ORIGINAL ARTICLE

The Diagnostic Accuracy of Computed Tomography in Pediatric Chronic Rhinosinusitis

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Objective: To determine the accuracy of computed tomography (CT) in the diagnosis of pediatric chronic rhinosinusitis (CRS).

Setting: Multi-institutional prospective dual cohort study.

Methods: Two cohorts of children undergoing CT of the paranasal sinuses were prospectively evaluated. The first cohort consisted of children undergoing CT in preparation for endoscopic sinus surgery (diseased group). The second cohort consisted of children undergoing CT for nonsinusitis reasons (nondiseased control group). Sinus CT scans were scored according to the Lund-MacKay system. Diagnostic accuracy was quantified with the receiver operating characteristic curve. Sensitivity, specificity, and predictive value analyses were conducted.

Results: A total of 66 pediatric patients (mean age, 8 years) were studied in the diseased group and exhibited a mean Lund score of 10.4 (95% confidence interval, 9.2-11.5); 192 control patients (mean age, 9 years) exhibited a mean Lund score of 2.8 (95% confidence interval, 2.4-3.2). The area under the curve for the receiver operating characteristic was 0.923 ($P<.001$), indicating excellent diagnostic accuracy. Adopting a Lund score cutoff of 5 to represent true disease, the CT scan demonstrated a sensitivity and specificity of 86% and 85%, respectively. Lund scores of 2 or less have an excellent negative predictive value, whereas Lund scores of 5 or greater have an excellent positive predictive value (ie, strongly indicate true disease).

Conclusions: The sinus CT scan demonstrates excellent diagnostic accuracy for the diagnosis of pediatric CRS, with excellent sensitivity and specificity. However, its predictive value depends substantially on the base rate prevalence of CRS in the population being evaluated.

Arch Otolaryngol Head Neck Surg. 2004;130:1029-1032

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ALTHOUGH THE TRUE PREVALence of pediatric chronic rhinosinusitis (CRS) is unknown, symptoms compatible with its diagnosis such as chronic mucopurulent rhinorrhea may affect as many as 20% of the pediatric population at some point during childhood.[1] Recently, a concerted research effort has been devoted to evaluate the impact on quality of life and medical and surgical treatment outcomes for pediatric CRS.[2] Unfortunately, the diagnosis of pediatric CRS has not received substantial attention in the literature. The clinical diagnosis of pediatric CRS may be complicated for several reasons. First, children are often unable to specifically verbalize many of their symptoms. Thus, quantification of symptom presence and severity is often obtained vicariously from the parent or caregiver. Second, pediatric patients are also often subject to other disease entities, which may have a significant overlap with the symptoms associated with pediatric CRS. Examples include allergic rhinitis, recurrent viral upper respiratory tract infections, chronic adenoiditis, and eustachian tube dysfunction. Finally, the diagnosis of pediatric CRS may be confounded by the fact that physicians are more apt to treat symptoms in this patient population because of difficulties in discerning overlapping diagnoses. Often, diagnostic studies such as computed tomography (CT) or nasal endoscopy are avoided because of their semiinvasive nature or the necessity for anesthesia. This often results in extended courses of empiric therapeutic trials before diagnostic testing for CRS is considered.

Given the health impact of pediatric CRS, the significant treatment expenditures incurred, and the fact that outcomes vary substantially between these overlapping diagnoses, it is of clinical and practical importance to be able to accu-

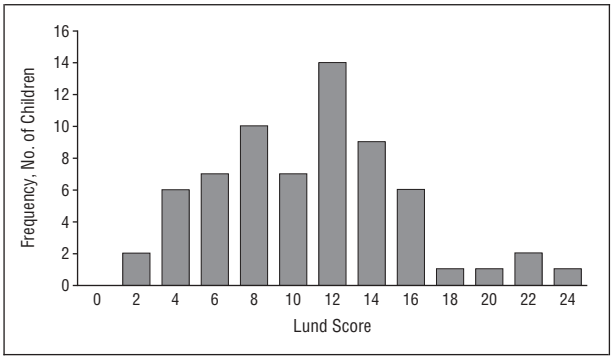

Figure 1. Staging distribution of children with chronic rhinosinusitis. See "Methods" section for explanation of Lund-Mackay scoring system.

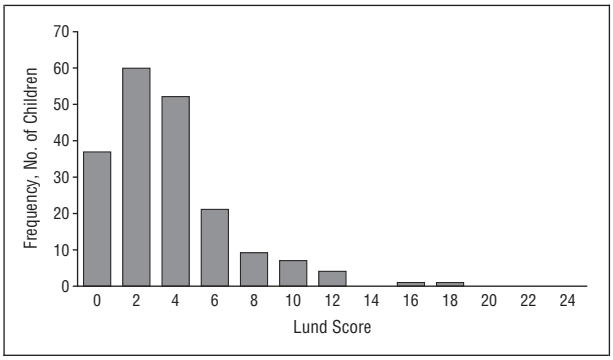

Figure 2. Staging distribution of children without chronic rhinosinusitis. See "Methods" section for explanation of Lund-Mackay scoring system.

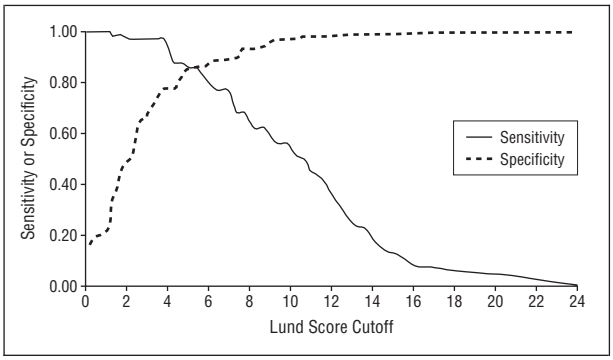

Figure 3. Sensitivity and specificity of the sinus computed tomographic scan for chronic rhinosinusitis. See "Methods" section for explanation of Lund-Mackay scoring system.

rately diagnose pediatric CRS. The CT scan has emerged as the gold standard diagnostic test for CRS in general.[3-5] It is substantially more sensitive and specific than plain film radiography.[6] It also provides a potential "surgical road map" should surgery be required. Although it has become the de facto gold standard, the diagnostic accuracy of the pediatric paranasal sinus CT scan has not been established. This study was conducted to determine the accuracy of the pediatric sinus CT scan and to determine parameters that would establish criteria for a "positive" pediatric sinus CT scan for the diagnosis of CRS.

METHODS

Two pediatric patient populations were prospectively constructed for the purpose of this analysis. The first (diseased) group consisted of pediatric patients scheduled to undergo endoscopic sinus surgery (ESS) for medically refractory CRS. All of these patients met clinical criteria for the diagnosis of CRS, for whom extended courses of traditional medical management for their CRS had failed.[7] Standard demographic information including age, sex, and medical comorbid conditions were collected. Patients were excluded if they had cystic fibrosis, intracranial or orbital complications of sinusitis (eg, acute sinusitis with orbital cellulitis), or previous sinus surgery. Each patient underwent preoperative CT scanning in the axial and coronal planes. These CT scans were collated and scored according to the Lund-Mackay system along with standard demographic data.[4] The Lund-Mackay staging system scores each sinus (anterior ethmoid, posterior ethmoid, maxillary, frontal, and sphenoid sinuses) according to the following scale: 0 (no opacification), 1 (partial opacification), or 2 (complete opacification). The ostiomeatal complex is scored as 0 (not occluded) or 2 (occluded). Left and right sides are staged separately and the scores are summed so that the total Lund score may range from 0 to 24 for each patient.

A second control (nondiseased) group of pediatric patients was assembled from a previously reported group of patients undergoing CT scan for nonsinusitis diagnoses.[8] These patients served as control patients if they had no previous history of CRS based on the electronic medical record and had not undergone sinus or facial surgery. Standard demographic information was also collected for this group. Each of these CT scans was also staged according to the Lund-Mackay system. For both groups, sinuses that were not developed were assigned a null value. The corresponding Lund score was then scaled up to range from 0 to 24 by scaling with the factor 12/n, where n represents a number of scorable (pneumatized) sinuses.[9]

The results of the CT staging were then compared between the diseased and control groups. Standard descriptive data were computed. The diagnostic accuracy of the CT scan in distinguishing CRS (diseased) patients from control (nondiseased) patients was established using the receiver operating characteristic curve.[5] Diagnostic sensitivity and specificity analyses were conducted. Finally, positive and negative predictive values were computed based on 2 base rate prevalences. The base rate prevalence of 0.50 was chosen to represent the population presenting for nonspecialty (ie, pediatric primary care) diagnostic evaluation of pediatric CRS. A base rate prevalence of 0.80 was chosen to represent the prevalence of CRS in a group of pediatric patients undergoing specialty (ie, pediatric allergy or otolaryngologic) evaluation of CRS.[5] Naturally, the a priori probability (base rate prevalence) of true pediatric CRS would more likely be present in patients undergoing specialty evaluation, hence the elevated base rate prevalence chosen for analysis of that population.

RESULTS

A total of 66 pediatric patients were identified for the diseased group, with a mean age of 8 years. The mean total Lund score for this group was 10.4 (95% confidence interval, 9.2-11.5). The histogram of the Lund-Mackay staging distribution for this patient population is depicted in **Figure 1**. A total of 192 control patients were also studied (mean age, 9 years). The total Lund score for the control group was 2.8 (95% confidence interval, 2.4-3.2). The histogram of the Lund-Mackay staging distribution for the control patients is depicted in **Figure 2**.

The sensitivity and specificity of the pediatric sinus CT scan for the diagnosis of CRS are graphically depicted in **Figure 3**. The receiver operating characteris-

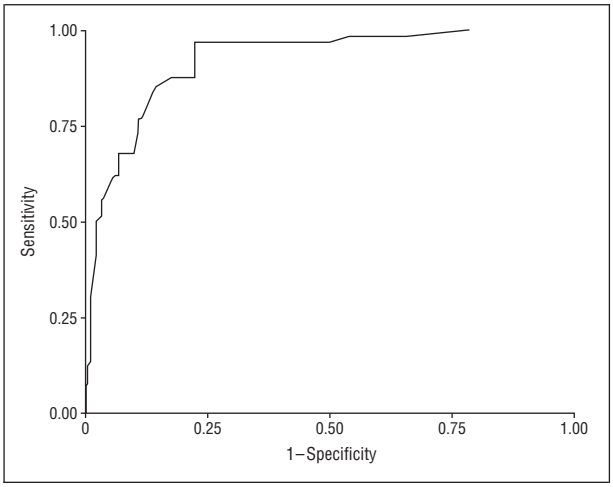

Figure 4. Receiver operating characteristic curve. See "Methods" section for explanation of Lund-Mackay scoring system.

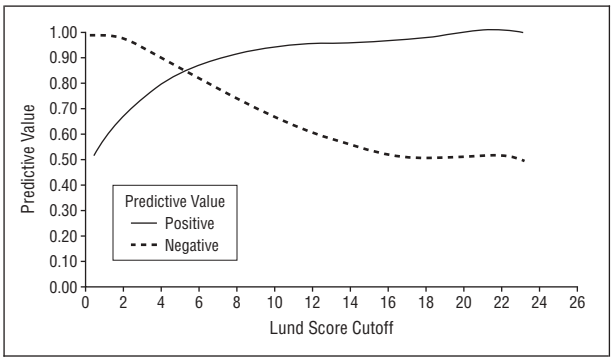

Figure 5. Positive and negative predictive values based on base rate prevalence of 0.50. See "Methods" section for explanation of Lund-Mackay scoring system.

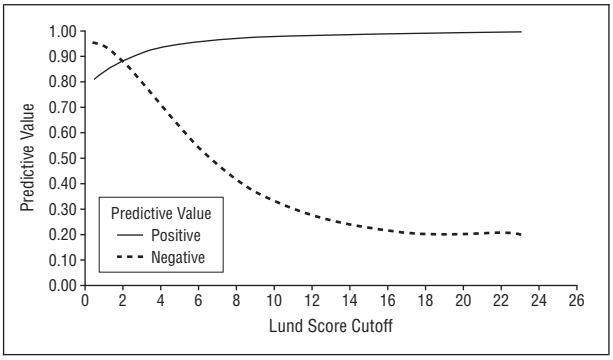

Figure 6. Positive and negative predictive value based on base rate prevalence of 0.80. See "Methods" section for explanation of Lund-Mackay scoring system.

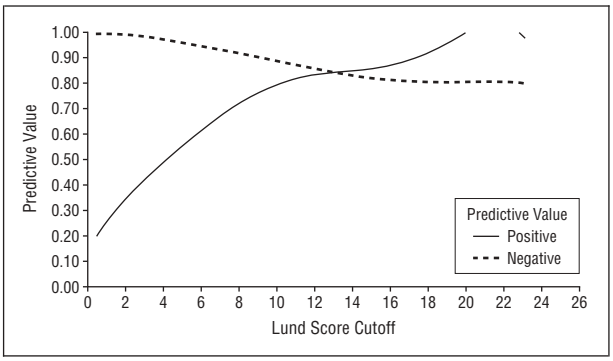

Figure 7. Positive and negative predictive values based on base rate prevalence of 0.20. See "Methods" section for explanation of Lund-Mackay scoring system.

tic curve for the pediatric sinus CT scan is presented in **Figure 4**. The area under the curve was 0.923 ($P<.001$) indicating that the pediatric sinus CT scan exhibits excellent discriminant ability between diseased and nondiseased groups.[10] As indicated by Figure 3, adopting a Lund score cutoff for disease vs nondiseased patients of 5 offers a sensitivity and specificity of 86% and 85%, respectively.

The results of the positive and negative predictive value analysis are depicted in **Figure 5** and **Figure 6** for base rate prevalences of 0.50 and 0.80, respectively.[5] As noted, the positive and negative predictive value of the sinus CT scan for pediatric CRS will significantly depend on the a priori base rate prevalences in the population under consideration for evaluation with CT. **Figure 7** shows the predictive value analysis for a low base rate prevalence of CRS at 0.20, illustrating the decline in diagnostic accuracy with decreasing base rate prevalence.

COMMENT

Children with signs and symptoms of pediatric CRS often represent a diagnostic and therapeutic conundrum. Because of a significant overlap and symptoms between CRS and more common pediatric aerodigestive tract diagnoses such as chronic adenoiditis, chronic tonsillitis, allergic rhinitis, and eustachian tube dysfunction, pediatric CRS is often considered much later in the course of diagnosis and treatment. Therefore, pediatricians and otolaryngologists are forced to rely on objective measures such as nasal endoscopy and radiography for the diagnosis of CRS in children.[11] Common radiographic findings associated with CRS in children have been reported in the literature.[6,12,13] Children with CRS typically display a higher volume of radiographic abnormality compared with adults with CRS but are less likely to have septal deviation. [14] Overall, in contrast to acute rhinosinusitis, limited information is available in the literature regarding the accuracy of the radiographic diagnosis of CRS in children.

The paranasal sinus CT scan is generally considered the gold standard diagnostic radiographic study in CRS. It is widely believed to be extremely sensitive for mucosal inflammation in the paranasal sinuses. In adult patients, we recently quantified the sensitivity, specificity, and predictive values for the paranasal sinus CT scan for the diagnosis of adult CRS.[5] In that study, we found that the CT scan exhibited good overall accuracy (area under the receiver operating characteristic curve, 0.802) and solid sensitivity and specificity scores (approximating 85% and 59%, respectively) for the diagnosis of CRS.

Because of the high sensitivity of the CT scan for mucosal inflammation in the paranasal sinuses, it is indeed possible that the CT scan can identify "incidental"

mucosal findings that do not represent true "sinus" disease.[15] This extreme sensitivity of the CT scan may lead to overdiagnosis on a radiographic basis, especially given that it is commonly believed that children are more subject to incidental upper respiratory tract infections and other mucosal inflammations, which could lead to false-positive CT scan results. We previously examined the "normal" or incidental Lund score in children and found that, somewhat surprisingly, children without CRS exhibited a rather low incidental Lund score of approximately 2.8.[8] Such incidental findings on sinus CT scan were actually less common than similarly studied adult patients without CRS.[9] Therefore, it becomes less likely that false-positive results will occur with the pediatric sinus CT. The present data indicate that the sinus CT can be relied on as an accurate diagnostic test in the evaluation of pediatric CRS. The CT scan exhibits excellent accuracy as evidenced by the receiver operating characteristic curve. The area under the curve, 0.923, is considered excellent according to accepted standards of accuracy.[10] In fact, this area under the curve was higher than that found in an adult patient population undergoing a similar analysis.[5]

The present data indicate that the sinus CT scan exhibits good sensitivity and specificity in the diagnosis of pediatric CRS. For example, adopting a Lund score cutoff of 5 as indicating the presence of true disease (ie, Lund scores $\geq$5 indicate a positive CT scan result for pediatric CRS) would exhibit a sensitivity and specificity of 85% and 86%, respectively. However, sensitivity and specificity values cannot be considered without some knowledge and consideration of the base rate prevalence. It is well known that the diagnostic accuracy of any test, especially in one with a pseudo linear scale for abnormality, will be dependent on the a priori likelihood of the presence of disease, in other words, the base rate prevalence or pretest probability. When the base rate prevalence of disease is high, the specificity of the test becomes more important, whereas when the base rate prevalence is low, the sensitivity of the test becomes more important in establishing accuracy. Therefore, we also conducted predictive value analyses to demonstrate this important feature of the diagnostic accuracy of CT. Otolaryngologists are likely to encounter high base rate prevalences of CRS in pediatric patients being evaluated for sinonasal symptoms. Typically, maximal medical management at the primary care level has failed in these patients, and they are being considered, possibly, for surgical intervention. In these instances, to avoid unnecessary surgery, otolaryngologists commonly rely on the CT scan to exclude patients who do not have true CRS.

From a practical standpoint, the present data support the following ranges for the radiographic diagnosis of CRS in the pediatric patient population. A Lund score ranging from 0 to 2 may be considered "normal" since scores in this range exhibit excellent negative predictive values, allowing for the exclusion of true disease. Similarly, Lund scores of 5 or greater may be considered diagnostically "positive" for the radiographic presence of CRS since the scores exhibit high positive predictive values confirming the presence of disease. Lund scores of 3 to 4 may be considered somewhat equivocal, and additional weight should be placed on the clinical and perhaps endoscopic evidence of disease.

Finally, no single diagnostic test for CRS in children can be used in isolation. Physicians must adjust and temper results obtained from paranasal sinus CT scans according to the diagnostic accuracy of the CT scan and factor in the possibility of clinical overlap with other diagnoses and other clinical features of disease presentation to optimize the diagnosis of pediatric CRS. As pediatric CRS remains a clinical diagnosis, the CT scan should justly be considered as a supplementary test providing corroborative evidence for the diagnosis of pediatric CRS.

Submitted for publication November 24, 2003; final revision received March 17, 2004; accepted April 30, 2004.

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