct completely. Complications were observed in 79.84% of all cases of FBA in our study. Emphysema, atelectasis and pneumonia were the main complications of FBA. When the airway was locally obstructed, more air entered into the airway than came out of the airway, causing emphysema. When the airway was completely obstructed, less air entered into the airway than came out, while air in the airway was gradually absorbed, causing atelectasis. As a result of the accumulation of secretions near the site of inflammation, pneumonia often occurred. There were 7 cases in our study of serious complications such as pneumothorax, pneumomediastinum, subcutaneous emphysema, and pneumorrhachis. Pneumomediastinum and pneumothorax may have been due to the extension of trapped air from alveolar rupture along the perivasculature. There were two reasons for the pneumomediastinum caused by bronchial foreign bodies: first, due to obstructive emphysema, the blood vessels attached to the alveolae were excessively suppressed, and the chest negative pressure was so high that the bottom the vessel fractured, causing the air to enter into the connective tissue around the blood vessels. The mediastinum had negative pressure and the air along the peripheral blood vessels was squeezed and entered into the mediastinum. Second, the bronchioles burst and the air entered into the tissues around the bronchioles and finally entered into the mediastinum. Similarly, severe pneumomediastinum affected the posterior mediastinum. Air entered into the prevertebral fascia along the thoracic spinal nerve sheath into the outside of the spinal canal. Due to gravity, intracranial epidural gas accumulated.

Foreign bodies were located in the right main bronchus, left main bronchus and trachea, at a frequency of 26.95%, 33.39% and 12.54%, respectively. In adults, the likelihood of a foreign body entering the right bronchial tree is much higher because the right bronchus is wider and more vertical than the left. The differences are less pronounced in our study because the airway in children is immature and the differences between the right and left bronchus trees in children are not significant.

Most of the foreign bodies that we retrieved were organic objects. We found that peanuts were the most common foreign bodies accounting for 340 cases (57.63%) of FBA followed by sunflower seeds. Together, they accounted for 79.63% of all cases. This result may be due to the food habits in our area. Nuts may not be properly masticated due to the absence of molar teeth in young children and nuts fragmented by the incisors are much more likely to be aspirated. Other types of foreign bodies included semen juglandis, Chinese chestnut, soybean, fruits, bone, rice and other object such as whistles, soil, and plastic objects. We also found that in older children, the more likely culprits were non-organic products, consistent with other published reports[11,12].

This study showed that the sensitivity and specificity of three-dimensional reconstructed CT imaging at evaluating the presence of a foreign body were 99.83% and 99.89%, respectively. This technique is a promising, non-invasive modality for identifying FBA. It enables simultaneous visualization of inner and outer structures of the tracheobronchial tree (extra and intra-lu-

minal anatomy), thus clearly showing the cause of fibreoptic findings. It can lead to the correct diagnosis, assist and direct fibreoptical bronchoscopy, and can give additional information when FBA is suspected. This technique does not require additional radiation exposure, but provides additional information to the spiral CT examination. Haliloglu et al[13] compared CT virtual bronchoscopy and rigid bronchoscopy in cases of foreign bodies aspiration in children and found that CT fiberoptic bronchoscopy showed similar results to rigid bronchoscopy and revealed the exact location of the foreign body.

Three-dimensional CT imaging also has some drawbacks. The main drawback is that it cannot remove foreign bodies, thus it cannot be used as a therapeutic tool. Also, a foreign body that results in an incomplete obstruction may present as complete obstruction on three-dimensional CT images. Furthermore, retained secretions and artifacts may result in false-positives, as 3D-CT cannot show the morphology, vascularity or color of the mucosa, and it cannot detect endoluminal lesions smaller than 2-3 mm. In our study, there was one false-positive case and one false-negative case. The former may have occurred because the three-dimensional reconstructed CT image could not distinguish a secretion from a foreign body, the latter occurred because the foreign body was an apple fragment too small to be observed in the three-dimensional CT images.

Conclusions

FBA is a serious problem among children, but it is completely preventable. Parents of young children should not give them peanuts, sunflower seeds, beans and other food that is easy to aspire. They should also ensure that their children do not run or jump when they are eating, and teach them not to put toys into their mouths. In summary, when respiratory symptoms are present, parents and doctors must be vigilant about the clinical history, conduct a careful physical examination combined with three-dimensional CT imaging. Together, these practices will enable expedient identification of a foreign body, so that bronchoscopy can be performed in a timely manner.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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