Sinus Computed Tomography Imaging in Pediatric Cystic Fibrosis: Added Value?

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Abstract

Study Objective. To evaluate the prevalence of computed tomography (CT) sinus imaging in a pediatric cystic fibrosis (CF) population, determine changes in Lund Mackay (LM) scores over time, and estimate radiation exposure.

Study Design. Case series with chart review.


Subjects and Methods. In total, 202 pediatric patients with CF who underwent endoscopic sinus surgery (ESS) were included. The total number of CT scans was calculated for each patient, with specific focus on the indications for and subsequent outcomes of the sinus CT scan subgroup.

Results. Patients underwent a total of 1718 CT scans, 832 of which were sinus CT scans (mean of 4.2 sinus scans per patient). Disease evaluation (54%) and preoperative planning (35%) were the most common indications. Otolaryngologists were more likely to order imaging for preoperative evaluation, and those scans were more likely to result in surgery compared with those requested by other physicians ($P < .001$). Ninety CT scans (10.8%) led to no change in management. There was no significant difference in LM scores between patients admitted to the hospital or prescribed antibiotics and those who were not. There was also no significant change in LM score following ESS after adjusting for age and sex ($P = .23$).

Conclusion. Based on LM scores, all sinus CT scans in patients with CF reveal moderate to severe sinus disease. Effort should be made to minimize radiation exposure in patients with CF by limiting sinus CT scans to the preoperative context or for evaluation of potential sinusitis complications.

Keywords
cystic fibrosis, chronic rhinosinusitis, sinusitis, computed tomography, radiation, sinus imaging

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There are more than 12,000 children with cystic fibrosis (CF) in the United States.1 Cystic fibrosis is an autosomal recessive disease caused by a mutation in the CF transmembrane regulator (CFTR) gene on chromosome 7. There are over a dozen known mutations, with F508del mutation being the most common. These mutations lead to altered chloride ion transport across cell membranes. As a result, normal respiratory secretions become more viscous, contributing to inhibition of normal mucociliary transport, sinonasal inflammation, and, in some patients with CF, obstructive polyposis.

With the advent of new medical therapies, the life expectancy of patients with CF has increased dramatically. The current median life expectancy is 40.7 years, whereas 30 years ago, survival was limited to the first decade of life.1 Now that patients with CF are surviving to adulthood, repeated exposure to ionizing radiation is of greater concern. Children and adolescents are particularly susceptible to potential radiation-induced carcinogenesis because of the sensitivity of developing organs such as the thyroid, breast, and gonads,2 as well as a lifetime for radiation effects to manifest. In addition, there is a lack of size-based adjustments in pediatric computed tomography (CT) body imaging at many institutions.

In the pediatric CF population, the need for frequent imaging increases the potential risk for significant cumulative lifetime doses of ionizing radiation given the multisystem involvement of this disease.3 The aims of this study are to (1) review the overall prevalence of CT imaging in our pediatric CF population with a focus on paranasal sinus...

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imaging indications and outcomes, (2) evaluate changes in Lund-Mackay (LM) scores over time, and (3) estimate radiation exposure secondary to sinus CT imaging.

**Methods**

The Boston Children’s Hospital Institutional Review Board approved this study, and its guidelines were followed. A case series with chart review was performed on all patients diagnosed with CF who underwent endoscopic sinus surgery (ESS) at Boston Children’s Hospital from January 2004 to 2014. Patients with CF with incomplete records or imaging from outside institutions that could not be viewed in our system were excluded. Patient records and imaging were reviewed to identify patient demographics, endoscopy findings, number of CT scans, indications for imaging, specialty of the ordering physicians, and outcomes. Indications for imaging were grouped into 5 categories: (1) disease evaluation, (2) preoperative, (3) headache symptoms, (4) prior to lung transplantation, and (5) concern for intracranial and/or orbital complication of sinusitis. The disease evaluation category included all patients who had a CT scan, and the ordering physician planned to change medical management based on imaging rather than consider surgical intervention. These patients had symptoms of sinus disease (nasal congestion, rhinorrhea, postnasal drip) and/or recurrent CF exacerbations. All of the paranasal sinus CT scans were reviewed by pediatric otolaryngologists (E.A. and O.G.) and scored according to the LM staging system. Lund-Mackay scores have excellent sensitivity and specificity for pediatric chronic rhinosinusitis (CRS). Discrepancies between reviewer scores were resolved by consensus. The LM staging score evaluates each sinus and the ostiomeatal complex. Each sinus is graded between 0 and 2 (0 = no abnormality, 1 = partial opacification, or 2 = total opacification). The ostiomeatal complex is scored either 0 = not occluded or 2 = occluded. A total score can range from 0 to 24. Both the average number of sinus CT scans per patient and the average time between the CT scans were determined. The average radiation dose per CT scan was estimated from dose reports containing values for the computed tomography dose index (CTDI) and dose length product (DLP) when available. Both CTDI and DLP values are based on the CTDI head phantoms (16 cm diameter). Dose reports were not available prior to 2010. In addition, estimates for effective dose were obtained using previously published age-based DLP conversion factors.

Chi-square test was used to compare indications and outcomes of CT scans by ordering physicians. The Wilcoxon rank sum test or Kruskal-Wallis test was used to compare the LM score between groups. The change in LM score over time per patient was also calculated. The autoregressive model was used to evaluate change in LM score following ESS. This model assumes the LM score depends on whether the patient underwent sinus surgery, previous LM score, age, and sex. The generalized estimating equations (GEE) approach was employed to account for individual specific correlations in these longitudinal data. All statistical analyses were conducted using SAS version 9.3 (SAS Institute, Cary, North Carolina).

**Results**

Of the 202 patients who met the inclusion criteria, 54% were female. The mean (SD) age at first sinus CT scan was 10.2 (6) years. A total of 1718 CT scans were performed on this group during the study period (0.85 CT scans per patient per year). Almost half of the CT scans performed were paranasal sinus CT scans (n = 832) (Figure 1). Sinus CT scans were performed 4.2 times per patient (median 3.5, ranging from 1-14) during a mean follow-up of 6.2 years (0.2-17.4 years). For patients with more than 2 sinus CT scans (81%; n = 163), the average time between imaging was 1.8 years. For the 14 patients who underwent more than 10 sinus CT scans, they received CT scans on average every 1.1 years. Seven patients required general anesthesia for their initial CT scan.

**Indications and Outcomes Based on Ordering Physician**

As shown in Figure 2, disease evaluation (54%) and preoperative planning (35%) were the most common indications for obtaining a sinus CT. Among patients who had a CT scan for disease evaluation, approximately 4% of the time they had a repeat CT scan within 6 months prior to proceeding to sinus surgery. Otolaryngologists were more likely to order sinus CT scans for preoperative evaluation (66%) compared with other physicians (15%; P < .001). Alternatively, pediatricians, pulmonologists, or other physicians were more likely to order a sinus CT for headache or alternative disease evaluation (76%) than otolaryngologists (32%; P < .001).

Fifty-eight percent of the sinus CT scans resulted in the performance of ESS, 29% led to a change in oral antibiotic therapy, and 9% resulted in intravenous (IV) antibiotic therapy initiation. Sinus CT scans ordered by otolaryngologists were more likely to result in surgery compared with those ordered by other physicians (75% vs 49%; P < .001) but
less likely to result in hospital admission, IV antibiotic initiation, or oral antibiotic therapy change \((P < .05)\). Image-guided ESS was conducted in 108 of 503 sinus surgeries (21%). We found no difference in the frequency of image-guided ESS between first and revision ESS (19% vs 23%; \(P = .33\)).

**Lund-Mackay Scores by Outcome of Sinus CT Scans**

Collectively, the mean (SD) LM score for all patients was 15.0 (6.0) (Table 1). Patients younger than 5 years had significantly lower LM scores compared with older patients due to sphenoid and frontal underdevelopment \((P = .017)\). There were no significant differences in LM scores between patients who were admitted to the hospital or administered IV or oral (PO) antibiotics \((P = .80, .50, \text{and} .60, \text{respectively})\).

Of 163 patients who had a repeat CT scan following intervention, there was no significant change in LM score following ESS compared with the medical intervention group after adjusting for age and sex (adjusted difference of -0.5; \(P = .23\)) (Table 2). In subgroup analysis, there was no evidence of differences in the change in LM score following sinus surgery by sex or age \((P \text{ for interaction} = .33 \text{ and } .23, \text{respectively})\).

Nasal endoscopy findings and LM scores were compared among 148 patients who had enough clinical data to determine a Lund-Kennedy score. The mean (SD) Lund-Kennedy score was 4.8 (3.1). Lund-Kennedy score was weakly correlated with LM score (Spearman correlation, \(r = 0.26; P < .001\)).

**Radiation Dose**

The technique for performing sinus CTs evolved during the study period. Initially, CT examinations consisted of sequential coronal images \((\text{kilovolt peak/milli-ampere/slice thickness [kVp/mA/ST]} \text{ in mm:} 120/170-200/3-5)\). With the advent of high-speed helical CT units and the implementation of surgical navigation techniques, axial and coronal images were acquired for approximately a 1-year period \((\text{kVp/mA/ST in mm/table speed/pitch/rotation:} 120/200/2.5-3/3/1.0:1/1)\). Shortly thereafter, the protocol changed to helical acquisitions with reformatted coronal images \((\text{kVp/ST/table speed/pitch/rotation:} 120/180-200/2.5-3/5.625/0.562:1/0.5-1)\) until approximately 2012. Low-dose techniques were subsequently implemented, reducing the mA to 35 to 100.

A total of 145 dose reports were available for the dosimetry analysis. Average values and range for CTDI, DLP, and effective dose were 11.3 milligray (mGy) (range, 6.5-22.3), 144.3 mGy-cm (range, 68.2-311.83), and 0.29 millisievert (mSv) (range, 0.13-0.72), respectively.

**Discussion**

The evaluation and management of CF-associated rhinosinusitis were not included in the recently published American Academy of Otolaryngology—Head and Neck Surgery Foundation clinical consensus statement on pediatric CRS. It is generally accepted that all patients with CF have evidence of chronic sinusitis on paranasal sinus imaging. Nasal polyposis is also detected in 33% to 57% of patients with CF on nasal endoscopy. Despite these significant objective findings of sinus disease, a relatively small percentage of patients with CF are symptomatic. Endoscopic sinus surgery has been shown to improve symptoms and quality of life in symptomatic patients, but its role in asymptomatic patients is inconclusive. The impact of EES on lower respiratory tract disease is controversial, with some studies suggesting improvement in pulmonary function testing while other studies show no benefit.

Given that all patients with CF will have imaging findings of sinusitis, it is critical to determine when sinus CT imaging is actually necessary. During the 10-year study period, each patient with CF at our institution underwent an average of 4.2 sinus CT scans, approximately 1 scan every 2.5 years. Sinus CT imaging for disease evaluation alone is an area where unnecessary imaging could potentially be avoided. There was no significant difference in LM scores between patients who were admitted to the hospital or administered IV/PO antibiotics based on their CT scan; this indicates the management decision was based on clinical rather
than imaging findings. Although otolaryngologists were significantly more likely to order CT scans for preoperative evaluation (Figure 2), over 100 sinus CT scans were also ordered by otolaryngologists for alternative indications, indicating all specialists could be more judicious in their use of imaging in this population. Our findings suggest a multidisciplinary discussion regarding the utility of sinus CT imaging in all patients with CF would be worthwhile prior to image acquisition.

Repeat sinus imaging in the same patient is another area where otolaryngologists could potentially avoid unnecessary radiation exposure for patients with CF. In our study, there was no significant difference in LM scores between those who underwent ESS and those treated medically (P = .23) (Table 2), indicating LM scores tend to be stable over time in patients with CF regardless of intervention. Note that the mean time between imaging studies was 1.8 years; therefore, LM scores may be lower immediately following intervention. This hypothesis is difficult to test because, in the absence of a suspected complication, there is no clinical indication to repeat imaging in this context. Given that LM scores are unlikely to change significantly between imaging studies, we suggest obtaining a CT scan in patients with CF prior to their initial surgical intervention. In this context, low-dose sinus CT imaging is reasonable for preoperative planning, patient counseling, and for intraoperative image guidance. In the absence of previous surgical disruption, follow-up imaging in adolescent patients with fully developed paranasal sinuses can be avoided with the knowledge that important anatomic landmarks such as the skull base

### Table 1. Lund-Mackay Score Based on 832 Sinus CT Scans in 202 Patients with Cystic Fibrosis.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>No. of Patients</th>
<th>No. of CT Scans</th>
<th>Lund-Mackay Score</th>
<th>Maxillary</th>
<th>Anterior Ethmoid</th>
<th>Posterior Ethmoid</th>
<th>Sphenoid</th>
<th>Frontal</th>
<th>Osteomeatal Complex</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>202</td>
<td>832</td>
<td>15.0 (6.0)</td>
<td>3.2 (1.0)</td>
<td>2.9 (1.2)</td>
<td>2.2 (1.3)</td>
<td>2.5 (1.4)</td>
<td>1.9 (1.8)</td>
<td>2.3 (1.8)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>93</td>
<td>387</td>
<td>15.5 (6.2)</td>
<td>3.3 (1.0)</td>
<td>3.1 (1.2)</td>
<td>2.4 (1.3)</td>
<td>2.6 (1.4)</td>
<td>1.7 (1.9)</td>
<td>2.5 (1.8)</td>
</tr>
<tr>
<td>Female</td>
<td>109</td>
<td>445</td>
<td>14.6 (5.8)</td>
<td>3.2 (1.0)</td>
<td>2.9 (1.3)</td>
<td>2.2 (1.2)</td>
<td>2.4 (1.4)</td>
<td>2.0 (1.8)</td>
<td>2.1 (1.8)</td>
</tr>
<tr>
<td>Age at CT scan, y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>&lt;5</td>
<td>40</td>
<td>57</td>
<td>13.9 (5.5)</td>
<td>3.5 (0.9)</td>
<td>3.2 (1.1)</td>
<td>2.8 (1.4)</td>
<td>1.5 (1.8)</td>
<td>0.3 (1.1)</td>
<td>2.5 (1.8)</td>
</tr>
<tr>
<td>5-9</td>
<td>68</td>
<td>202</td>
<td>15.9 (5.8)</td>
<td>3.5 (0.9)</td>
<td>3.2 (1.2)</td>
<td>2.6 (1.3)</td>
<td>2.7 (1.5)</td>
<td>1.3 (1.7)</td>
<td>2.6 (1.7)</td>
</tr>
<tr>
<td>10-14</td>
<td>51</td>
<td>234</td>
<td>15.3 (5.9)</td>
<td>3.3 (0.9)</td>
<td>3.0 (1.1)</td>
<td>2.3 (1.2)</td>
<td>2.6 (1.4)</td>
<td>2.0 (1.8)</td>
<td>2.2 (1.8)</td>
</tr>
<tr>
<td>≥15</td>
<td>43</td>
<td>339</td>
<td>14.5 (6.2)</td>
<td>2.9 (1.1)</td>
<td>2.8 (1.3)</td>
<td>2.0 (1.3)</td>
<td>2.4 (1.3)</td>
<td>2.4 (1.7)</td>
<td>2.0 (1.8)</td>
</tr>
<tr>
<td>Total No. of surgeries performed on patient</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-2</td>
<td>129</td>
<td>338</td>
<td>13.8 (6.1)</td>
<td>3.1 (1.1)</td>
<td>2.8 (1.3)</td>
<td>2.0 (1.3)</td>
<td>2.2 (1.4)</td>
<td>1.8 (1.7)</td>
<td>2.0 (1.8)</td>
</tr>
<tr>
<td>3-4</td>
<td>48</td>
<td>277</td>
<td>15.3 (5.8)</td>
<td>3.2 (1.0)</td>
<td>3.0 (1.2)</td>
<td>2.3 (1.3)</td>
<td>2.6 (1.4)</td>
<td>1.8 (1.8)</td>
<td>2.4 (1.8)</td>
</tr>
<tr>
<td>≥5</td>
<td>25</td>
<td>217</td>
<td>16.6 (5.7)</td>
<td>3.6 (0.8)</td>
<td>3.1 (1.2)</td>
<td>2.5 (1.3)</td>
<td>2.7 (1.4)</td>
<td>2.2 (1.9)</td>
<td>2.6 (1.7)</td>
</tr>
</tbody>
</table>

Abbreviation: CT, computed tomography.

*Values are mean (SD) score. Mean Lund-Mackay score differed by sex (P = .024), age at CT scan (P = .017), and total number of surgeries performed (P < .001).

### Table 2. Change in Lund-Mackay Scores following Surgical Intervention.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Adjusted Difference (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>−0.50 (−1.32 to 0.32)</td>
<td>.23</td>
</tr>
<tr>
<td>Subgroup</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change in LM score comparing surgery vs no surgery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>−0.82 (−2.46 to 0.83)</td>
<td>.33</td>
</tr>
<tr>
<td>Male</td>
<td>−0.06 (−1.36 to 1.25)</td>
<td>.93</td>
</tr>
<tr>
<td>Change in LM score comparing surgery vs no surgery by age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5 years</td>
<td>−1.70 (−4.73 to 1.34)</td>
<td>.27</td>
</tr>
<tr>
<td>5-10 years</td>
<td>−0.20 (−3.58 to 3.17)</td>
<td>.91</td>
</tr>
<tr>
<td>10-15 years</td>
<td>1.94 (−1.57 to 5.46)</td>
<td>.28</td>
</tr>
<tr>
<td>≥15 years</td>
<td>1.79 (−1.34 to 4.93)</td>
<td>.26</td>
</tr>
</tbody>
</table>

Abbreviations: CI, confidence interval; LM, Lund-Mackay.

*Adjusted difference and P value were based on the autoregressive model adjusted for age and sex.
and lamina papyracea are unlikely to change significantly in these patients. Their initial CT scan should suffice for subsequent image-guided ESS procedures. In younger patients with CF, LM scores are significantly lower due to underdeveloped frontal and sphenoid sinuses (Table 1). Follow-up imaging in this group may be necessary depending on the time span between surgical procedures due to age-related anatomical changes; this decision should be patient specific.

When imaging is restricted to the preoperative context, the number of sinus CT scans can be reduced dramatically. A recent study using a strict imaging protocol in 277 patients with CF followed over a period of 11 years revealed only 10 (26%) sinus CT scans to be performed for indications other than preoperative evaluation. As in our series, such imaging did not change the management course in those patients.

While estimates of cancer risk are hypothetical and speculative, it is prudent to adopt the as low as reasonably achievable (ALARA) criteria when designing pediatric protocols. Protocol optimization ideally provides information required for image-guided surgical techniques and diagnostic quality images of the bony structures of the sinus while using the lowest dose possible. Based on our experience, the dose level required for routine sinus CT is well below that of a routine brain CT scan. The American College of Radiology reference value for a pediatric brain CT is 35 mGy, while our mean sinus CTDI was 11.3 mGy. Although the CTDI for sinus imaging is relatively low, it is still important to limit imaging, especially in this population, in whom imaging of the chest and abdomen is also common. Advanced techniques such as iterative reconstruction algorithms and improvements in detector technology show promise to further reduce radiation doses.

The main limitation of our study is its retrospective design. Data included in this series were recorded for purposes other than this study; therefore, some elements of the decision-making process for each patient may be missing. Given the nature of CF, it is possible some CT scans were performed in the preoperative context, but surgery was never performed because the patient was not sufficiently stable for surgical intervention. This would have led to the CT scan being categorized mistakenly as “disease evaluation” rather than “preoperative.” In addition, the average number of studies performed was likely underestimated as CT scans performed outside our institution were not recorded. Computed tomography dose reporting did not reach maturity until after 2012, and there were no dose reports on our scanners prior to 2010, thus limiting the dose information available for this study. Standard reporting in the form of a Radiation Dose Structured Report should overcome this limitation in future studies.

Conclusion
All patients with CF have relatively high LM scores regardless of clinical context. Routine imaging for disease evaluation is probably not necessary and represents an area where radiation exposure can be decreased in these patients. Clinicians should limit paranasal sinus imaging to the preoperative context or the evaluation of suspected sinusitis complications. In this context, otolaryngology consultation should be considered prior to imaging. In addition, LM scores for individual patients do not change significantly with time or intervention. If there has been no prior surgical anatomical disruption and the child is of an age in which significant developmental changes between imaging studies are unlikely, then repeat paranasal sinus imaging can also be avoided.

Author Contributions
Ozgul Gergin, acquisition of data, analysis and interpretation of data, drafting of the manuscript; Kosuke Kawai, analysis and interpretation of data, drafting of the manuscript, statistical analysis; Robert D. MacDougall, acquisition of data, analysis and interpretation of data, drafting of the manuscript; Caroline D. Robson, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content; Ethan Moritz, acquisition of data, critical revision of the manuscript for important intellectual content; Michael Cunningham, study concept and design, analysis and interpretation of data, critical revision of the manuscript for important intellectual content; Eelam Adil, study concept and design, acquisition of data, analysis and interpretation of data, drafting of the manuscript, critical revision of the manuscript for important intellectual content.

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References