Reciprocal Predictive Accuracy of Sinonasal Symptom Severity, Nasal Endoscopy, and Frequency of Past Chronic Rhinosinusitis Exacerbations

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Abstract

Objective. We sought to determine whether chronic rhinosinusitis (CRS) symptom severity, endoscopic exam findings, and acute exacerbation of CRS (AECRS) frequency—all important and distinct clinical manifestations of CRS—would be predictive of each other and, therefore, inform when further assessment of each other metric should be pursued.

Study Design. Cross-sectional cohort study.

Setting. Tertiary academic rhinology clinic.

Subjects and Methods. In total, 241 patients with CRS were prospectively recruited and completed the 22-item Sinonasal Outcome Test (SNOT-22) to reflect CRS symptom severity. AECRS frequency was assessed using the number of sinus infections as well as CRS-related antibiotics and CRS-related oral corticosteroids used in the past 3 months. An endoscopy score was calculated for each patient.

Results. SNOT-22 score and AECRS were predictive of each other while AECRS and endoscopy score were not predictive of each other. SNOT-22 score could be used to predict having, in the past 3 months, at least 1 sinus infection (area under the curve [AUC] = 0.727; P < .001), at least 1 CRS-related antibiotic used (AUC = 0.691; P < .001), or at least 1 CRS-related oral corticosteroid course used (AUC = 0.655; P < .001). Having a SNOT-22 score ≥30 could be predicted by reporting at least 1 sinus infection (AUC = 0.634; P < .001), CRS-related antibiotics (AUC = 0.614; P < .001), or CRS-related oral corticosteroids (AUC = 0.616; P < .001) in the past 3 months. These relationships held for patients with and without nasal polyps.

Conclusion. The predictive power of CRS outcome measures reflecting symptomatology, AECRS frequency, and endoscopic findings may be of clinical utility in situations where time or resources are limited to perform an ideally full assessment of patients with CRS.

Keywords
chronic rhinosinusitis (CRS), chronic rhinosinusitis exacerbations, sinonasal symptom severity, antibiotics usage, corticosteroid usage, SNOT-22

Chronic rhinosinusitis (CRS) is an inflammatory disease of the sinonasal mucosa that is extremely common, affecting up to 10% of the population.1,2 CRS is a heterogeneous disease with many possible underlying mechanisms of development and persistence.4-9 Due to chronic sinonasal symptoms and exacerbation of CRS itself or other comorbidities, CRS leads to a significant quality-of-life decrease in patients with CRS that ultimately drives billions of dollars in direct and indirect costs every year.10-15

The diagnosis of CRS is dependent on the presence of symptomatology, and it is these symptoms that are most often assessed in the clinical setting. The frequency of acute CRS exacerbations (AECRS) is also significantly associated

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with decreased quality of life or exacerbation of comorbid asthma. In the ideal situation, the clinical assessment of patients with CRS therefore includes a detailed history, including the completion of validated questionnaires—such as the 22-item Sinonasal Outcome Test (SNOT-22)—that reflect CRS symptomatology, assessment of AECRS frequency, and a nasal endoscopy. However, realistic considerations in the clinic impose practical constraints on the ability to perform the ideal assessment of each patient with CRS. The clinical support staff may not exist to provide and instruct patients on the use of the SNOT-22. Limited clinic time may also force the practitioner to focus on the most classical manifestations of CRS—sinonasal symptomatology—at the expense of assessing for AECRS. Given the practical constraints that are faced by practitioners in the clinic, the ability to maximize the information derived from any one metric of CRS severity would potentially be of clinical utility. For example, can CRS symptom severity provide insight into, and therefore trigger further evaluation of, AECRS frequency? In a clinic where resources do not exist to implement the completion of a SNOT-22 by each patient with CRS, is it possible to use AECRS frequency to gain insight into the SNOT-22 score? How much insight into patient-reported outcome measures can be gleaned from the endoscopic exam, which can be performed in any otolaryngologist’s office?

We hypothesized that although CRS severity, AECRS frequency, and endoscopic exam findings are distinct and largely independent clinical manifestations of CRS, each could be used to gain insight into the status of the other. We therefore sought to determine the relationships between—and predictive abilities of—CRS symptom severity, as reflected by SNOT-22 score, endoscopic exam, and metrics for AECRS. We believe that this information will be clinically informative by further maximizing the insight gained from each piece of clinical history or exam finding collected.

Materials and Methods

Study Participants

This study was approved by the Massachusetts Eye and Ear Infirmary Human Studies Committee. We prospectively recruited adult patients of 18 years or older meeting the clinical consensus guideline-established criteria for CRS. All study participants provided informed consent for inclusion. To have a homogeneous CRS cohort, our inclusion criteria included comorbid diagnoses of vasculitis, cystic fibrosis, sarcoidosis, immunodeficiency, and active AECRS. To remove the confounding effect of recent endoscopic sinus surgery, patients who had endoscopic sinus surgery within the past 6 months were excluded.

Study Design and Data Collection

This is a cross-sectional cohort study. A total of 241 study participants were recruited, and all data were collected at enrollment. Age, sex, and smoking history of all participants were recorded. Any participant who was a current or former tobacco smoker was considered a smoker for this study. All participants completed the SNOT-22. Since there are no consensus criteria for defining an AECRS, the frequency of AECRS was measured using 3 previously described surrogate measures: the number of sinus infections and the number of courses of CRS-related antibiotics and steroid usage in the past 3 months as reported by the participant. For each participant, the evaluating rhinologist assessed (1) a diagnosis of asthma based on clinical history and a prior diagnosis, (2) aeroallergen hypersensitivity based on formal allergy testing, (3) utilization of intranasal corticosteroids (spray or irrigation), (4) a history of aspirin sensitivity, and (5) the presence of nasal polyps on the basis of nasal endoscopy, which was also used to calculate a Lund-Kennedy endoscopy score for each patient.

Statistical Analysis

All analysis was performed with the statistical software package R (www.r-project.org). All associations with AECRS metrics as a dependent variable were performed with negative binomial regression. All associations with SNOT-22 as a dependent variable were performed with linear regression. Multivariable models used to study these associations controlled for participant age, sex, polyps, asthma, history of smoking, history of allergic rhinitis, and intranasal corticosteroid use. Analysis of receiver operating characteristic (ROC) curves was performed with the pROC package. Analysis of receiver operating characteristic (ROC) curves was performed with the pROC package. A value for significance of the ROC curve was determined by Wilcoxon rank-sum test. A total of 241 participants were recruited to have 80% power at a significance level of .05 to detect a large effect size (AUC = 0.7) for SNOT-22 to be predictive of AECRS metrics (under the assumption that at least 20% of study participants would report having at least 1 AECRS in the prior 3 months for each AECRS metric) for both participants with and without nasal polyps.

Results

Patient Characteristics

The clinical and demographic characteristics of study participants are described in Table 1. The participants’ mean age was 53.2 years (95% confidence interval [CI], 22.9-78.9 years). Participants’ mean SNOT-22 score was 36.2 (95% CI, 2-81), and the mean endoscopy score was 3.1 (95% CI, 0-10). Participants reported a mean of 0.8 (95% CI, 0-4) sinus infections, 0.7 (95% CI, 0-3) CRS-related antibiotic courses, and 0.4 (95% CI, 0-3) CRS-related oral corticosteroid courses in the prior 3 months. In the past 3 months, 48.1% of participants reported having at least 1 sinus infection, 41.1% reported using at least 1 antibiotic course for CRS, and 25.7% reported using at least 1 oral corticosteroid course for CRS.

SNOT-22 and Endoscopy Score as Predictive Measures for AECRS Frequency

Assessment of CRS symptomatology and endoscopic findings are routine elements in the evaluation of any patient
with CRS, with CRS symptomatology frequently assessed using the SNOT-22 and endoscopic findings frequently assessed using endoscopy score. We therefore sought to determine the accuracy of SNOT-22 and endoscopy score for detecting patients who had any of our AECRS metrics in the past 3 months (Figure 1). We found that SNOT-22 score (area under the curve [AUC] = 0.727; 95% CI, 0.663-0.790; \( P < .001 \)) was a statistically significant test for detecting patients who reported any sinus infections in the past 3 months while endoscopy score was not (AUC = 0.552; 95% CI, 0.441-0.662; \( P = .359 \)). A SNOT-22 score greater than 41 provided 55.2% sensitivity and 80.8% specificity for detecting patients who reported having at least 1 sinus infection in the prior 3 months. Even after controlling for age, sex, history of smoking, polyps, asthma, aeroallergen hypersensitivity, and intranasal corticosteroid use, SNOT-22 was significantly associated with having at least 1 sinus infection in the prior 3 months (odds ratio [OR] = 1.03; 95% CI, 1.02-1.05; \( P < .001 \)), which indicates that every 20-point increase in SNOT-22 is associated with an OR of 2 for having at least 1 sinus infection in the past 3 months.

SNOT-22 score (AUC = 0.691; 95% CI, 0.623-0.759; \( P < .001 \)) was also a statistically significant test for detecting patients who reported taking any antibiotics for their CRS in the past 3 months while endoscopy score was not (AUC = 0.471; 95% CI, 0.358-0.584; \( P = .618 \)). A SNOT-22 score greater than 40 provided 58.6% sensitivity and 76.1% specificity for detecting patients who reported using at least 1 course of antibiotics for their CRS in the prior 3 months.

Even after controlling for age, sex, history of smoking, polyps, asthma, aeroallergen hypersensitivity, and intranasal corticosteroid use, SNOT-22 was significantly associated with having used at least 1 CRS-related antibiotics course in the prior 3 months (OR = 1.03; 95% CI, 1.02-1.05; \( P < .001 \)), which reflects that every 20-point increase in SNOT-22 is associated with an OR of 2 for having used at least 1 CRS-related antibiotics course in the past 3 months.

SNOT-22 score (AUC = 0.655; 95% CI, 0.579-0.731; \( P < .001 \)) was a statistically significant test for detecting patients who reported using any CRS-related oral corticosteroids in the past 3 months. We also found that SNOT-22 score (AUC = 0.552; 95% CI, 0.421-0.683; \( P = .439 \)) was a statistically significant test for detecting patients who reported taking any oral corticosteroids for their CRS in the past 3 months.

### Table 1. Characteristics of Study Participants (N = 241).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demographics</strong></td>
<td></td>
</tr>
<tr>
<td>Age, mean (SD), y</td>
<td>53.2 (15.8)</td>
</tr>
<tr>
<td>Sex, %</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>51.0</td>
</tr>
<tr>
<td>Female</td>
<td>49.0</td>
</tr>
<tr>
<td>Smoking, %</td>
<td>29.5</td>
</tr>
<tr>
<td>Comorbidities, %</td>
<td></td>
</tr>
<tr>
<td>Asthma</td>
<td>24.5</td>
</tr>
<tr>
<td>Aspirin sensitivity</td>
<td>4.1</td>
</tr>
<tr>
<td>Aeroallergen hypersensitivity</td>
<td>43.2</td>
</tr>
<tr>
<td><strong>CRS characteristics</strong></td>
<td></td>
</tr>
<tr>
<td>Nasal polyps, %</td>
<td>41.1</td>
</tr>
<tr>
<td>Previous sinus surgery, %</td>
<td>34.4</td>
</tr>
<tr>
<td>Intranasal steroid use, %</td>
<td>62.2</td>
</tr>
<tr>
<td>Endoscopy score, mean (SD)</td>
<td>3.1 (2.5)</td>
</tr>
<tr>
<td>SNOT-22 score, mean (SD)</td>
<td>36.2 (22.1)</td>
</tr>
<tr>
<td>Sinus infections in the past 3 months, mean (SD)</td>
<td>0.8 (1.1)</td>
</tr>
<tr>
<td>CRS-related antibiotic courses in the past 3 months, mean (SD)</td>
<td>0.7 (1.1)</td>
</tr>
<tr>
<td>CRS-related oral corticosteroid courses in the past 3 months, mean (SD)</td>
<td>0.4 (0.9)</td>
</tr>
</tbody>
</table>

**Abbreviations:** CRS, chronic rhinosinusitis; SNOT-22, 22-item Sinonasal Outcome Test.

### Figure 1. Receiver operating characteristic curves for the (A) 22-item Sinonasal Outcome Test (SNOT-22) and (B) endoscopy score for detecting patients with chronic rhinosinusitis (CRS) who reported any sinus infections in the past 3 months, (C) SNOT-22 and (D) endoscopy score for detecting patients with CRS who have reported using any CRS-related antibiotics in the past 3 months, and (E) SNOT-22 and (F) endoscopy score for detecting patients with CRS who reported using any CRS-related oral corticosteroids in the past 3 months. The SNOT-22 threshold scores with the highest sum of sensitivity and specificity are marked on panels A (corresponding to SNOT-22 score \( > 41 \)), C (corresponding to SNOT-22 score \( > 40 \)), and E (corresponding to SNOT-22 score \( > 36 \)).
patients who reported using at least 1 course of oral corticosteroids for their CRS in the past 3 months. Even after controlling for age, sex, history of smoking, polyps, asthma, aeroallergen hypersensitivity, and intranasal corticosteroid use, SNOT-22 was significantly associated with having used at least 1 CRS-related oral corticosteroids course in the past 3 months (OR = 1.02; 95% CI, 1.01-1.04; 
\( P \) = .006), which reflects that every 32-point increase in SNOT-22 is associated with an OR of 2 for having used at least 1 CRS-related oral corticosteroids course in the past 3 months.

The AUC statistics for the predictive ability of SNOT-22 for our AECRS metrics reflect a large effect size and, therefore, a strong predictive ability.\(^26\) We also stratified study participants by whether or not they had nasal polyps and found that SNOT-22 score but not endoscopy score was a statistically significant test (demonstrating large effect size regardless of polyps) for identifying patients who had AECRS, although this relationship was more accurate for patients with nasal polyps (\textbf{Table 2}).

\begin{table}
\centering
\begin{tabular}{|l|c|c|c|c|}
\hline
Characteristic & AUC (95\% CI) & \( P \) Value & Optimal Cutoff Value\(^a\) & Sensitivity, \% & Specificity, \% \\
\hline
CRS with nasal polyps & & & & & \\
\hline
Sinus infections in past 3 months & & & & & \\
\hline
SNOT-22 score & 0.787 (0.700-0.876) & <.001 & >28 & 80.5 & 65.5 \\
Endoscopy score & 0.567 (0.395-0.740) & .458 & — & — & — \\
\hline
CRS-related antibiotics in past 3 months & & & & & \\
\hline
SNOT-22 score & 0.756 (0.655-0.857) & <.001 & >29 & 81.2 & 61.2 \\
Endoscopy score & 0.630 (0.459-0.800) & .177 & — & — & — \\
\hline
CRS-related oral corticosteroids in past 3 months & & & & & \\
\hline
SNOT-22 score & 0.664 (0.556-0.773) & .010 & >19 & 96.6 & 35.7 \\
Endoscopy score & 0.595 (0.414-0.775) & .339 & — & — & — \\
\hline
CRS without nasal polyps & & & & & \\
\hline
Sinus infections in past 3 months & & & & & \\
\hline
SNOT-22 score & 0.686 (0.600-0.774) & <.001 & >41 & 52.0 & 79.1 \\
Endoscopy score & 0.429 (0.281-0.578) & .429 & — & — & — \\
\hline
CRS-related antibiotics in past 3 months & & & & & \\
\hline
SNOT-22 score & 0.655 (0.564-0.746) & .001 & >40 & 56.7 & 77.3 \\
Endoscopy score & 0.383 (0.242-0.524) & .383 & — & — & — \\
\hline
CRS-related oral corticosteroids in past 3 months & & & & & \\
\hline
SNOT-22 score & 0.665 (0.556-0.774) & .004 & >36 & 72.7 & 62.4 \\
Endoscopy score & 0.431 (0.260-0.602) & .451 & — & — & — \\
\hline
\end{tabular}
\caption{Accuracy of Measures of CRS Severity to Detect Acute Exacerbation of CRS Metrics.}
\end{table}

Abbreviations: AUC, area under the curve; CI, confidence interval; CRS, chronic rhinosinusitis; SNOT-22, 22-item Sinonasal Outcome Test; —, not applicable.

\(^a\)Maximizes the sum of sensitivity and specificity.

\textbf{AECRS Frequency as a Predictive Measure for SNOT-22 Score and Endoscopy Score}

While SNOT-22 and endoscopy score are frequently used in the assessment of patients with CRS, utilization of these metrics is clearly dependent on certain resources that are not available to all physicians. We therefore sought to determine if simply asking patients about the frequency of sinus infections, CRS-related antibiotics usage, and CRS-related oral corticosteroids usage would provide insights into the patients’ SNOT-22 scores (specifically a SNOT-22 score ≥30, which is predictive of patients who may be good candidates for endoscopic sinus surgery\(^27\)) and endoscopy scores (specifically an endoscopy score >0, which indicates any endoscopic findings) (\textbf{Figure 2}). We found that the number of sinus infections in the past 3 months was predictive of a SNOT-22 score ≥30 (AUC = 0.634; 95\% CI, 0.560-0.707; \( P < .001 \)) but not predictive of an endoscopy score >0 (AUC = 0.532; 95\% CI, 0.457-0.607; \( P = .902 \)). Reporting at least 1 sinus infection in the past 3 months provided 68.3\% sensitivity and 58.4\% specificity for detecting patients with SNOT-22 score ≥30. The number of sinus infections reported in the past 3 months was significantly associated with a SNOT-22 score ≥30 (OR = 1.99; 95\% CI, 1.41-2.80; \( P < .001 \)).

CRS-related antibiotics used in the past 3 months was also predictive of a SNOT-22 score ≥30 (AUC = 0.614; 95\% CI, 0.538-0.689; \( P < .001 \)) but not predictive of an endoscopy score of >0 (AUC = 0.506; 95\% CI, 0.428-0.584; \( P = .149 \)). Reporting use of at least 1 course of CRS-related antibiotics in the past 3 months provided 69.2\% sensitivity and 53.5\% specificity for detecting patients with a SNOT-22 score ≥30. The number of CRS-related antibiotics used in the past 3 months was significantly associated with a SNOT-22 score ≥30 (OR = 1.58; 95\% CI, 1.15-2.19; \( P = .005 \)).

We also found that the number of CRS-related oral corticosteroids courses used in the past 3 months was predictive of a SNOT-22 score ≥30 (AUC = 0.616; 95\% CI, 0.525-0.708; \( P < .001 \)) but not an endoscopy score of >0 (AUC
Reporting use of at least 1 course of CRS-related antibiotics in the past 3 months provided 74.1% sensitivity and 49.2% specificity for detecting patients with a SNOT-22 score ≥30. The number of CRS-related oral corticosteroids used in the past 3 months was significantly associated with a SNOT-22 score ≥30 (OR = 2.06; 95% CI, 1.29–3.27; P = .002).

The AUC statistics for the predictive ability of AECRS metrics for identifying patients with a SNOT-22 score ≥30 reflect a medium effect size.26 We also repeated our analyses to determine the accuracy of AECRS metrics for predicting a SNOT-22 score ≥30 or an endoscopy score >0 in study participants stratified by whether or not they had nasal polyps (Table 3 and Table 4). Similar to what we found for the entire study cohort, in both patients with and without nasal polyps, AECRS metrics were much more predictive of having a SNOT-22 score ≥30 than of having an endoscopy score >0.

**Discussion**

The clinical evaluation of CRS has historically centered on the assessment of chronic symptomatology and objective findings on nasal endoscopy. Symptomatology is the focus of subjective, patient-reported CRS outcome measures since chronic symptomatology has been identified as the primary driver of decreased quality of life.10,12 Endoscopic findings are frequently assessed as objective measures of CRS disease status. However, as our knowledge of CRS and the drivers of its downstream consequences—such as decreased quality of life and lost productivity—increases, so too does the number of disease characteristics that we ideally want to assess in the clinical evaluation of our patients with CRS. Some of these disease characteristics may require special equipment or instruments, which limits broad usage. Perhaps more important, the assessment of all disease characteristics that continue to be identified requires increasing amounts of time in the clinic. One solution is to identify links and associations between different disease characteristics such that assessment

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**Figure 2.** Receiver operating characteristic curves for number of sinus infections in the past 3 months to detect the (A) 22-item Sinonasal Outcome Test (SNOT-22) score ≥30 and (B) endoscopy score >0, number of chronic rhinosinusitis (CRS)—related antibiotics taken in the past 3 months to detect (C) SNOT-22 score ≥30 and (D) endoscopy score >0, and number of CRS-related oral corticosteroid courses taken in the past 3 months to detect (E) SNOT-22 score ≥30 and (F) endoscopy score >0. Marked on panels A, C, and E are thresholds of reporting 1 or more of the corresponding acute exacerbation of CRS metrics, which have the highest sum of sensitivity and specificity in each of those panels.

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### Table 3. Accuracy of Acute Exacerbation of CRS Metrics to Detect SNOT-22 Score ≥30.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>AUC (95% CI)</th>
<th>P Value</th>
<th>Optimal Cutoff Value&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CRS with nasal polyps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinus infections in past 3 months</td>
<td>0.725 (0.638–0.813)</td>
<td>&lt;.001</td>
<td>&gt;0</td>
<td>61.5</td>
<td>80.9</td>
</tr>
<tr>
<td>CRS-related antibiotics in past 3 months</td>
<td>0.698 (0.615–0.780)</td>
<td>&lt;.001</td>
<td>&gt;0</td>
<td>50.0</td>
<td>87.2</td>
</tr>
<tr>
<td>CRS-related oral corticosteroids in past 3 months</td>
<td>0.654 (0.577–0.732)</td>
<td>&lt;.001</td>
<td>&gt;0</td>
<td>38.5</td>
<td>91.5</td>
</tr>
<tr>
<td><strong>CRS without nasal polyps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinus infections in past 3 months</td>
<td>0.654 (0.570–0.738)</td>
<td>.001</td>
<td>&gt;0</td>
<td>63.2</td>
<td>63.6</td>
</tr>
<tr>
<td>CRS-related antibiotics in past 3 months</td>
<td>0.596 (0.510–0.682)</td>
<td>.035</td>
<td>&gt;0</td>
<td>54.0</td>
<td>63.6</td>
</tr>
<tr>
<td>CRS-related oral corticosteroids in past 3 months</td>
<td>0.588 (0.525–0.650)</td>
<td>.014</td>
<td>&gt;0</td>
<td>27.6</td>
<td>89.1</td>
</tr>
</tbody>
</table>

**Abbreviations:** AUC, area under the curve; CI, confidence interval; CRS, chronic rhinosinusitis; SNOT-22, 22-item Sinonasal Outcome Test.

<sup>a</sup>Maximizes the sum of sensitivity and specificity.
In this study, we found that SNOT-22 score and the various metrics for AECRS frequency were predictive of each other. In contrast, AECRS metrics and endoscopy score were not predictive of each other. Although unknown why, it is possible that SNOT-22 but not endoscopy score is predictive of AECRS due to shared pathophysiology, but this finding is more likely a reflection of previous work showing endoscopy score to generally be poorly associated with any kind of patient-reported outcome measure for CRS.\(^\text{29,30}\)

While we did not perform radiographic imaging, prior studies have shown radiographic CRS severity to be associated—albeit in limited ways—with CRS symptoms,\(^\text{31}\) so it is possible that radiography would better associate with AECRS frequency. In contrast, SNOT-22 has been validated as not only as metric for short-term symptom burden but also as a reflection of long CRS symptom control\(^\text{32}\)—a relationship that likely explains why SNOT-22 is strongly predictive of past AECRS frequency.

Based on our results, we would recommend that a SNOT-22 score of greater than 40 be used as a general threshold for triggering further evaluation of and consideration for AECRS. However, our results also suggest that in patients with CRS with nasal polyps, a lower SNOT-22 threshold around 30 can be used. Taken from another perspective, our results also show that the frequency of AECRS metrics may also be predictive of SNOT-22 score. In all cases—for the general CRS population, including both those with and without nasal polyps—we show that reporting at least 1 AECRS metric (sinus infection, CRS-related antibiotic, or CRS-related oral corticosteroid) is predictive of having a SNOT-22 score ≥30 in a highly specific manner. It is important to note that our findings show that SNOT-22 score and AECRS metrics are not perfectly predictive of each other—their sensitivities and specificities are not in all cases so high that they can be used as sole predictors for each other. However, their sensitivities and specificities nevertheless may be used to inform the status of the other CRS disease characteristic in the clinical setting. We believe that our findings, particularly with respect to detection of patients having AECRS, may inform management of patients with CRS. Since consideration of AECRS is incorporated into management of patients with CRS\(^\text{20}\) and distinct pathophysiologic mechanisms for AECRS\(^\text{33}\) suggest that past AECRS could be reflective of future AECRS, identification of patients who are experiencing AECRS may therefore be informative for management of CRS.

### Table 4. Accuracy of Acute Exacerbation of CRS Metrics to Detect Endoscopy Score >0.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>AUC (95% CI)</th>
<th>P Value</th>
<th>Optimal Cutoff Value</th>
<th>Sensitivity, %</th>
<th>Specificity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CRS with nasal polyps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinus infections in past 3 months</td>
<td>0.462 (0.361-0.564)</td>
<td>.481</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CRS-related antibiotics in past 3 months</td>
<td>0.524 (0.425-0.623)</td>
<td>.632</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CRS-related oral corticosteroids in past 3 months</td>
<td>0.503 (0.413-0.593)</td>
<td>.950</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>CRS without nasal polyps</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinus infections in past 3 months</td>
<td>0.529 (0.435-0.622)</td>
<td>.553</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CRS-related antibiotics in past 3 months</td>
<td>0.601 (0.517-0.685)</td>
<td>.034</td>
<td>&gt;1</td>
<td>91.3</td>
<td>30.2</td>
</tr>
<tr>
<td>CRS-related oral corticosteroids in past 3 months</td>
<td>0.451 (0.384-0.518)</td>
<td>.188</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Abbreviations: AUC, area under the curve; CI, confidence interval; CRS, chronic rhinosinusitis; SNOT-22, 22-item Sinonasal Outcome Test; —, not applicable.

\(^{a}\)Maximizes the sum of sensitivity and specificity.
This study should be interpreted in the context of its limitations. This is a cross-sectional study and, therefore, is not indicative of how SNOT-22, endoscopy score, and AECRS frequency may be used to predict each other in the future. It is also possible that comorbidity status, like the presence of polyps, may affect the strength and accuracy of the relationships we have described here, but this possibility will need to be explored in future studies that are specifically powered to that end. In addition, we asked patients to recall their past CRS-related antibiotic usage, past CRS-related oral corticosteroid usage, and frequency of past sinus infections. Although asking patients to recall their past CRS-related medication usage and past CRS exacerbations not only is validated for CRS\textsuperscript{34} but also has been used for countless other diseases as well, such as asthma or allergic rhinitis,\textsuperscript{35,36} such methodology may be influenced by recall bias.

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Author Contributions
Marlene M. Speth, performed the study and wrote/revised the manuscript; Robert A. Gaudin, performed the study and wrote/revised the manuscript; Lloyd P. Hoehle, performed the study and wrote/revised the manuscript; Katie M. Phillips, performed the study and wrote/revised the manuscript; David S. Caradonna, performed the study and wrote/revised the manuscript; Stacey T. Gray, performed the study and wrote/revised the manuscript; Ahmad R. Sedaghat, designed, performed the study and wrote/revised the manuscript.

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