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ORIGINAL RESEARCH

Relationship Between the Level of CCL13 in Nasal Mucosa Tissue and Postoperative Recurrence in Patients with Chronic Rhinosinusitis

Wen Zhao[1], Haili Li[1], Feng Jing[1], Shiqing Xiao[1], Huijing Jia[1], Hongwei Chen[2], Wei Zhao[1]

[1]Department of Otolaryngology, Baoding No.1 Central Hospital, Baoding, 071000, People's Republic of China; [2]Department of Science and Education, Baoding No.1 Central Hospital, Baoding, 071000, People's Republic of China

Correspondence: Wei Zhao, Department of Otolaryngology, Baoding No.1 Central Hospital, Baoding, 071000, People's Republic of China, Email Wei_Zhaoxx56@163.com

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Purpose: To investigate the relationship between the expression levels of Chemokine C-C Motif Ligand 13 (CCL13) in nasal mucosal tissue and the likelihood of postoperative recurrence in patients with chronic rhinosinusitis (CRS).

Patients and Methods: In this retrospective study, we collected clinical data from 230 CRS patients who underwent functional endoscopic sinus surgery at our hospital from January 2022 and December 2023. Based on follow-up results, patients were divided into a recurrence group (66 cases) and a non-recurrence group (164 cases). The concentration of CCL13 in nasal mucosal tissue was measured using ELISA. Statistical analyses were performed using Spearman correlation analysis, multivariate logistic regression analysis, receiver operating characteristic (ROC) curve analysis, and a nomogram model.

Results: After a one-year follow-up period, the recurrence rate was 28.70%. The concentration of CCL13 was significantly higher in the recurrence group compared to the non-recurrence group ($P<0.05$). A negative correlation was observed between CCL13 levels and the Lund-Mackay score ($r=-0.425$, $P<0.001$). Multivariate analyses indicated that the presence of nasal polyps, the Lund-Mackay score, and CCL13 concentration were independent risk factors for postoperative recurrence ($P<0.05$). ROC curve analysis showed that the area under the curve (AUC) for CCL13 in predicting recurrence was 0.727 ($P<0.05$), with a sensitivity of 51.22% and a specificity of 89.39% at a threshold of 422.3 pg/mL. The nomogram model demonstrated strong predictive capabilities, with AUC values of 0.80 in the training set and 0.85 in the validation set.

Conclusion: The expression level of CCL13 is an independent predictor of postoperative recurrence in CRS and holds significant assessment value. However, this study has some limitations, including its retrospective design and potential selection bias. Future prospective studies are needed to further validate these findings.

Keywords: chronic rhinosinusitis, chemokine C-C Motif Ligand 13, functional endoscopic sinus surgery, recurrence, predictive value

Introduction

Chronic rhinosinusitis (CRS) is a commonly encountered upper respiratory tract disorder, marked by persistent inflammation of the nasal mucosa and paranasal sinuses, with a duration typically exceeding 12 weeks. It significantly impairs patients' quality of life, leading to symptoms such as nasal congestion, rhinorrhea, hyposmia, and headache, and may even trigger ocular or intracranial complications.[1,2] The development of CRS is intricate and arises from multiple contributing factors. It encompasses the interplay of infections, allergic responses, immune system irregularities, structural defects, and various environmental influences.[3–6] The main pathological features include inflammatory cell infiltration, mucosal edema, glandular hyperplasia, and secretory retention.[7] If not promptly and effectively treated, the inflammation may spread to adjacent tissues or organs, leading to other severe complications and significantly affecting patients' quality of life.[8] Functional endoscopic sinus surgery (FESS) has become one of the standard treatments for severe CRS patients, effectively improving symptoms with good cost-effectiveness and safety.[9–11] However, the postoperative recurrence rate remains relatively high.[12] Studies have shown that postoperative recurrence in CRS patients is associated with various clinical factors, including comorbidities,

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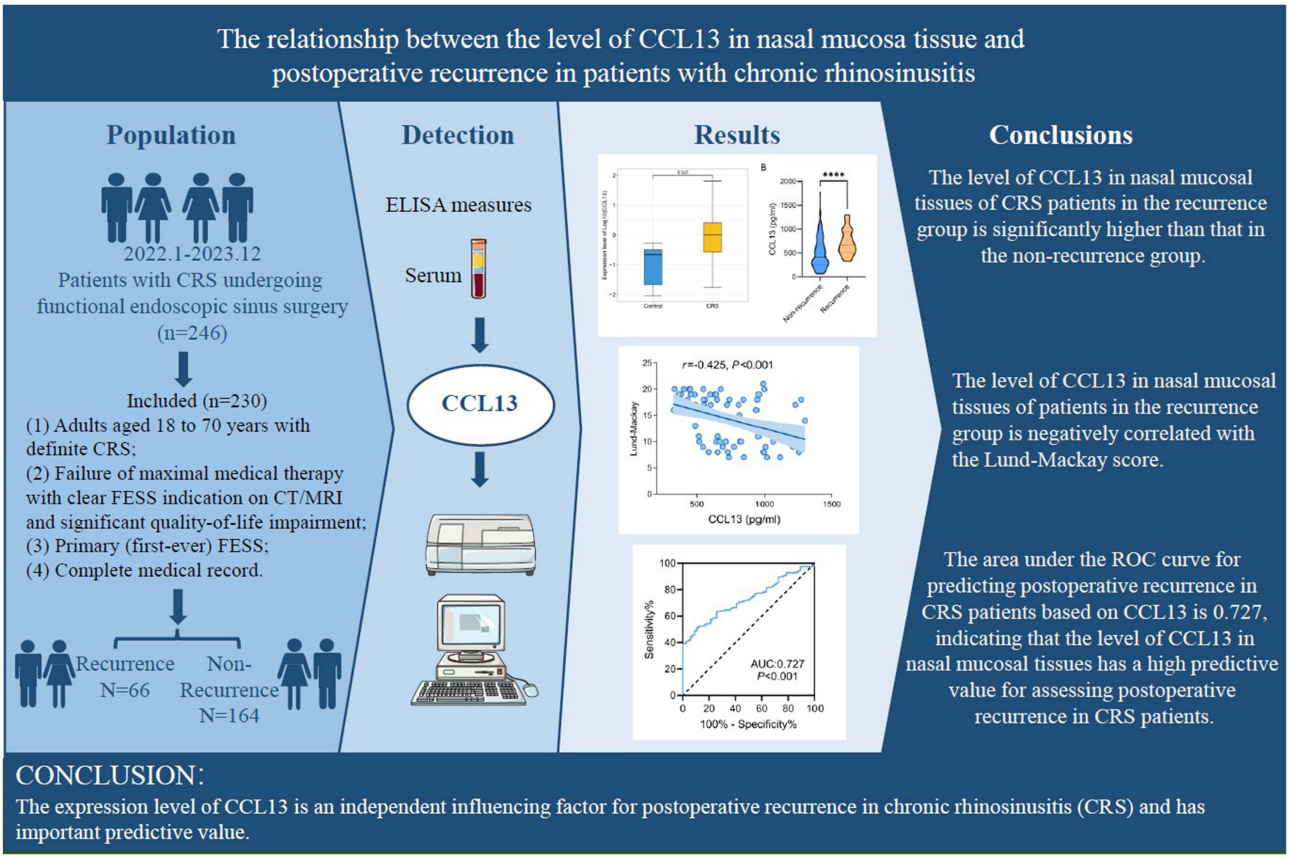
Graphical Abstract



postoperative infections, and computed tomography (CT) scores of the sinuses.[13] Therefore, identifying key factors influencing postoperative recurrence is crucial for improving patient outcomes.

Chemokines are a class of small-molecule cytokines that specifically attract specific leukocytes to migrate to inflammatory sites, participating in the regulation of inflammatory response.[14,15] CCL13 (Chemokine C-C Motif Ligand 13), as an important member of the chemokine family, has been implicated in the pathogenesis of various inflammatory diseases.[16,17] In the pathological process of CRS, the inflammatory response of nasal mucosa tissue is a critical link, with pathological changes such as inflammatory cell infiltration, mucosal edema, and glandular hyperplasia closely related to the abnormal expression of inflammatory factors.[18] CCL13 has been demonstrated to be significantly upregulated in nasal polyps, correlating with eosinophil infiltration and a Th2-dominant inflammatory milieu.[19] Bioinformatics analysis in our study has also revealed that CCL13 is significantly upregulated in the nasal tissue of patients with CRS compared with healthy nasal tissue. However, the relationship between CCL13 expression levels and postoperative recurrence in CRS patients remains to be elucidated.

This investigation seeks to elucidate the association between CCL13 expression and postoperative recurrence in CRS patients. The approach involves quantifying the expression levels of CCL13 in nasal mucosa tissue specimens and correlating these findings with the patients' clinical characteristics and postoperative follow-up outcomes. This study could provide new theoretical bases for the clinical treatment of CRS, offer potential intervention targets for reducing postoperative recurrence rates, thereby improving patient outcomes and enhancing their quality of life.

Materials and Methods

Bioinformatics Analysis

The GSE36830 dataset documented the differential gene expression profiles in uncinate tissues between CRS patients and healthy controls. GEO2R was employed for analysis, with the screening criteria set as "P<0.05 and absolute value of logFC > 1" to identify differentially expressed genes in the uncinate tissues of CRS patients. R software was utilized to generate a differential gene expression map.

Study Subjects

Based on previous studies, the recurrence rate within one year after FESS in CRS patients is approximately 20.70%.[12] To ensure statistical rigor, the required sample size was estimated with PASS 15.0 software using the single-proportion confidence-interval approach. Assuming an expected one-year recurrence rate of 20.70%, a two-sided 90% confidence level, and a margin of error of 5%, the normal-approximation formula indicated that 196 patients would be necessary.

This retrospective single-centre cohort study conducted at Baoding No. 1 Central Hospital included 246 consecutive patients with CRS who underwent FESS between January 2022 and December 2023.

Inclusion Criteria: (1) Adults aged 18 to 70 years with definite CRS, defined by symptoms lasting ≥12 weeks (≥1 major: nasal obstruction or anterior/posterior mucopurulent discharge; plus ≥1 minor: facial pain/pressure or hyposmia/anosmia) and objective inflammation on nasal endoscopy (discharge in middle meatus/olfactory cleft, oedema/polyps) or CT (opacification of ostiomeatal complex/sinuses).[20] (2) Failure of maximal medical therapy with clear FESS indication on CT/MRI and significant quality-of-life impairment. (3) Primary (first-ever) FESS. (4) Complete medical record.

Exclusion criteria: (1) Active malignancy; (2) Severe cardiac, cerebral, hepatic, renal, haematologic or primary immunodeficiency disease; (3) Uncontrolled psychiatric disorder; (4) Other acute or chronic severe infection; (5) Previous nasal/paranasal surgery; (6) Pregnancy or lactation; (7) Systemic corticosteroids or other hormonal therapy within 4 weeks of surgery; (8) Nasal trauma history; (9) Immunomodulators or high-dose antibiotics with known mucosal effects within 1 month pre-op; (10) Occupational or environmental exposure to pollutants/chemicals that could influence mucosal inflammation.

Clinical Data Collection

Comprehensive baseline and clinical variables were recorded: sex, age, BMI, disease duration, laterality (unilateral vs bilateral), smoking and alcohol history, comorbid diabetes and hypertension, atopy (serum total IgE ≥ 100 kU L^{-1} or positive skin-prick test), physician-diagnosed asthma (symptoms plus reversible airway obstruction or positive bronchial provocation), presence of nasal polyps, post-operative adhesions or surgical-site infection, and pre-operative Lund-Mackay score on non-contrast CT. The Lund-Mackay system grades each ipsilateral sinus and the ostiomeatal complex 0–2 points (unilateral maximum 12, bilateral maximum 24); higher scores reflect more extensive mucosal inflammation.[13]

Detection of CCL13 Expression Level in Nasal Mucosa Tissue

CCL13 levels in nasal mucosal tissue were quantified using the Solarbio® Human MCP-4/CCL13 ELISA Kit (SEKH-0238, Solarbio, Beijing, China) according to the manufacturer's instructions. Briefly, tissue samples collected during surgery were rapidly thawed and placed on ice. The samples were rinsed with ice-cold phosphate-buffered saline (PBS), minced, and homogenized in PBS containing protease inhibitors at a tissue-to-buffer ratio of 1:9 (w/v). The homogenate underwent repeated freeze-thaw cycles and brief sonication to ensure complete lysis. Following centrifugation at 5000 × g for 5–10 minutes at 2–8 °C, the supernatant was collected and stored at −20 °C until analysis.

Prior to the assay, both the ELISA reagents and samples were equilibrated to room temperature for 30 minutes. The microplate was pre-wetted and dried before use. Standard solutions were prepared using serial dilutions. Samples and standards were added to the plate and incubated at 37 °C. Subsequently, biotinylated detection antibody, enzyme conjugate, substrate, and stop solution were added sequentially according to the protocol. Optical density (OD) was measured at 450 nm using a microplate reader. CCL13 concentrations were determined by interpolating from a standard

curve generated using known concentrations of recombinant CCL13. To minimize potential detection bias, laboratory personnel performing the ELISA were kept blinded to all clinical data and sample identifiers.

Follow-Up

Follow-up visits were scheduled biweekly within the first month after surgery, monthly from 1 to 3 months postoperatively, and quarterly after 3 months. All medical staff involved in the follow-up process underwent unified training and used a standardized assessment form to document the follow-up results, ensuring the completeness and consistency of the data. Postoperative follow-up of patients was conducted for one year via telephone consultations and outpatient clinic evaluations. Recurrence was assessed based on symptom recurrence (unimproved or minimally improved symptoms such as nasal congestion, hyposmia, and rhinorrhea), imaging recurrence (abnormal findings on nasal endoscopy, such as ostiomeatal complex stenosis or atresia, extensive adhesions, mucosal congestion and edema in the sinus cavity, large amounts of mucoid or purulent discharge in the nasal cavity, and nasal polyp formation), and changes in CT score (no significant decrease in Lund-Mackay score compared to preoperative levels, or the appearance of new high-score areas).[20] Follow-up visits were scheduled biweekly within the first month after surgery, monthly from 1 to 3 months postoperatively, and quarterly thereafter. All medical staff involved in the follow-up process underwent unified training and used a standardized assessment form to document the follow-up results, ensuring the completeness and consistency of the data.

Statistical Methods

Statistical analysis was conducted utilizing SPSS version 26.0. For categorical variables, frequencies, expressed as percentages, were calculated, and group differences were assessed through the chi-square test. For quantitative data that adhered to a normal distribution, means and standard deviations ($\bar{x} \pm s$) were computed, with group comparisons performed using the *t*-test. In instances where quantitative data did not conform to a normal distribution, medians and interquartile ranges [M (Q1, Q3)] were employed, and the Mann–Whitney *U*-test was utilized for comparative analysis between groups. Spearman correlation analysis was applied to determine the relationship between the expression of CCL13 in nasal mucosa and the Lund-Mackay score within the recurrence group. Moreover, multivariate logistic regression analysis was executed to pinpoint factors that affect postoperative recurrence in patients with CRS. The predictive capability of CCL13 expression levels for postoperative recurrence in CRS patients was assessed through receiver operating characteristic (ROC) curve analysis. The optimal ROC threshold was determined based on the Youden index, which maximizes the sum of sensitivity and specificity. The dataset was randomly partitioned into training and validation sets with a ratio of 7:3. Logistic regression analysis was subsequently performed using R software to develop a nomogram model aimed at predicting postoperative recurrence following FESS in CRS patients. ROC curves, calibration curves, and decision curves were generated to appraise the predictive performance and clinical utility of the nomogram. A p-value of less than 0.05 was deemed statistically significant.

Results

Comparison of Clinical Data Between the Recurrence and Non-Recurrence Groups

After one year of follow-up, 16 out of 246 CRS patients were lost to follow-up (No significant differences was found in baseline characteristics between the lost-to-follow-up group and the remaining cohort). Based on the occurrence of recurrence within a one-year period, the remaining 230 patients were divided into a recurrence group (66 cases) and a non-recurrence group (164 cases), resulting in a recurrence rate of 28.70%. Statistical analysis revealed no significant differences between the recurrence and non-recurrence groups with respect to gender, age, body mass index, disease duration, lesion site, smoking history, alcohol consumption history, diabetes, hypertension, presence of asthma, postoperative nasal adhesion, or postoperative infection ($P>0.05$). Nevertheless, notable statistical variations were identified regarding the occurrence of nasal polyps as well as the Lund-Mackay scores ($P<0.05$) (Table 1).

Table 1 Comparison of Clinical Data Recurrence and Non-Recurrence Groups

Indicators	Recurrence Group (n=66)	Non-Recurrence Group (n=164)	$x^2/t/Z$	*P*
Gender (n/%)			0.017*	0.506
Male	36 (54.55)	91 (55.49)		
Female	30 (45.45)	73 (44.51)		
Age [M (Q1, Q3), years]	41.00 (37.00,47.25)	40.50 (36.25,47.75)	−0.363#	0.717
Body Mass Index ($\bar{x} \pm s$, kg/m^2)	23.35±2.63	23.22±2.88	0.318 ^	0.750
Disease Duration [M (Q1, Q3), years]	5.00(5.00,6.00)	6.00(5.00,6.00)	−1.898#	0.058
Location Site (n/%)			0.123*	0.419
Unilateral	27(40.91)	63(38.41)		
Bilateral	39(59.09)	101(61.59)		
Smoking History (n/%)			0.708*	0.245
Yes	26 (39.39)	55 (33.54)		
No	40 (60.61)	109 (66.46)		
Alcohol Consumption History (n/%)			0.007*	0.526
Yes	35 (53.03)	86 (52.44)		
No	31 (46.97)	78 (47.56)		
Diabetes (n/%)			0.002*	0.539
Yes	30 (45.45)	74 (45.12)		
No	36 (54.55)	90 (54.88)		
Hypertension (n/%)			0.141*	0.409
Yes	34 (51.52)	80 (48.78)		
No	32 (48.48)	84 (51.22)		
Concomitant Asthma (n/%)			1.314*	0.160
Yes	27 (40.91)	54 (32.93)		
No	39 (59.09)	110 (67.07)		
Atopy (n/%)			3.359*	0.067
Yes	24 (36.36)	40 (24.39)		
No	42 (63.64)	124 (75.61)		
Presence of Nasal Polyps (n/%)			8.019*	0.003
Yes	23 (34.85)	91 (55.49)		
No	43 (65.15)	73 (44.51)		
Postoperative Nasal Adhesion (n/%)			0.968*	0.201
Yes	30 (45.45)	63 (38.41)		
No	36 (54.55)	101 (61.59)		
Postoperative Infection (n/%)			2.203*	0.108
Yes	10 (15.15)	14 (8.54)		
No	56 (84.85)	150 (91.46)		
Lund-Mackay Score [M (Q1, Q3), points]	16.00 (10.00,18.25)	10.00 (8.00,14.00)	−4.822#	0.000

Notes: #represents Z value, *represents χ^2 value, ^represents t value.

Comparison of CCL13 Expression Levels in Nasal Mucosa Tissue Between the Two Groups of CRS Patients

The GSE36830 microarray study documented gene expression profiles in uncinate tissues obtained from both healthy individuals and patients with CRS. The analysis indicated a notable upregulation of CCL13 expression within the uncinate tissues of CRS patients when contrasted with the control group (Figure 1A). Additionally, an examination of the correlation between CCL13 levels and postoperative recurrence in CRS patients revealed that the expression of CCL13 in nasal mucosal tissue was significantly elevated in the recurrence group compared to the non-recurrence group, demonstrating a statistically significant difference ($Z = -5.389$, $P<0.05$) (Figure 1B).

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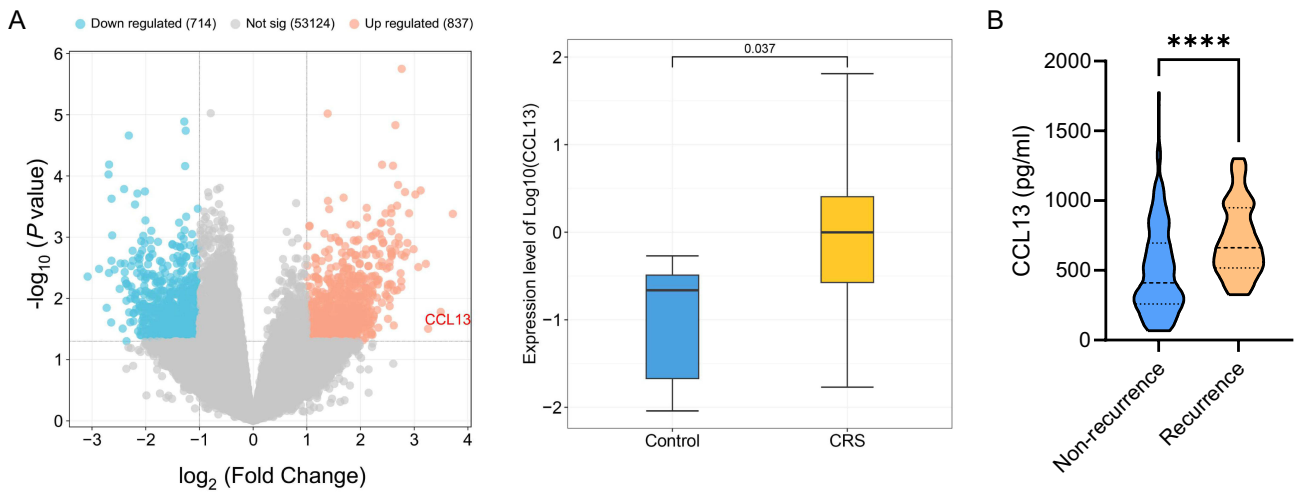

Figure 1 Comparison of CCL13 Expression Levels in Nasal Mucosa Tissue of CRS Patients. (**A**) Expression of CCL13 in uncinate tissues of CRS patients from the GSE36830 microarray. (**B**) CCL13 levels in nasal mucosa tissue of CRS patients in the recurrence and non-recurrence groups.
Notes: The "****" symbol signifies a *P*-value < 0.0001.

Correlation Between CCL13 and Lund-Mackay Scores in Nasal Mucosa Tissue of the Recurrence Group

Spearman correlation analysis revealed a negative correlation between CCL13 levels and Lund-Mackay scores in nasal mucosa tissue of the recurrence group (r = −0.425, *P<0.001*) (Figure 2).

Analysis of Factors Influencing Postoperative Recurrence in CRS Patients

Logistic regression analysis was conducted with postoperative recurrence in CRS patients as the dependent variable (yes = 1, no = 0) and the presence of nasal polyps (yes = 1, no = 0), Lund-Mackay scores (actual values), and CCL13 (actual values) as independent variables. The results showed that the presence of nasal polyps, Lund-Mackay scores, and CCL13 were risk factors for postoperative recurrence in CRS patients (*P<0.05*) (Table 2).

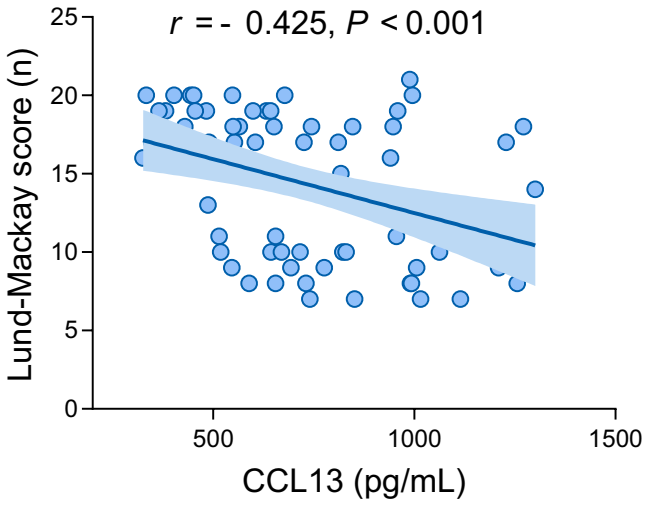

Figure 2 Correlation between CCL13 and Lund-Mackay Scores in Nasal Mucosa Tissue of the Recurrence Group.

Table 2 Multivariate Logistic Regression Analysis of Factors Influencing Postoperative Recurrence in CRS Patients After FESS

Variable	*β*	*S.E*	*Walds*	*P*	*OR*	95% CI
Combined with Nasal Polyps	0.945	0.342	7.642	0.006	2.573	1.317–5.030
Lund-Mackay Score	0.184	0.039	22.047	0.000	1.202	1.113–1.298
CCL13	0.002	0.001	19.912	0.000	1.002	1.001–1.004

Abbreviations: CRS, chronic rhinosinusitis; FESS, functional endoscopic sinus surgery; CCL13, chemokine C-C Motif Ligand 13.

ROC Curve Analysis of the Predictive Value of CCL13 Expression Levels in Nasal Mucosa Tissue for Postoperative Recurrence in CRS Patients

ROC curves were employed to assess the prognostic significance of CCL13 expression levels in nasal mucosal tissue concerning postoperative recurrence in patients with CRS. The analysis revealed an area under the ROC curve of 0.727 ($P<0.05$) for CCL13. At a threshold of 422.3 pg/mL, the sensitivity was determined to be 51.22%, while the specificity reached 89.39% (Figure 3).

Construction and Validation of the Nomogram Prediction Model

A nomogram prediction model was developed to forecast postoperative recurrence in CRS patients following FESS, utilizing the outcomes derived from logistic regression analysis. This model facilitated the quantification of scores corresponding to each independent risk factor, as well as the calculation of a cumulative score, enabling the estimation of the likelihood of postoperative recurrence in CRS patients post-FESS (Figure 4).

ROC curves were employed to analyze the model's discriminative performance. Findings indicated that the AUC for the training cohort was 0.80 (95% Confidence Interval: 0.73–0.87), demonstrating a sensitivity of 0.68 and specificity of 0.81. Conversely, in the validation cohort, the AUC was recorded at 0.85 (95% Confidence Interval: 0.76–0.94), with a sensitivity of 0.62 and an impressive specificity of 0.97 (Figure 5).

To assess the calibration capability of the nomogram prediction model concerning postoperative recurrence in patients with CRS following FESS, calibration curves alongside the Hosmer-Lemeshow goodness-of-fit test were employed. The results showed good consistency between the predicted and actual values (training set: $x^2 = 6.322$, $P = 0.611$; validation

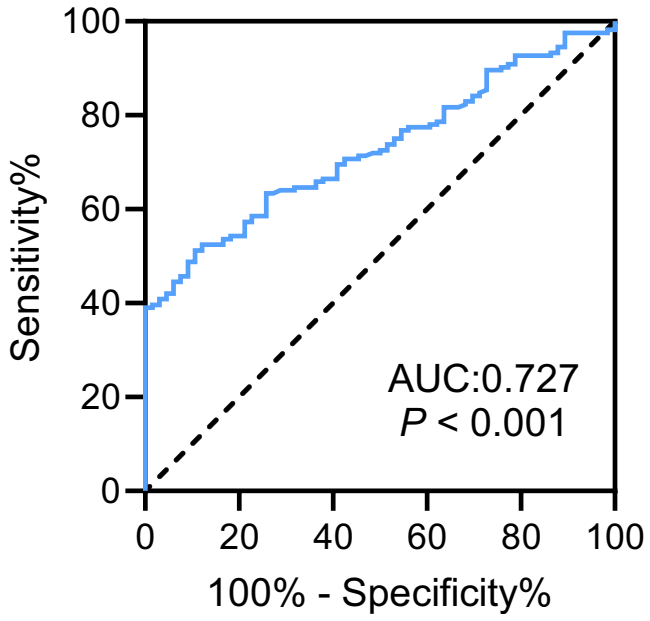

Figure 3 ROC Curve for Determining the Predictive Value of CCL13 Expression Levels for Postoperative Recurrence in CRS Patients.

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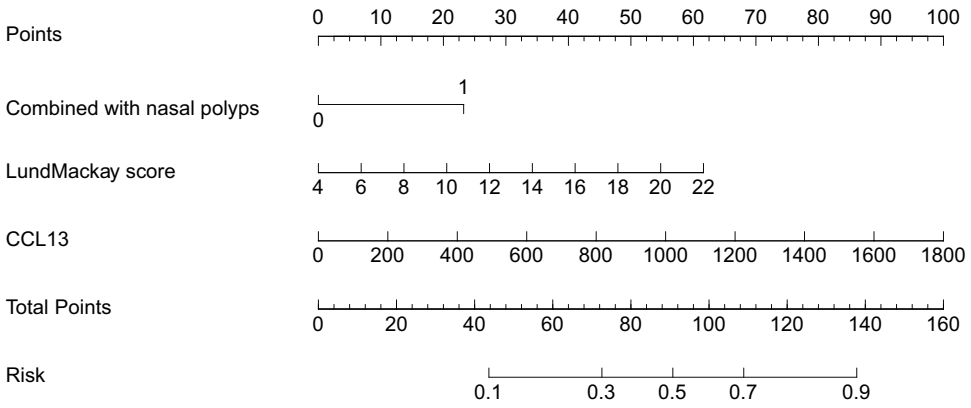

Figure 4 Nomogram Model for Predicting Postoperative Recurrence in CRS Patients after FESS.

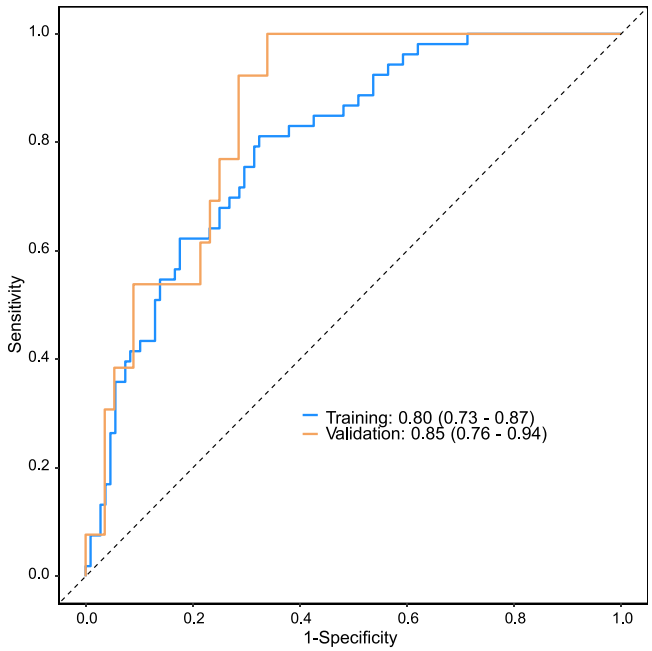

Figure 5 ROC Curve for the Nomogram Model Predicting Postoperative Recurrence in CRS Patients after FESS.

set: $x^2 = 4.967$, $P = 0.761$). The P-values in both the training and validation sets were greater than 0.05, indicating good calibration ability of the prediction model (Figure 6A and B).

The clinical effectiveness of the model was evaluated using decision curve analysis. The results indicated that when the threshold probabilities were 0.05–0.82 in the training set and 0.10–0.90 in the validation set, utilizing the nomogram prediction model for risk assessment yielded a higher net benefit compared to either intervening in all patients or not intervening at all. This demonstrates that the model holds certain application value in clinical practice (Figure 7A and B).

Discussion

CRS is a common chronic upper respiratory disease in otorhinolaryngology, characterized by nasal obstruction, rhinorrhea, and head/facial pain, which significantly affects patients' quality of life. Epidemiological surveys indicate that its overall prevalence in China is 10%, imposing not only considerable suffering on patients but also a heavy economic burden on the healthcare system and society.[21,22] The etiology of CRS is complex and diverse, with a long disease course and a tendency for recurrent episodes. The mechanisms underlying postoperative recurrence are particularly intricate, involving multiple factors such as nasal anatomical structures, external environments, and patients' own conditions.[23,24]

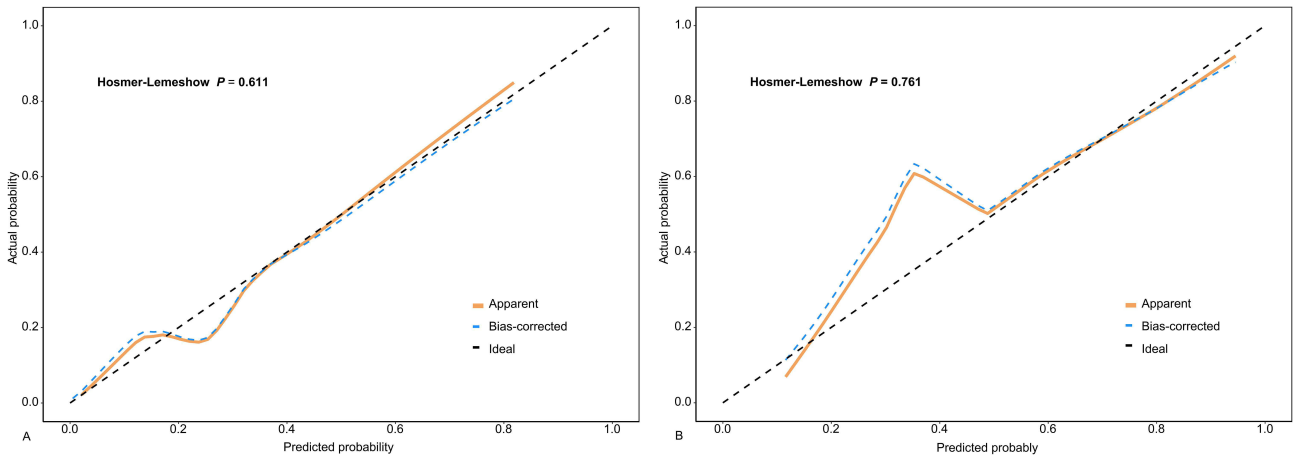

Figure 6 Calibration Curve for the Nomogram Model Predicting Postoperative Recurrence in CRS Patients after FESS. (**A**) Training set. (**B**) Validation set.

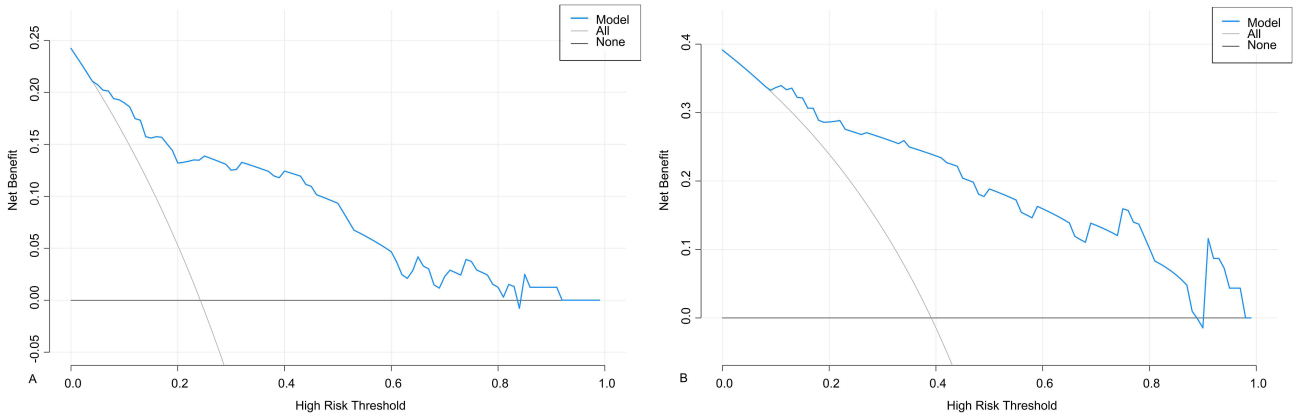

Figure 7 Decision Curve for the Nomogram Model Predicting Postoperative Recurrence in CRS Patients after FESS. (**A**) Training set. (**B**) Validation set.

Among these, persistent inflammatory responses and dysregulation of the immune system play crucial roles in recurrence.[25,26]

CCL13 is an important member of the CC chemokine family, primarily involved in inflammatory responses and immune regulation. By binding to G-protein-coupled receptors on cell surfaces, it induces the chemotaxis and activation of monocytes, macrophages, T cells, eosinophils, and immature dendritic cells, thereby exacerbating inflammatory responses.[27] Studies have shown that CCL13 may play a significant role in the inflammatory responses of asthma.[28] Additionally, research has found that a CCL13-derived synthetic peptide, CDIP-2, can exert anti-inflammatory effects by acting on CCR1, CCR2, and CCR3 chemokine receptors, significantly alleviating airway inflammation.[29] Furthermore, literature suggests that the transcription level of CCL13 in nasal mucosa is persistently elevated in patients with chronic rhinosinusitis with nasal polyps (CRSwNP), and it is closely associated with eosinophil infiltration and a Th2 inflammatory microenvironment.[30] It can be inferred that CCL13 contributes to the progression of CRSwNP by influencing eosinophil infiltration and the Th2 inflammatory microenvironment in the local microenvironment. In chronic rhinosinusitis without nasal polyps (CRSsNP), CRSsNP is typically characterized by neutrophil infiltration, accompanied by the overproduction of TGF-β2 and subsequent fibrosis.[31] In some diseases, CCL13 has been shown to be associated with increased neutrophils.[32,33] This study further analyzed the relationship between CCL13 levels and postoperative recurrence in CRS patients. The findings indicated that the concentrations of CCL13 within the nasal mucosal tissue were markedly elevated in the recurrence group compared to those in the non-recurrence group. Moreover, CCL13 was an independent influencing factor for postoperative recurrence in CRS

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patients, suggesting that elevated CCL13 expression levels are associated with CRS recurrence. The possible mechanism is that CCL13, by influencing the nasal microenvironment, including the recruitment of monocytes, neutrophils, and eosinophils, accelerates the inflammatory response and further disrupts the local immune microenvironment. This disruption weakens the body's defense against pathogens and reduces pathogen clearance capacity, thereby increasing the likelihood of postoperative recurrence.

ROC analysis was employed to assess the prognostic significance of CCL13 in relation to the recurrence of symptoms following FESS in patients diagnosed with CRS. The results showed that the area under the ROC curve for CCL13 was 0.727, indicating that the level of CCL13 in nasal mucosa tissue has a relatively high predictive value for assessing postoperative recurrence in CRS patients. However, CCL13's sensitivity was relatively low at 51.22%, indicating that it may not be sufficient as a standalone marker to identify all patients at risk of recurrence. Conversely, its high specificity of 89.39% highlights its ability to minimize false positives, thus preventing unnecessary interventions in low-risk patients. Therefore, we propose using CCL13 as an auxiliary marker in conjunction with other clinical factors, such as the Lund-Mackay score and the presence of nasal polyps, to enhance prediction accuracy. Future research should focus on optimizing the CCL13 threshold or exploring its combination with other biomarkers to further improve the performance of predictive models.

Logistic regression analysis revealed that the presence of nasal polyps and Lund-Mackay scores were also significant factors influencing postoperative recurrence in CRS patients, consistent with previous research findings.[34,35] This suggests that in postoperative management of CRS patients, timely assessment of Lund-Mackay scores should be conducted to reduce the risk of postoperative recurrence. Meanwhile, for patients with nasal polyps, more aggressive postoperative interventions and follow-ups may be necessary. A previous study has identified atopy as an adverse prognostic factor in CRS,[36] yet another has found no association between atopic status and postoperative quality of life or the need for revision surgery.[37] The absence of a relationship between atopy and disease recurrence in the present cohort may reflect the relatively mild phenotype of our atopic patients, as well as differences in sample size, population characteristics, and the duration of postoperative follow-up. Furthermore, whereas a prior study identified asthma as an independent predictor of unfavorable CRS outcomes,[38] we were unable to corroborate this association. This discrepancy most likely reflects the milder asthma phenotype in our cohort—predominantly well-controlled disease with infrequent exacerbations—together with a shorter follow-up window that may have attenuated the influence of lower-airway comorbidity on surgical recurrence. We derived a logistic-regression nomogram to quantify individual recurrence risk after FESS in CRS patients and internally validated it in independent training and validation sets. The model showed solid discrimination (AUC 0.80 and 0.85), adequate calibration (Hosmer-Lemeshow P = 0.611 and 0.761), and positive net benefit over threshold probabilities of 5–82% and 10–90%, respectively. Pending external validation, the nomogram may help clinicians risk-stratify patients at the bedside.

However, this study has several limitations. First, its single-center design and relatively small sample size may limit generalizability. Second, external validation was not performed; thus, our findings need to be confirmed in independent, multicenter cohorts to enhance robustness. Third, the one-year follow-up period was relatively short, and longer-term follow-up is required to clarify the role of CCL13 in predicting long-term prognosis. Finally, further validation of CCL13 expression using complementary techniques—such as Western blotting and immunohistochemistry—is warranted, along with mechanistic studies to elucidate its functional role in disease recurrence.

In summary, this study explored the factors related to postoperative recurrence in CRS patients and proposed a prediction model based on CCL13 expression levels. The results showed that the presence of nasal polyps, Lund-Mackay scores, and CCL13 levels were important factors influencing recurrence. The constructed nomogram model can provide an effective risk assessment tool for clinicians to help individualize the management of postoperative recurrence risk in CRS patients. Future research should focus on multi-center validation and the exploration of other potential biomarkers to further improve the prognostic assessment system for CRS patients. Additionally, further investigation into the specific mechanisms of CCL13 in the pathophysiology of CRS may help identify new therapeutic targets and improve the prognosis for patients with CRS.

Conclusion

In summary, our study has identified that elevated levels of CCL13 in nasal mucosa, the presence of nasal polyps, and higher Lund-Mackay scores are significant factors associated with postoperative recurrence in patients with CRS. The nomogram model constructed based on these factors demonstrated strong predictive capabilities in both the training and validation cohorts. However, it is important to acknowledge the limitations of our study. The retrospective, single-center design and relatively small sample size may introduce selection bias and limit the generalizability of our findings. Future research should focus on external validation in larger, multi-center cohorts to confirm the predictive value of CCL13 and refine our prognostic assessment system. This will help to further establish the clinical utility of the nomogram model and improve the management of postoperative recurrence in CRS patients.

Data Sharing Statement

The data used to support the findings of this study are available from the corresponding authors upon request.

Ethical Statement

This study involving human participants was conducted in accordance with the Declaration of Helsinki and received ethical approval from the Baoding No.1 Central Hospital (Approval Number: 2023051). Due to the retrospective nature of the research, written informed consent was waived; however, confidentiality and anonymity of the participants were strictly maintained throughout the study.

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Disclosure

The authors report no conflicts of interest in this work.

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