RESEARCH PAPER

Radiodensity on Serial Chest *X*-rays for the Diagnosis of Foreign Body Aspiration in Children

[*]Eun Song Song, [*†]Dong Kyun Han, Hwa Jin Cho, [‡]In Seok Jeong, [$]Namsik Yoon, Jae Sook Ma And Young Kuk Cho

From Departments of Pediatrics and [‡]Thoracic and Cardiovascular Surgery, Chonnam National University Hospital, Chonnam National University Medical School;[†]Departments of Pediatrics, Chonnam National University Hwasun Hospital, Chonnam National University Medical School and [$]The Heart Center of Chonnam National University Hospital, the Research Institute of Medical Sciences of Chonnam National University, Gwangju, South Korea.

*Correspondence to: Young Kuk Cho, Department of Pediatrics, Chonnam National University Medical School, 42 Jebong-ro, Dong-gu, Gwangju 501-757, South Korea. youngcx@hanmail.net. *ESS and DKH contributed equally to the paper.*

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Objectives: To evaluate the utility of measuring lung radiodensity from chest *X*-ray for the diagnosis of foreign body aspiration

Methods: Records of 59 children with foreign body aspiration were retrospectively reviewed. Lung radiodensity and radiodensity ratio (right/left lung radio density) before and after foreign body removal were measured. Radiodensity was calculated as the relative score compared with the tenth thoracic vertebra body (100 points) and the background (0 point). The change of radiodensity ratio (difference in radiodensity ratio of the second *X*-ray from that of first *X*-ray) was compared between 22 patients (foreign body group) and 22 normal subjects (control group).

Results: In the group of foreign body in the left bronchus, the mean (SD) radiodensity of the left lung [53.5 (12.8)] was lower than that of the right lung [60.8 (7.7), $P<0.01$] and it increased after foreign body removal [60.0 (6.9), $P=0.02$]. The radiodensity ratio decreased from 1.20 (0.30) to 0.96 (0.09) ($P<0.01$) after foreign body removal. In the group with a foreign body in the right bronchus, the radiodensity of the right lung [51.8 (12.8)] was lower than that of left lung [62.0 (11.7), $P=0.03$], and it also increased after foreign body removal [58.4 (9.6), $P=0.03$]. The change of radiodensity ratio in the foreign body group [15.7 (17.8)%] was higher than the control group [5.4 (4.3)%, $P=0.01$] and the cutoff value was 7.5%.

Conclusion: Radiodensity from chest *X*-ray could be a useful tool for diagnosing foreign body aspiration in children.

Keywords: *Bronchial foreign body aspiration, Chest radiography, Diagnosis*.

Foreign body aspiration is one of the most common causes of accidental death in children under the age of 3 years [1]; the gold standard for diagnosis is bronchoscopic inspection [2]. However, bronchoscopy is an invasive procedure that requires general anesthesia and may occasionally result in serious complications in children [3]. Recently, chest multidetector computed tomography (CT) was introduced as a noninvasive diagnostic technique for foreign body aspiration in children, but it has a radiation exposure hazard, in addition to reports of false positive results [4-6].

If foreign body aspiration is suspected in adults or well cooperating older children, patients should undergo both inspiratory and expiratory chest *X*-ray [7]. However, it is difficult to get chest *X*-ray at each cycle of respiration in younger children. For them, repetitive chest *X*-ray can be helpful [8].

The radiodensity of *X*-ray images has been used for evaluation of physical properties of materials, such as teeth, stone, and medications in the human body [9-11]. Unilateral emphysema or decreased radiodensity is the typical radiological sign of foreign body aspiration, due to the check-valve obstruction exerted by the foreign body [8]. The purpose of this study was to evaluate the usefulness of measuring the radiodensity from chest *X*-ray for the diagnosis of foreign body aspiration.

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Methods

Records of 59 patients <15 years of age who underwent bronchoscopy through a rigid bronchoscope for the treatment of foreign body aspiration at Chonnam National University Hospital, between January 2003 and December 2009 were retrospectively reviewed. This study was approved by the Institutional review board of the Chonnam National University Hospital. Among these, 22 patients (Aspiration group) had two serial chest *X*-rays before bronchoscopy. Serial chest *X*-rays were also collected from 22 patients without abnormal pulmonary infiltration and respiratory symptoms (control group) from January 2003 to December 2009. Reviewed parameters included patient age, gender, durations of symptoms before bronchoscopy, initial chest radiographic findings, types of foreign bodies, anatomic location of foreign body, length of hospital stay, and complications.

Radiodensity of chest X-rays: In all patients, conventional anterior-posterior chest *X*-rays were performed in the supine position using a Bucky table TH2 (Philips Medical System, Hamburg, Germany) and read with an ADC Compact Plus storage phosphor system (Agfa, Leverkusen, Germany). To prevent chest rotation, the chest *X*-rays were rechecked when the tracheal shadow deviated from the mediastinal area. Chest radiographic digital data were sent to a picture archiving and communications system (PACS; Marotech, Seoul, Korea). Photoshop CS2 imaging editing software (Adobe Systems, San Jose, CA, USA) was used to measure the radiodensity using the histogram tool [12]. Based on different exposure to radiation, the following radio-density scoring system was used. Lung radiodensity was determined relative to the average radiodensity of the body of the tenth thoracic vertebra (100 points) and the background (0 points), which was outside of the body. The margin of the lung was delimited by the rib cage, cardiac border, and diaphragm (***Fig.* 1**). The lung radiodensity was calculated as (average radiodensity of the lung [A or B] – average radiodensity of background [D]) ÷ (average radiodensity of the 10^{th} thoracic vertebra body [C] – average radiodensity of the background [D]) ×100 (***Fig.* 1**) [9]. The radiodensity ratio was defined as the relative radiodensity of the right lung compared to the left lung (radiodensity of the right lung ÷ radiodensity of the left lung). The change of radiodensity ratio was defined as the relative change in the radiodensity of the second *X*-ray from that of first *X*-ray for comparison of the FBA and control groups. It was calculated (%) as absolute value (radiodensity ratio of the first *X*-ray – ratio of radiodensity of the second *X*-ray) × 100. To evaluate inter-observer variability in radiodensity measurements, two independent observers blindly calculated the scoring system at different times in the first 59 chest *X*-rays before foreign body removal. Intra-observer variability analyses also were performed several months after the primary measurements in 56 chest *X*-rays after foreign body removal.

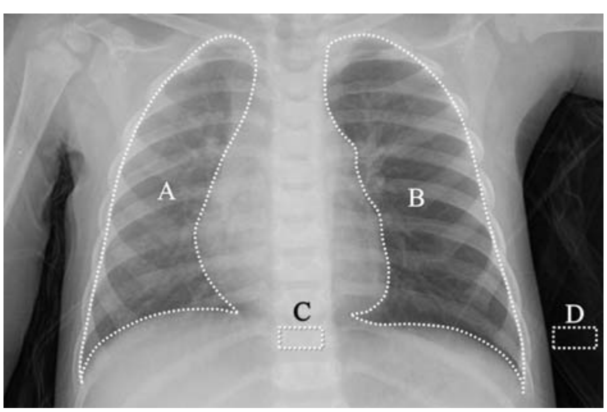

FIG.1 *Chest X-ray AP-Supine showing the areas of radiodensity measurement.*

Radiodensity of chest CT: Among 59 patients with FBA, 30 (50.8%) received a chest CT using a HiSpeed Advantage helical scanner (GE Medical Systems, Milwaukee, WI, USA) with the patient in the supine position. CT was performed using 1-mm slice collimation from the lung apices to the level of the adrenal glands with use of a conventional algorithm. The scanning was performed under sedation without a breath hold. Chest CT digital data were sent to the PACS. Lung radiodensity by CT was calculated as average of mean value of lung Hounsfield units (HU) on each plane.

Statistical analyses: Data are expressed as mean (SD). The statistical analyses were performed with the Student's t test or Wilcoxon signed rank sum test, using SPSS software for Windows version 19.0 (SPSS, Chicago, IL, USA). Receiver operator characteristic analysis was performed to define the change of radiodensity ratio at which the sensitivity and specificity were optimal. Correlations were tested by using the simple linear regression method. P values <0.05 were considered statistically significant.

RESULTS

***Table* I** gives the baseline characteristics of the study subjects. The most common abnormal finding of chest *X*-ray was hyperinflation (37 cases; 62.7%). Other alterations were atelectasis (4 cases; 6.8%) and segmental atelectasis with hyperinflation (2 cases; 3.4%). The other 16 cases (27.1%) did not have definitive *X*-ray abnormality. In three cases (5.1%), the foreign bodies were visible. A chest CT was checked in 30 patients (50.8%). Among them, 21 (70%) had definitive or suggestive foreign body, such as material in bronchus, but the remaining 9 (30%) had no evidence of foreign body. The most common abnormal finding from chest CT was hyperinflation (18 cases; 60%), followed by atelectasis (5 cases; 16.7%), segmental atelectasis with hyperinflation (3 cases; 10%), and pneumonic infiltration (2 cases; 6.7%). In contrast, two showed normal CT findings. The origin of aspirated foreign body was predominantly vegetal (79.9% of the cases), followed by bone (8.5%) and metallic (6.8%). There was no necessity to perform thoracotomy. No death occurred.

TABLE I PATIENT CHARACTERISTICS AND CLINICAL PRESENTATIONS ACCORDING TO THE LOCATION OF THE FOREIGN BODY

	Left bronchus (n=36)	*Right bronchus (n=14)*	*Trachea or both bronchi (n=9)*	*Total (n=59)*
Age (mo), mean (SD)	20.5 (12.3)	22.5 (6.7)	22.6 (10.8)	21.3 (10.9)
Boys, *n* (%)	21 (58.3)	7 (50.0)	6 (66.7)	34 (57.6)
Aspiration history, *n* (%)	30 (83.3)	9 (64.3)	8 (88.9)	47 (79.7)
Lag time (d), mean (SD)	13.5 (25.9)	12.9 (26.2)	2.9 (6.5)	9.7 (21.2)
Initial presentation, *n* (%)				
Cough	28 (77.8)	12 (85.7)	5 (55.6)	45 (76.3)
Dyspnea	7 (19.4)	5 (35.7)	4 (44.4)	16 (27.1)
Fever	7 (19.4)	4 (28.6)	0 (0)	11 (18.6)
Vomiting	4 (11.1)	3 (21.4)	2 (22.2)	9 (15.3)
Cyanosis	5 (13.9)	1 (7.14)	2 (22.2)	8 (13.6)
Wheezing, *n* (%)	13 (36.1)	2 (14.3)	4 (44.4)	19 (32.2)
Decreased breath sounds, *n* (%)	4 (11.1)	1 (7.1)	0	5 (8.4)

TABLE II LUNG RADIODENSITY ON SERIAL RADIOGRAPHS BEFORE AND AFTER FOREIGN BODY REMOVAL (*N*=22)

Location of FB	*Right lung*		*Left lung*	
	Before FB removal	*After FB removal*	*Before FB removal*	*After FB removal*
Left bronchus	60.8 (7.7)	57.8 (8.8)	53.5 (12.8)*	60.0 (6.9)#
Right bronchus	51.8 (12.8)	58.4 (9.6)*	62.0 (11.7)*	61.0 (9.6)
Trachea both bronchi	56.9 (7.1)	61.9 (6.7)	57.0 (6.4)	64.4 (10.9)
‡Control (*n*=22)	53.9 (8.2)		56.2 (8.6)	

*FB: Foreign body; Data are presented as mean (SD). *P<0.05 vs right lung before FB removal. #P<0.05 vs left lung before FB removal; ‡Children without history of foreign body aspiration and with normal chest X-ray.*

Inter-observer and intra-observer variability in the measurement of the lung radiodensity from chest *X*-ray showed excellent correlation (r = 0.96; *P*< 0.01 and r = 0.98; *P*<0.01, respectively). The mean inter-observer and intraobserver variance were 1.2 (2.7) and 0.8 (1.5), respectively.

In those with a foreign body in either bronchus, the radiodensity of the ipsilateral lung was lower than that of the opposite lung (*P*<0.05) and it was significantly increased after foreign body removal (***Table*** **II**). ***Table*** **III** presents the mean radiodensity ratio before and after foreign body removal.

The mean age of the FBA group (*n*=22) undergoing serial chest *X*-ray was 23.6 (15.7) months and that of the control group (*n*=22) was 27.3 (15.8) months. The change of radiodensity ratio in the FBA groups [15.7 (17.8)] before foreign body removal was significantly higher than the control groups [5.4 (4.3) %, *P*=0.01], and the cutoff value in change of radiodensity ratio was 7.5% (area under the receiver operating characteristic curve (AUC)=0.705, sensitivity 63.6%, and specificity 72.7%). Among 13 normal findings of initial chest *X*-ray, 6 (46.1%) underwent serial chest *X*-ray. The change of radiodensity ratio of 3 patients (50.0%) exceeded 7.5%. After foreign body removal, the change of radiodensity ratio in the FBA group was significantly decreased to 6.9 (4.3) % (*P*=0.01) and the cutoff value in change of radiodensity ratio was 7.4% (AUC=0.725, sensitivity 63.6%, and specificity 78.9%).

TABLE III RADIODENSITY RATIO BEFORE AND AFTER FOREIGN BODY (FB) REMOVAL

Location of FB	*Before removal*	*After removal*
Left bronchus	1.20 (0.30)	0.96 (0.09)*
Right bronchus	0.87 (0.33)	0.96 (0.07)
Trachea or both bronchi	1.00 (0.07)	0.97 (0.11)

*FB: Foreign body; Data in mean (SD). *P<0.05 vs before FB removal.*

WHAT IS ALREADY KNOWN

- Conventional chest radiography has very limited role in diagnosis of foreign body aspiration in children.

WHAT THIS STUDY ADDS?

- Radiodensity measurement in digital chest *X*-rays could be a useful tool for diagnosing foreign body aspiration in children.

Among 35 patients with a foreign body in the left bronchus, 15 patients (42.9%) received chest CT. The CT radiodensity of the right lung was –609.2 (75.3) HU and that of the left lung was –655.7 (285.6) HU (*P*=0.08). Among 14 patients with foreign body in the right bronchus, 9 patients (64.3%) received chest CT. The CT radiodensity of the right lung was –723.2 (106.6) HU and that of the left lung was –591.5 (79.8) HU (*P*=0.01). Among 10 patients with foreign body in both lungs or in the trachea, 6 patients (60.0%) received chest CT. The CT radiodensity of the right lung was –654.0 (82.6) HU and that of the left lung was –660.8 (31.3) HU (*P*=0.60). Good correlation was observed between CT radiodensity and chest *X*-ray radiodensity (r = 0.64; *P*<0.01; ***Fig. 2***).

DISCUSSION

In this retrospective study, the radiodensity of the lung ipsilateral to foreign body aspiration FBA was found to be decreased, indicating hyperinflation caused by check valve type obstruction, whereas the radiodensity of the contralateral lung was increased. After removal of the foreign body, the radiodensity was normalized in both lungs. The radiodensity ratio was normalized after removal of the foreign body, with values similar to normal control.

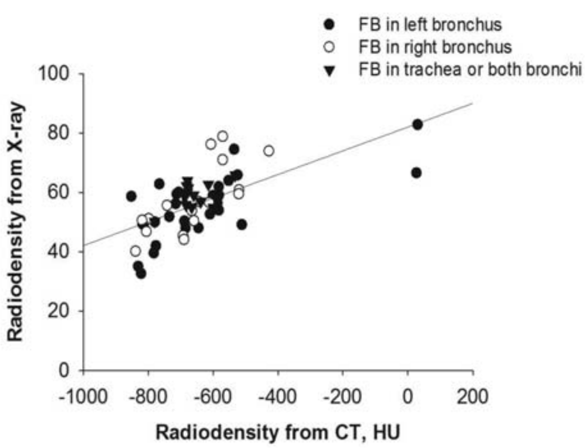

FIG. 2 *Correlation between lung radiodensity from X-ray and those from computed tomography (CT) according to the locations of foreign body (FB).*

We could not perform the inspiratory and expiratory chest *X*-rays [14], because 93% of patients in this study were children under the age of 3 years. Therefore, we checked serial chest *X*-ray regardless of respiration and calculated the change of radiodensity ratio. Recently, multi-detector CT was introduced as a non-invasive technique that provides realistic 3-dimensional views of the tracheobronchial tree [15]. We also evaluated the accuracy of chest radiodensity compared with chest CT. In our study, the radiodensity from *X*-ray showed good correlation with radiodensity from CT.

There were some limitations of this study. Among 59 patients with FBA, only 22 were checked with a repeat chest *X*-ray before foreign body removal. Although all chest *X*-rays showed that the trachea shadow was located in the mediastinal area, *X*-ray radiodensity could be affected by body position or rotation.

In conclusion, this study indicates that the radiodensity of the chest *X*-ray could be a useful tool for diagnosing foreign body aspiration and detecting the location of the foreign bodies in children.

Contributors: ESS, DKH, YKC: study planning, design and writing of the manuscript; HJC, JSM: data collection and analysis; ISJ, NY: study planning and comment. ESS and DKH contributed equally to all aspects of this paper.

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Competing interests: None stated.

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