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Avoiding unnecessary bronchoscopy in children with suspected foreign body aspiration using computed tomography☆

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ABSTRACT

Background: Bronchoscopy is the standard of care for diagnosis and treatment of foreign body aspiration (FBA). Drawbacks of this approach include its invasiveness, the potential for exacerbation of reactive airway disease, and the need for general anesthesia. Computed tomography (CT) can potentially identify patients with FBA, thereby avoiding unnecessary bronchoscopies in patients with at-risk reactive airways.
Methods: A retrospective review was performed to identify patients who underwent CT and/or bronchoscopy for suspected foreign body aspiration (FBA) from June 2012 to September 2018. Variables included clinical history, exam findings, radiographic findings, and operative findings. A telephone survey was performed for patients who had a CT without bronchoscopy. Three radiologists performed rereads of all CTs.
Results: A total of 133 patients were evaluated for FBA, and 84 were treated with bronchoscopy. For those with a CT demonstrating a foreign body, findings were confirmed on bronchoscopy in 17/18 (94.4%). For those with bronchoscopy alone, 39/64 (60.9%) were found to have a foreign body ($p < 0.01$). CT excluded FBA in 49 patients. Sensitivity was 100%, specificity was 98%, and interobserver reliability was excellent ($\kappa = 0.88$).
Conclusion: CT is an accurate and reliable diagnostic tool in the evaluation of FBA that can increase the rate of positive bronchoscopy.
Type of study: Retrospective comparative study.
Level of evidence: Level III.

Contents

Foreign body aspiration (FBA) is a relatively common problem in the pediatric population, representing approximately 17,500 emergency room visits and 2000 inpatient hospitalizations in the United States each year [1]. It is most commonly seen in patients younger than four years of age [2–17]. Consequences can be devastating, with 2.2% of

☆ **How this paper will improve care:** A retrospective review of patients with suspected foreign body aspiration suggests that those who undergo a low-dose CT scan of the chest are significantly less likely to receive unnecessary bronchoscopies. Specificity is 98% and sensitivity is 100%.

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hospitalized patients suffering an anoxic brain injury and with a mortality rate of 1.8% [1].

Grossly abnormal physical exam findings and specific plain film findings (evidence of radiopaque objects, unilateral hyperexpansion, or unilateral atelectasis) confirm the diagnosis, and these patients should undergo bronchoscopy [3–5,9–13,16,17]. Unfortunately, the clinical picture is often less clear, and the provider must decide which patients should undergo bronchoscopic evaluation. Plain films are used routinely (90%–100% of patients), but do not exclude the diagnosis, as approximately one-third of patients with FBA will have a normal chest X-ray (CXR) [3–20]. Algorithms and multivariable models utilizing history, physical exam, and plain films still only reach sensitivity and specificity of approximately 70% and 60%, respectively [16,17].

Although rigid bronchoscopy is the gold standard for diagnosis and the definitive therapeutic intervention for FBA, it remains an invasive procedure that requires exposure to anesthesia in a patient with respiratory symptoms, and which risks exacerbation of reactive airway disease. Complications ranging in severity from temporary desaturation to cardiac arrest occur at a rate of 2.6%–14%, with major complications occurring in 1% and mortality in 0.42%–0.8% [2,3,10,17,21]. For patients who do undergo bronchoscopy for suspected FBA, the rate at which this diagnosis is confirmed with bronchoscopy varies widely in the literature, from 30% to 93% [1,4,5,9,10,12–17]. A diagnostic tool that is both superior to plain films and less invasive than bronchoscopy is needed; this void could potentially be filled with computed tomography (CT).

The purpose of this study was to compare patients presenting with possible FBA who underwent bronchoscopy alone to those who had a low-dose CT scan of the chest, with or without bronchoscopy. The primary outcome was the rate of positive bronchoscopy, which we hypothesized would be greater in the group undergoing a preprocedure CT. The secondary outcomes were to evaluate the impact of CT on complication rate and procedure time, and to examine the diagnostic properties of CT for the diagnosis of FBA.

1. Methods

1.1. Study design and patient selection

All patients younger than 18 years of age who were evaluated for foreign body aspiration at a single tertiary children's hospital from June 1, 2012 to October 1, 2018 were included for retrospective review. Patients who underwent bronchoscopy were identified by current procedural terminology (CPT) code (31,622 and 31,535), ICD-9 code (33.2 and 98.1 codes), and ICD-10 code (0 BC codes). At our hospital, the on-call Radiologist began routinely recommending a volumetric CT Chest for patients presenting with suspected foreign body aspiration who underwent a foreign body series of chest X-rays; the Emergency Department physician would then decide whether to order the CT, usually in consultation with the on-call Pediatric Surgeon. Patients who underwent CT were identified by searching all dictated CT Chest reports including the phrase “foreign body” using mPower™ (Nuance Communications, Burlington, MA). A representative CT image showing an aspirated foreign body is shown in Fig. 1. The charts of these patients were then cross-referenced and reviewed to ensure the concern at the time of presentation was FBA. All patients who underwent bronchoscopy emergently were excluded from the study. Approval for this retrospective study was granted by the Akron Children's Hospital Institutional Review Board (IRB Number 1316740-1).

1.2. Follow-up telephone survey

In order to validate negative CT findings, all patients who had FBA ruled out by normal chest CT and who did not undergo bronchoscopy were included in a follow-up telephone survey. Patients' families who did not speak English or who did not have a working telephone number listed in their medical record were excluded. The included patients were mailed an information sheet describing the study. Two weeks after sending the information sheet, phone calls were made to the patients' families, and permission was obtained for participation in a survey. The survey addressed persistent respiratory symptoms, readmission to the hospital for respiratory symptoms, whether the patient underwent a bronchoscopy after discharge, and, if so, whether a foreign body was found.

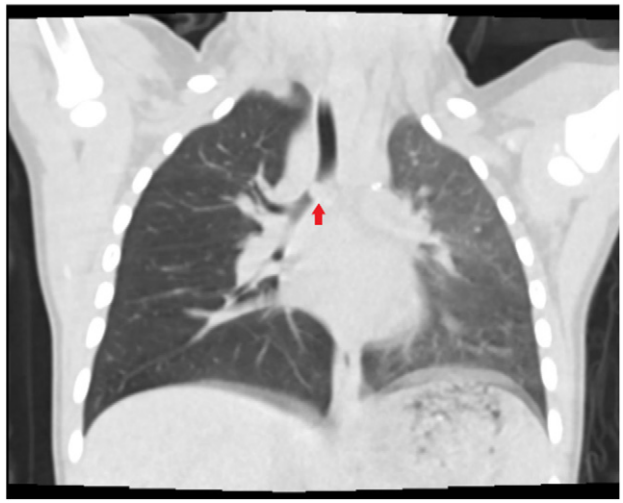

Fig. 1. Coronal view of an aspirated foreign body on computed tomography, with arrow marking the location of the foreign body.

1.3. Interobserver variability

All patients who underwent a CT Chest for evaluation of possible foreign body aspiration had their images reread by two of three staff radiologists, blinded to the initial read. Based on the initial read and the rereads, interobserver reliability was calculated.

1.4. Statistical analysis

Examination of data included calculation of full summary statistics followed by distribution-based statistical testing (Wilcoxon rank-sum test), which was completed to assess for potential differences in continuous (chi-squared test of independence for categorical) demographic and baseline characteristics, as well as clinical outcome measures.

A receiver operating characteristic (ROC) curve analysis was performed to assess the potential diagnostic ability of both CT and CXR on FBA. Patients were considered to be true negatives if no foreign body was found on bronchoscopy, if they responded to the survey and did not have a foreign body found after discharge, or if they had a normal respiratory exam in the electronic medical record after discharge. Patients without follow-up (either by survey or in the EMR) were excluded from this analysis. Statistical analyses were completed using SAS 9.4 / 14.2 © (SAS Institute, Cary, NC). All testing was two-tailed and evaluated at the type I error rate of $\alpha = 0.05$ level of statistical significance.

2. Results

A total of 142 patients were evaluated for foreign body aspiration during the study period; nine were excluded owing to an emergent presentation, leaving 133 patients. A description of the patient population is shown in Fig. 2. There was no evidence of baseline differences between the two groups (CT ± bronchoscopy vs. bronchoscopy only) for

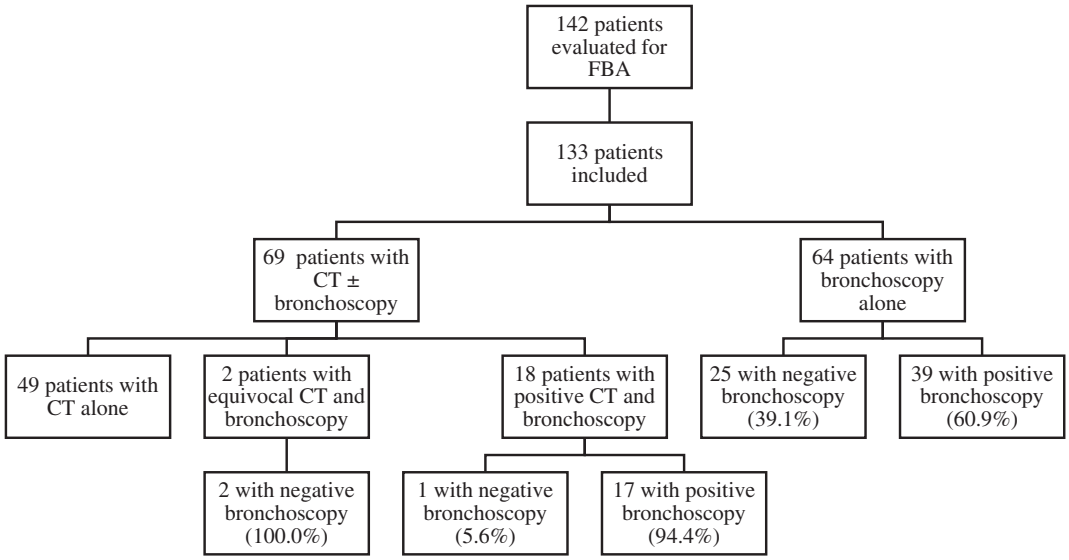

Fig. 2. Flow diagram of patient population.

age, duration of symptoms, or gender ($p = 0.78$, 0.54, and 0.28, respectively). The median age of the patients was 1.8 years (range, 0.18 to 17.28 years) and the majority were male (81/133, 60.9%). Of the studied patients, 64 (48.1%) were evaluated with bronchoscopy alone, and 69 (51.9%) were evaluated with CT with or without bronchoscopy. Five of the 69 patients (7.2%) undergoing a CT required sedation for the scan (four with intranasal midazolam, one with intravenous midazolam). Ten patients (14.5%) had their CT performed at a satellite hospital. The average dose-length product (DLP) of the low-dose CT Chest for all patients was 50.1 ± 67.7 mGy-cm; since DLP is dependent on patient size, when limiting only to patients under the age of 4, the average was 28.6 ± 5.4 mGy-cm. The baseline characteristics of the groups are shown in Table 1.

In terms of the primary outcome, there were 64 patients who underwent bronchoscopy alone to determine presence or absence of a foreign body, versus 20 patients who had both CT and bronchoscopy. Details of the procedural findings are shown in Table 2. Of those who had bronchoscopy alone, 39 (60.9%) had a foreign body found during the procedure. Of the 20 patients with a prebronchoscopy CT, 18 were read as positive; 17 of these patients (94.4%) had a foreign body found on bronchoscopy. Patients with only a bronchoscopy were significantly less likely to have a positive bronchoscopy than those who had a positive CT prior to bronchoscopy (RR 0.71, 95% CI 0.59–0.91, $p < 0.01$). The one false-positive was noted to have a motion artifact at the level of concern at the time of the study. For the 17 patients who had their foreign body confirmed, 16 (94.1%) had the location of the foreign body correctly predicted on CT; the one discordant finding located the foreign body in the right lower lobe bronchus instead of the predicted bronchus intermedius. There were two patients who had a CT read that was equivocal, but which favored pneumonia over FBA; both of these patients had negative bronchoscopies.

In terms of the secondary outcomes, patients who underwent bronchoscopy alone were no more likely to suffer a complication than those who had a CT with or without bronchoscopy ($p = 0.13$). The complications and outcome measures are listed in Table 3. There was also no evidence of significant differences between the groups in terms of steroid use, time to procedure, length of procedure, or length of stay ($p = 0.62$, 0.53, 0.20, and 0.05, respectively). The median time to bronchoscopy for all patients was 6.5 h (IQR 3.1–13.4 h); the median time to a CT result was 3.0 h (IQR 2.2–5.0 h). This difference was statistically significant ($p < 0.01$).

Of the 49 patients who had a CT but did not undergo subsequent bronchoscopy, 44 were eligible for the follow-up telephone survey. There were 34 patients who responded to the survey, for a response rate of 77%; follow-up medical records were available for an additional nine patients. The median time to follow-up was 1.23 years (IQR 0.87–1.69 years). Three patients (9%) ultimately underwent bronchoscopy for their symptoms; none of these patients were found to have a foreign body on evaluation.

Table 1
Baseline characteristics between groups.

		Bronchoscopy-Only ($n = 64$)	CT ± Bronchoscopy ($n = 69$)	p-Value
	Median Age in Years (IQR)	1.9 (1.1–3.2)	1.8 (1.1–4.0)	0.70
	Number of Males (%)	42 (65.6)	39 (56.5)	0.28
	Median Duration of Symptoms in Days (IQR)	0.0 (0.0–2.0)	0.0 (0.0–4.0)	0.54
History	Choking (%)	42 (65.6)	42 (60.9)	0.57
	Dyspnea (%)	14 (21.9)	21 (30.4)	0.26
	Cough (%)	50 (78.1)	51 (73.9)	0.57
	Wheeze/Stridor (%)	38 (59.4)	38 (55.1)	0.62
	Tachypnea (%)	13 (20.3)	19 (27.5)	0.33
Physical Exam	Nasal Flaring (%)	5 (7.8)	3 (4.4)	0.40
	Retractions (%)	16 (25.0)	19 (27.5)	0.74
	Decreased Breath Sounds (%)	17 (26.6)	9 (13.0)	0.05
	Normal (%)	21 (33.3)	29 (46.8)	0.13
CXR	Hyperinflation (%)	27 (42.9)	22 (35.5)	0.40
	Atelectasis (%)	12 (19.0)	10 (16.1)	0.67
	Radiopaque Foreign Body (%)	7 (11.1)	2 (3.2)	0.09

Table 2
Details of bronchoscopic procedures.

Type of Foreign Body (%)	
Nut/Seed/Kernel	28 (50.0)
Other Organic	9 (16.1)
Inorganic	15 (26.8)
Unspecified	4 (7.1)
Location of Foreign Body (%)	
Trachea	5 (8.6)
Carina	4 (6.9)
Right Mainstem Bronchus	19 (32.8)
Right Upper Lobe Bronchus	1 (1.7)
Bronchus Intermedius	5 (8.6)
Right Middle Lobe Bronchus	1 (1.7)
Left Mainstem Bronchus	17 (29.3)
Left Lower Lobe Bronchus	2 (3.4)
Procedure Duration *median min (IQR)*	
Bronchoscopy-Only ($n = 64$)	18.5 (8.5–31.0)
CT and Bronchoscopy ($n = 20$)	12.5 (8.0–19.0)
Time to Procedure *median h (IQR)*	
Bronchoscopy-Only	6.6 (3.1–13.4)
CT and Bronchoscopy	5.8 (4.4–14.8)

The follow-up served as a validation for the negative bronchoscopy findings and allowed for calculation of the diagnostic properties of CT and CXR. ROC curve analysis results indicate a high level of diagnostic ability for CT, with an area under the curve of 0.99 (95% CI 0.97–1.00). CT chest for suspected FBA had sensitivity of 100%, specificity of 98%, positive-predictive value of 94%, and negative-predictive value of 100%. For CXR, ROC curve analysis results indicate a diagnostic ability no better than chance, with an area under the curve of 0.55 (95% CI 0.50–0.60). CXR for suspected FBA had sensitivity of 13%, specificity of 97%, positive-predictive value of 78%, and negative-predictive value of 58%.

The initial read and the blinded rereads were used to calculate inter-observer reliability. The overall agreement was almost perfect ($\kappa = 0.88$, $p < 0.001$), as was the agreement on the presence ($\kappa = 0.91$, $p < 0.001$) or absence ($\kappa = 0.90$, $p < 0.001$) of a foreign body. There was substantial agreement for equivocal reads ($\kappa = 0.65$, $p < 0.001$). Of note, the one false-positive was marked as negative on both of the blinded re-reads.

3. Discussion

Although use of CT for "virtual tracheobronchoscopy" in pediatric patients has been reported in the literature for nearly two decades [22], it has been used exceedingly sparingly in the diagnosis of FBA, with multiple studies reporting only a handful of patients who undergo CT [7,10,12,13,15,18,23]. When used, it has been shown to be superior to plain films at detecting radiolucent foreign bodies [20]. Behera et al. evaluated patients who had a CT and bronchoscopy for FBA, and found that 59/60 were confirmed, representing a positive-predictive value of 98.3% [19]. Adaletli et al. evaluated their patients who had a CT with or without bronchoscopy; they found that 13 of 16 patients were confirmed on bronchoscopy (81.2%) and that none of the 21 patients with a negative CT had recurrent obstructive symptoms [6].

Our series of 69 patients who underwent CT for evaluation of FBA is the largest to date, and is the only study comparing these patients to those who underwent bronchoscopy alone. Our positive bronchoscopy rate of 60.9% for patients with bronchoscopy alone is comparable to previous studies, the largest of which reported a rate of 41.5% [1]. Our positive predictive value was 94.1%, and we found no false negatives on our follow-up. The location was also able to be correctly predicted 94.1% of the time. Additionally, 49 patients were able to have the diagnosis of FBA excluded, thereby preventing an unnecessary bronchoscopy. Our telephone survey verified that none of the 34 contacted patients were later found to have a foreign body; chart review suggested the same for an additional nine patients. Our results also show impressive sensitivity of 100% and specificity of 98%, which are far superior to CXR alone (which had sensitivity of only 13% and specificity of 97%).

In addition to preventing unnecessary bronchoscopies, the use of CT for diagnosis in suspected cases can potentially prevent missing the diagnosis in cases that are clinically equivocal, which can occur up to 20% of the time with plain films [1]. With clinical presentation alone, FBA may be misdiagnosed as pneumonia in up to 33% of cases [3]. Complications associated with bronchoscopy occur most frequently in those with a diagnostic delay of greater than 24 h, with increasing likelihood and severity with greater duration in delay [4,21]. In our cohort, we had one patient who had months of respiratory symptoms prior to finally undergoing a CT that revealed a foreign body. However, our results show that there are no differences in terms of overall complications between those who had only a bronchoscopy and those who had a CT with or without bronchoscopy. All PICU admissions after the procedure were in the bronchoscopy-only group, but the number of this specific complication was too small to determine if this was statistically significant.

Another potential benefit of using CT to diagnose FBA is its applicability for triage in community hospitals, where a pediatric surgeon or otolaryngologist would not be available. In these hospitals, transfer to a referral hospital could potentially be avoided in cases of a negative CT. In our series, 10 patients (14.5%) were initially seen at a community hospital. The caveat to this benefit is that the community hospital would require a volumetric CT scanner, which is able to complete the scan in 0.3 s instead of the 8–9 s with a standard CT scanner. However, as long as this scanner is available, the high κ we found in our interobserver reliability suggests that any radiologist should be able to learn to consistently read these scans.

A concern with using CT for diagnosis of FBA is the radiation exposure associated with the imaging, owing to the potential risk for developing future malignancies. However, the low-dose protocol used at our institution had a DLP of 50.1 ± 67.7 mGy-cm for all patients, and only 28.6 ± 5.4 mGy-cm for patients less than the age of four. Both of these are only a fraction of the median DLP of 124.4 mGy-cm for a toddler undergoing an abdominal CT [24]. The use of abdominal CT was able to reduce the negative appendectomy rate by an order of magnitude, from 23.0% to 1.7% [25]. Our data show a similar reduction for negative bronchoscopy rate, from 39.1% to 6%, with even less radiation than an abdominal CT and without the need for contrast. Due to the ability of the CT to obtain sufficient images in only 0.3 s, only five of the 69 patients in our series required sedation, which was able to be achieved with midazolam alone. While serial sedation is obviously not ideal, particularly in a patient with respiratory symptoms, intranasal midazolam has been shown to be safe for CT imaging in children [26], and is frequently used prior to general anesthesia in elective operations [27]. None of the patients in our series had complications related to sedation, but

Table 3
Complications and outcome measures.

	N (%)	p-Value
Complications		0.13
Bronchoscopy-Only ($n = 64$)	13 (20.3)	
CT ± Bronchoscopy ($n = 69$)	5 (7.2)	
Follow-Up Bronchoscopy		
Bronchoscopy-Only	6 (9.4)	
CT ± Bronchoscopy	4 (5.8)	
PICU Admission		
Bronchoscopy-Only	6 (9.4)	
CT ± Bronchoscopy	0 (0.0)	
Unplanned Admission		
Bronchoscopy-Only	1 (1.6)	
CT ± Bronchoscopy	0 (0.0)	
Readmission		
Bronchoscopy-Only	0 (0.0)	
CT ± Bronchoscopy	1 (1.4)	
Systemic Steroids		0.62
Bronchoscopy-Only	24 (37.5)	
CT ± Bronchoscopy	23 (33.3)	

the rarity of sedation precludes this finding from being statistically significant.

Additionally, the time to diagnosis with CT is much faster than with bronchoscopy; the median time to procedure was 6.5 h, whereas the median time to a final read from the CT was 3.0 h. Furthermore, the potential risk of radiation must be weighed against the risk of anesthesia exposure and airway manipulation in a patient with respiratory symptoms, which could be exacerbated by an intervention.

This study had several limitations. As a retrospective chart review, it is subject to selection bias and coding errors. While there were no differences in the measured baseline characteristics between the two groups, since only 75.6% of the patients presenting after January 2016 underwent a CT scan, it is possible that there was a bias in which patients were selected for imaging that was not detected.

We were also unable to reach all eligible patients for the telephone survey. Although we were able to verify by survey that most patients who underwent CT without a bronchoscopy were never diagnosed with FBA, we relied on chart review for the remainder, and therefore could potentially have missed a patient who may have gone to another hospital to receive care. Future prospective and multicenter studies to validate the retrospective findings at our single institution are warranted.

4. Conclusion

Low-dose chest CT is a remarkably effective and consistent tool for diagnosing FBA in children, with a sensitivity of 100% and a specificity of 98%. Its use should be more widely adopted, as it can be performed quickly with minimal radiation exposure and can prevent unnecessary bronchoscopies.

Appendix A. Discussion: Avoiding Unnecessary Bronchoscopy in Children with Suspected Foreign Body Aspiration Using Computed Tomography

Presenter: Alexander Gibbons

Q. One question for you, and then one for the audience So, a question for you is, how low of a dose are you using for your cat scan? And are you using any intravenous contrast, or are you just doing noncon?

Alexander Gibbons Thank you for those questions. I was anticipating potentially getting a question about radiation dosing. For our radiation dosing, the overall dose limiting product for our entire cohort was 50 mg per cm. And then because this is largely a patient population of the toddler age group, we limited it to those under the age of four. And since this limiting product is really to height, we have a dose limiting product of 28. And just for reference, an abdominal CT in a toddler would be 125. In a similar age group, we're giving one-fifth of the radiation dosing.

And then in terms of your question for IV contrast, this is a noncon study. And it's also done very quickly, usually within six seconds. So the patient almost never needs any kind of sedation in order to get a high enough quality image in order to evaluate for a foreign body.

Q. So, how many people in this audience will start getting cat scans for foreign bodies? Kasper? Maybe. I see we have one more question.

Q. Hi. Ben Padilla from UCSF I have two questions. How did you decide which patients would get a CT scan, and which patients would go directly to bronchoscopy? And secondly, the incidence of foreign body was twice as high in the patients that had the CT scan preoperatively. It looked like there were about 60 patients in that group, and half of them were found to have a foreign body, whereas only about a third of the patients were found to have a foreign body on the CT scan. So does that suggest that about half of these foreign bodies are just asymptomatic and don't need to be retrieved?

Alexander. Thank you for the question. In terms of your first question, who got these CT scans? It was recommended by the radiologist after December 2015 for all patients to get it. And then at that point, it was dependent on either the emergency room physician or the surgeon whether they got it or not.

In terms of any baseline differences in terms of the two groups, there were no significant differences in baseline characteristics. And then in terms of why we had fewer foreign bodies found in the second arm, I'm not sure exactly. We had 49 patients who had the CT for evaluation and then didn't have any findings. But I'm not sure why exactly that was, and so our baseline characteristics were the same.

Q. Steven Lee, Los Angeles: Great study I just wanted to follow up. So who's actually ordering the CT scans? Because we find that one of the dangers of something like this is all of a sudden, like we have with appendicitis, the ER doctors started ordering all of them before we even were consulted and actually said this is a reasonable patient to order it. So is it the ED physicians? And my concern is, what's going to happen if they just start ordering that as their initial study. Thank you.

Alexander Gibbons Thank you for the question. Yes, there was a mix in this study population of whether the patient got a CT before or after. They were seen by the pediatric surgeon, and we would definitely recommend that they first be seen by a pediatric surgeon before committing to the CT scan.

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