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The effects of endoscopic sinus surgery on pulmonary function in chronic rhinosinusitis patients with asthma: a systematic review and meta-analysis

Yujie Cao[1] · Haiyu Hong[2] · Yueqi Sun[1] · Yinyan Lai[1] · Rui Xu[1] · Jianbo Shi[1] · Fenghong Chen[1]

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Abstract

Purpose Evidences showed improvements in clinical asthma outcomes following endoscopic sinus surgery (ESS) in chronic rhinosinusitis (CRS) patients with asthma. However, pulmonary function benefits have remained controversial up to date. The goal of this study was to conduct a systematic review and meta-analysis to investigate the effects of ESS on pulmonary function tests in CRS patients with asthma.

Methods Pubmed, Embase and Cochrane Library were searched up to March 2018 to obtain relevant studies. The researches that evaluated the effects of ESS on pulmonary function in CRS patients with asthma and had at least one parameter of pulmonary function tests before and after surgery were included in the study.

Results A total of 13 studies containing 421 patients satisfied the eligibility after judgment by 2 reviewers. These included three RCTs and ten case series. The heterogeneity in parameters of spirometry and difference in data presented forms across studies along with the lack of standard deviation of some data make it difficult to synthesize results. If data were unavailable for meta-analyses, descriptive statistics were used to report study outcomes. After qualitative and quantitative analysis, the weighted mean change after ESS in forced expiratory flow between 25% and 75% of vital capacity (FEF25–75%) was 0.21 L/s (95% CI 0.12–0.30); eight of ten studies supported that forced expiratory volume at 1 s (FEV1) improved after ESS; five of six studies supported that peak expiratory flow (PEF) improved after ESS. However, strength of evidence is generally low to insufficient.

Conclusion A generally low-quality evidence supports the association between ESS and improvements in FEF25–75%, FEV1 and PEF. A few studies met inclusion criteria for meta-analysis, which indicates the need for more high-quality studies to determine the effect of ESS.

Keywords Asthma · Chronic rhinosinusitis · Endoscopic sinus surgery · Pulmonary function tests · Systematic review · Meta-analysis

Introduction

Chronic rhinosinusitis (CRS) is a common inflammatory condition involving the nasal passages and cavities, potentially affecting 1.01–19.9% of the population worldwide [1] and 8% of the population in China [2]. Asthma is a chronic lung disease with variable and recurring symptoms, including airflow obstruction, bronchial hyperresponsiveness and underlying inflammation, in which the small airway is a major site involved [3, 4]. There is rising epidemiological evidence linking CRS and asthma. In 2008–2009, the Global Allergy and asthma Network of Excellence (GA2LEN) conducted a postal questionnaire in adults from 25 centers in Europe [5]. This study found a strong association between asthma and CRS.

✉ Jianbo Shi
Shijb@mail.sysu.edu.cn

✉ Fenghong Chen
chen_fenghong@163.com

[1] Otorhinolaryngology Hospital, The First Affiliated Hospital of Sun Yat-sen University, No. 58, Zhongshan 2nd Road, Guangzhou 510080, China

[2] Department of Otolaryngology, The Fifth Affiliated Hospital of Sun Yat-sen University, Zhuhai, China

The overall odds ratios for asthma with respect to CRS was 3.48. Meanwhile, CRS and asthma are similar in histology, with tissue eosinophil infiltration, increased glandular tissue and edema [6].

CRS coexisting with asthma, being a combination of two diseases, is one of the most challenging phenotypes to treat. Endoscopic sinus surgery (ESS) is a widely performed technique for the management of CRS patients who do not respond well to the medical treatment. The additional effects of ESS on asthmatic outcomes in CRS patients have been a concern of rhinologists and respirologists for years [7–19]. The assessments of asthma outcome consist of objective and subjective measures, including pulmonary function tests, overall asthma control, asthma attack frequency, etc. Pulmonary function tests are valuable methods that aid in the diagnosis and monitoring of patients with asthma, and spirometry is the most frequently used measure of pulmonary function. Spirometry measures expiratory flow and exhaled volume during a forced expiratory vital capacity maneuver. It can demonstrate obstruction and evaluate reversibility in patients ≥ 5 years old, and is a reliable objective measure to identify asthma [3, 20]. The primary outcome measures of spirometry are forced expiratory volume at 1 s (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio (FEV1%). The secondary outcome measures are peak expiratory flow (PEF), and forced expiratory flow between 25 and 75% of vital capacity (FEF25–75%). Results are presented in the forms of raw data (liters, liters/second) and percentage of predicted (% predicted).

Although, evidences showed improvements in clinical asthma outcomes in CRS patients following ESS, pulmonary function change after ESS has remained controversial up to date [7–19]. Vashishta et al. [21] conducted a meta-analysis in 2012 and reported that ESS in patients with concomitant asthma improved clinical asthma outcome measures, but not the lung function tests. However, the analysis about pulmonary function in that study was based on limited studies, reducing the strength of conclusion. Moreover, they included the studies about aspirin-exacerbated respiratory disease (AERD), which is also termed as Samter's Triad (asthma, nasal polyps and respiratory symptoms exacerbated by aspirin). AERD is a special syndrome, caused by an anomaly in the arachidonic acid-metabolizing cascade, which resulted in a worse outcome of ESS. With a new study [19] and excluding the studies exclusively focused on AERD, we re-conduct a systematic review and meta-analysis to investigate the effects of ESS on pulmonary function tests in CRS patients with asthma.

Materials and methods

The systematic review and meta-analysis was based on the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) criteria [22].

Literature search

Literature was searched by two authors in parallel using PubMed, Embase and the Cochrane Library in March 2018. The search strategy used in PubMed and Embase combined various terms for chronic sinusitis (sinusitis, chronic rhinosinusitis, nasal polyps), asthma, sinus surgery (endoscopic sinus surgery, sinus surgery, functional endoscopic sinus surgery, polypectomy, ESS, FESS) and pulmonary function tests (respiratory function tests, respiratory function test, pulmonary function tests, pulmonary function test, lung function tests, lung function test) to identify possible studies, while the search strategy used in Cochrane Library combined terms for chronic sinusitis (nasal polyps, sinusitis) and asthma. Studies included were restricted to English within the latest 20 years. After searching all databases, duplicates were removed. Then, the title and abstract of each study obtained by the search strategy were scanned. We aimed at studies that evaluated the effects of ESS on pulmonary function tests in CRS patients with asthma and had at least one parameter of pulmonary function tests before and after surgery. The exclusive criteria were as follows: (1) studies that exclusively focused on patients with AERD were excluded, as AERD is a special syndrome and presents much worse results of ESS; (2) studies that only included children. When a study met the inclusion criteria, the full text of the article was gathered to confirm the eligibility. References of included studies were reviewed to identify any additional articles. If more than one study from an institution had overlapping data, the study with the largest sample size or the complete data was chosen.

Data extraction

Information about the author, year of publication, study design, sample size, follow-up time, preoperative and postoperative pulmonary function test results were gathered from the included studies. The parameters of pulmonary function tests included FEF25–75%, FEV1, FEV1%, FVC and PEF. The parameters presented as mean ± standard deviation (SD) were extracted or calculated from literature for the meta-analysis. If data were not provided or could not be calculated from the provided data, we emailed the authors directly to obtain the raw data. If data were unavailable for meta-analyses, descriptive statistics were used to report study outcomes.

Meta-analysis

The Revman 5.3 software was used in performing the meta-analysis. Given expected heterogeneity, a random effects

model with inverse variance weighting was performed to generate the mean change after ESS, along with the forest plot and 95% confidence interval (CI). *P* values less than 0.05 were considered statistically significant. Every single study was removed one by one to examine the effect of the respective data, and articles of high heterogeneity were taken out for debate.

Results

Study characteristics

Based on the search strategy, a total of 91 articles were obtained (PubMed: 25; Embase: 34; Cochrane Library: 29; identified through references review: 3). Thirteen studies reported preoperative and postoperative pulmonary function tests results. These included three RCTs and ten case series. The selection process was presented in Fig. 1. The characteristics of these studies are listed in Table 1. They were performed between 1999 and 2014, involving 421 adult patients. The level of evidence was identified according to Centre for Evidence-Based Medicine (CEBM) criteria. The sample size was the number of patients that had CRS combined with asthma who underwent sinus surgery with regular medication treatments.

FEF25–75%

Two studies reported the change of FEF25–75% after ESS ($n = 69$). The weighted mean change in FEF25–75% was 0.21 L/s (95% CI 0.12–0.30) [8, 17]. Individual study findings and the forest plot are shown in Fig. 2.

FEV1 and FEV1 (% predicted)

Ten studies reported FEV1 as a parameter of spirometry with widely varied data. Eight of ten studies supported that FEV1 improved after ESS.

Six studies reported FEV1 in liters (L). Four of them presented the results as mean ± SD [8, 14, 17, 19]. However, one had high heterogeneity ($I^2 = 62\%$) and was excluded from the meta-analysis [14]. The weighted mean change of FEV1 of the other three studies was 0.09 L (95% CI

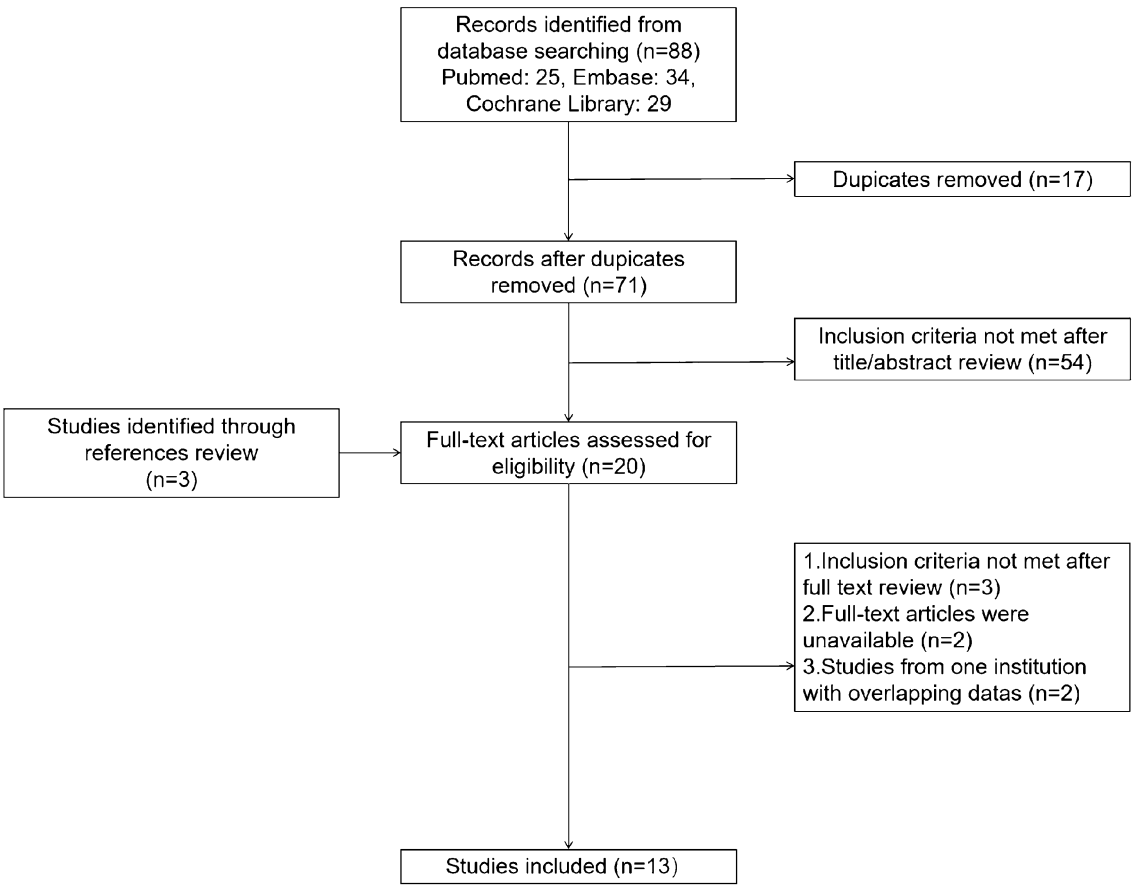

Fig. 1 Flow diagram for study selection process in the systematic review and meta-analysis

0.01–0.16, $n=94$) postoperatively [8, 17, 19]. Individual study findings and the forest plot are shown in Fig. 3. In Gulati et al.'s [14] study, FEV1 improved from preoperative 1.92 ± 0.73 L to postoperative 2.7 ± 0.87 L with a mean change of 0.78L (95% CI 0.28–1.28, $n=25$). The high heterogeneity of this study may come from its worse preoperative FEV1 and short follow-up time (3 months). The fifth study presented the median change of FEV1 [18]. Ehnhage et al. [18] conducted a double-blind, randomized, placebo-controlled study that involved patients with nasal polyposis and asthma ($n=51$) who underwent endoscopic sinus surgery (ESS) with ($n=23$) or without ($n=28$) fluticasone propionate nasal drops (FPND) 400 µg twice daily (bid) pre- and post-surgery. They reported that the median change in FEV1(L) was −0.03 ($p=0.48$) in the FPND group and 0.05 ($p=0.45$) in the placebo group postoperatively. The last study reported no statistically significant change in FEV1(L) postoperatively, but did not provide quantifiable values [10].

Four studies reported FEV1 (% predicted), and all of them had improvements postoperatively [11, 13, 15,

Table 1 Summary of the outcomes of pulmonary function tests post-ESS for CRS with asthma

First author	Year	Study design	Level of evidence	Sample size	Follow-up time (month)	Pulmonary function tests	
						Improved	No change
Dunlop [7]	1999	Retrospective	4	23	12	Peak flow	
Goldstein [8]	1999	Retrospective	4	13	Average 33.1		FEF25–75%, FEV1, FVC
Ikeda [9]	1999	Prospective	2b	15	6	PEF	
Dhong [10]	2001	Prospective	4	19	Average 20.7		FEV1, FVC
Batra [11]	2003	Retrospective	4	17	12–18	FEV1	
Dejima [12]	2005	Prospective	4	28	Average 37.4	PEF	
Ragab [13]	2006	Prospective	1b	21	12	FEV1	PEF
Gulati [14]	2008	Prospective	4	25	3	FEV1	
Nair [15]	2010	Prospective	4	70	6	FEV1, FVC	
Proimos [16]	2010	Prospective	4	86	12	FEV1, FEV1%, FVC, PEF	
Razmpa [17]	2010	Prospective	4	56	> 12		FEF25–75%, FEV1, FVC
Ehnhage [18]	2012	Retrospective	1b	23	12		FEV1
Chen [19]	2014	Prospective	4	25	12		FEV1, FEV1%, PEF

FEF25–75% forced expiratory flow between 25 and 75% of vital capacity, *FEV1* forced expiratory volume at 1 s, *FEV1%* FEV1/FVC ratio, *FVC* forced vital capacity, *PEF* peak expiratory flow

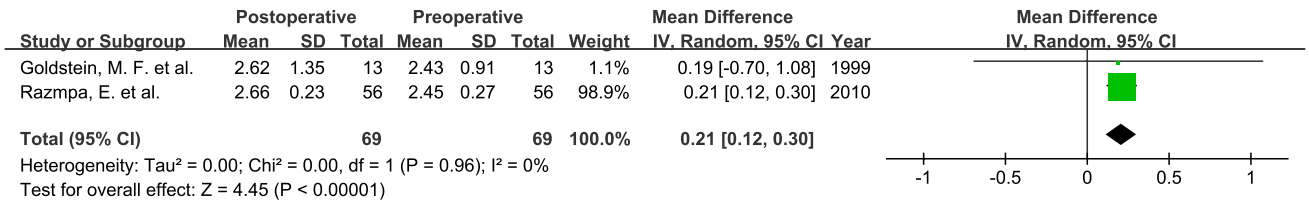

Fig. 2 Individual study findings and forest plot of the change in forced expiratory flow between 25 and 75% of vital capacity from preoperation to postoperation

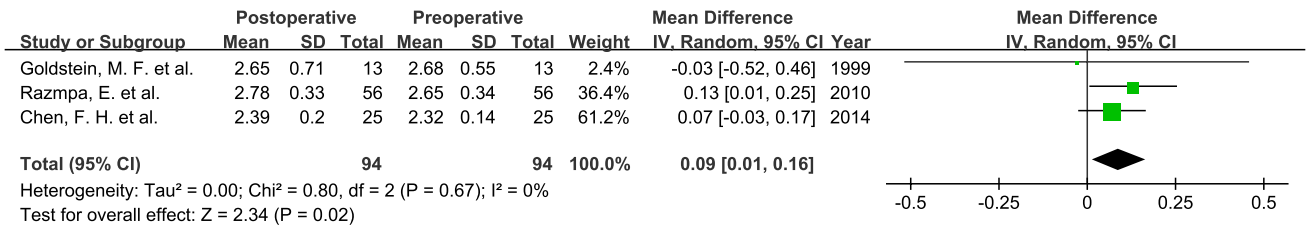

Fig. 3 Individual study findings and forest plot of the change in forced expiratory volume at 1 s from preoperation to postoperation

16]. Batra et al. [11] reported that FEV1 (% predicted) improved from 83 to 90% ($P < 0.014$) following ESS ($n = 17$). Nair et al. [15] reported that FEV1 (% predicted) improved from 64 to 86% without providing p value ($n = 70$). Proimos et al. [16] evaluated the FEV1 (% predicted) of 86 patients which improved from 66.0 ± 16.4% to 66.7 ± 16.4% ($p < 0.001$) after ESS. The forth study was a randomized prospective study of surgical compared with medical therapy in patients with CRS and concomitant asthma ($n = 21$) [13]. The 12-month FEV1 (% predicted) after ESS showed significant increase, with a change of 3.95 ± 7.87% compared with the baseline [13].

In summary, most studies supported that FEV1 and FEV1 (% predicted) improved after ESS. However, the strength of evidence on this topic is low.

PEF and PEF (% predicted)

PEF was reported by six studies. After qualitative and quantitative analysis, five of six studies supported that PEF improved after ESS with a low strength of evidence.

Two studies reported PEF in liter/second (L/s) as mean ± SD ($n = 53$) [12, 19]. The weighted mean change in PEF was 0.95 L/s (95% CI 0.65–1.24). Individual study findings and the forest plot are shown in Fig. 4. Another two studies reported the change of PEF in mean ± SD. Ikeda et al.'s [9] study enrolled CRS patients with asthma ($n = 21$) and divided them into two groups. In this study, 15 patients received ESS and 6 patients used intranasal corticosteroid spray alone as control. There was a significant increase in PEF (1.63 ± 0.75L/s, $p < 0.005$) in ESS group and no significant change in the control group postoperatively. Ragab et al.'s [13] randomized prospective study of surgical compared with medical therapy in patients with CRS and concomitant asthma reported that the change of PEF from baseline was 0.04 ± 0.12L/s ($p > 0.05$) after ESS ($n = 21$). Dunlop et al. [7] reported 28% of patients with improved PEF following surgery ($n = 23$), but did not provide p values. Proimos et al. [16] reported PEF (% predicted) improved from 67.5 ± 16.9% to 68.4 ± 17.1% ($p < 0.001$) following surgery ($n = 86$).

FEV1/FVC ratio (FEV1%)

Two studies [16, 19], with a total of 111 patients, commented on FEV1%. The weighted mean change was 0.00 postoperatively ($p = 0.93$).

FVC and FVC (% predicted)

Five studies reported FVC as a parameter of spirometry. Two studies reported FVC in liters (L) and in mean ± SD, with a total of 69 patients. The weighted mean change was 0.10 L, but this was not statistically significant ($p = 0.55$) [8, 17]. Two studies reported FVC (% predicted). Proimos et al. [16] reported FVC (% predicted) with improvement from preoperatively 83.5 ± 18.2% to 84.1 ± 18.1% ($p < 0.001$) after surgery ($n = 86$). Nair et al. [15] reported that FVC (% predicted) improved from 68 to 74% without providing p value following surgery ($n = 70$). One additional study reported no statistically significant change in postoperative FVC, but no quantifiable data were presented [10].

Discussion

This systematic review and meta-analysis suggested that ESS for CRS patients with asthma may improve pulmonary function in FEF25–75%, FEV1 and PEF, but with a limited number of studies and a low level of evidence in the literature, strength of evidence is generally low to insufficient. In the previous studies, the authors used different parameters and statistical methods to evaluate the effect of ESS on pulmonary functions in CRS patients, most of which had a small sample size, and the results were conflicting [7–19]. Vashishta et al. [21] performed a meta-analysis by reviewing the literatures till 2012. They did not find a significant change in lung function tests after ESS in CRS with concomitant asthma. The different conclusions of ours and Vashishta's study were probably caused by adding a new study and excluding the studies exclusively focusing on AERD in our study.

Asthma is a disease characterized by repeated episodes of airway obstruction. Therefore, physiologic assessment of changes in lung function is critical for evaluating the

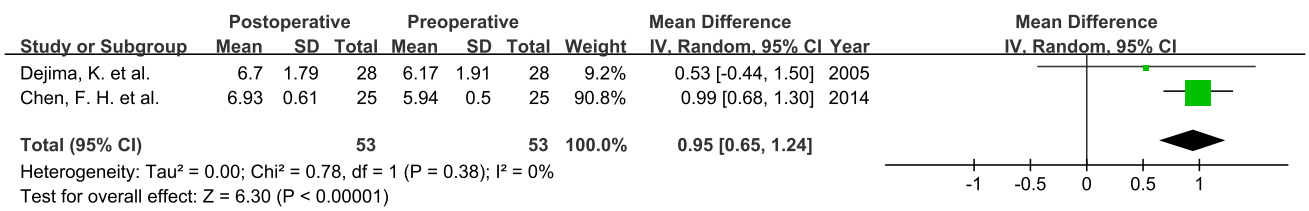

Fig. 4 Individual study findings and forest plot of the change in peak expiratory flow from preoperation to postoperation

therapeutic effect. Spirometry is a highly standardized test for asthma, which has multiple parameters. In our study, we found some of the parameters, FEF25–75%, FEV1 and PEF, showed improvement post-ESS. Historically, asthma was understood to be a disease primarily of the large airways. However, growing evidences show airways from large proximal to the small distal end are also involved in asthma [23–26]. The small airways are defined by an internal airway diameter of < 2 mm and accounts for 98.9% of the total lung volume [27]. The commonly used flow measure in small airway studies is FEF25–75%, which is considered reflective of small airway obstruction, and might predict the long-term persistence of asthma and poor asthma outcomes [28]. FEV1 is generally accepted as the gold standard for clinically evaluating airway obstruction and assessing response to therapy. However, this measurement does not provide a comprehensive evaluation of the entire bronchial tree and is most reflective of abnormalities in the large- and medium-sized airways. PEF is a measure of maximum instantaneous expiratory flow and can be self-administered on a daily basis [29]. It is an important tool in the management of asthmatic patients [30]. The beneficial effect of ESS for CRS patients with asthma on FEF25–75%, FEV1 and PEF observed in our study suggested an improved condition of pulmonary function after ESS.

FVC is the amount of air which can be forcibly exhaled from the lungs after taking the deepest breath possible, which is usually nearly normal in asthma. FEV1% is usually reduced during the attack and recovers to normal or nearly normal after thr attack. In our study, we did not find that these two measures improved significantly post-ESS. Asthma in attack is a contraindication for ESS. Sinus surgeons are advised to avoid performing ESS for patients with uncontrolled asthma in case of an asthma attack during surgery. This is probably the reason why we did not find that FVC, and FEV1% improved post-ESS.

Several mechanisms could play a role in lower airway dysfunction in patients with CRS. First, the nose protects lower airways through filtering and conditioning the inhaled air, and the diseased nose may impair these protective abilities and lead to allergens, as well as cold and dry air getting into lower airways [31, 32]. Moreover, the nasobronchial reflex mechanism contributes to the interaction between nose and lungs [32]. Furthermore, rhinosinusitis and asthma share a similar inflammatory pathophysiologic process [33, 34]. The above-mentioned mechanisms provide evidence for the unified airway hypothesis and a theoretical basis that using ESS in CRS patients with asthma to relieve nasal diseases may also improve the condition of asthma, and our study can be considered as additional evidence.

There were some limitations in our study. First, most of these studies were of low quality and lacked a comparison or control group. Only two studies were identified as level 1b evidence, and most articles were case series identified as level 4 evidence (Table 1). Moreover, the heterogeneity in parameters of spirometry and difference in data presented forms across studies along with the lack of standard deviation of some data makes it difficult to synthesize results. These above-mentioned limitations thus made the data inadequate and incapable of being summarized. Despite these limitations, this systematic review identified significant weaknesses in the literature regarding pulmonary function tests in CRS patients with asthma. Future studies with higher methodological quality and more comprehensive parameters could improve the level of evidence and better quantify effects of ESS on pulmonary function tests in CRS patients with asthma.

Conclusion

A generally low-quality evidence supports the association between ESS and improvements in FEF25–75%, FEV1 and PEF. A few studies met the inclusion criteria for the meta-analysis, which indicates the need for more high-quality studies to determine the effect of ESS on pulmonary function in CRS patients with asthma.

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Compliance with ethical standards

Conflict of interest No conflicts of interest to declare.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

References

1. Beule A (2015) Epidemiology of chronic rhinosinusitis, selected risk factors, comorbidities, and economic burden. GMS current topics in otorhinolaryngology, head and neck surgery 14:Doc11. https://doi.org/10.3205/cto000126
2. Shi JB, Fu QL, Zhang H, Cheng L, Wang YJ, Zhu DD, Lv W, Liu SX, Li PZ, Ou CQ, Xu G (2015) Epidemiology of chronic rhinosinusitis: results from a cross-sectional survey in seven Chinese cities. Allergy 70(5):533–539. https://doi.org/10.1111/all.12577
3. National Asthma E, Prevention P (2007) Expert panel report 3 (EPR-3): Guidelines for the diagnosis and management of asthma-summary report 2007. J Allergy Clin Immunol 120(5 Suppl):S94–S138. https://doi.org/10.1016/j.jaci.2007.09.043
4. Hamid Q, Song Y, Kotsimbos TC, Minshall E, Bai TR, Hegele RG, Hogg JC (1997) Inflammation of small airways in asthma. J Allergy Clin Immunol 100(1):44–51

5. Jarvis D, Newson R, Lotvall J, Hastan D, Tomassen P, Keil T, Gjomarkaj M, Forsberg B, Gunnbjornsdottir M, Minov J, Brozek G, Dahlen SE, Toskala E, Kowalski ML, Olze H, Howarth P, Kramer U, Baelum J, Loureiro C, Kasper L, Bousquet PJ, Bousquet J, Bachert C, Fokkens W, Burney P (2012) Asthma in adults and its association with chronic rhinosinusitis: the GA2LEN survey in Europe. Allergy 67(1):91–98. https://doi.org/10.1111/j.1398-9995.2011.02709.x
6. Virant FS (2001) Sinusitis and asthma: associated airway diseases. Curr Allergy Asthma Rep 1(3):277–281
7. Dunlop G, Scadding GK, Lund VJ (1999) The effect of endoscopic sinus surgery on asthma: management of patients with chronic rhinosinusitis, nasal polyposis, and asthma. Am J Rhinol 13(4):261–265
8. Goldstein MF, Grundfast SK, Dunsky EH, Dvorin DJ, Lesser R (1999) Effect of functional endoscopic sinus surgery on bronchial asthma outcomes. Arch Otolaryngol Head Neck Surg 125(3):314–319
9. Ikeda K, Tanno N, Tamura G, Suzuki H, Oshima T, Shimomura A, Nakabayashi S, Takasaka T (1999) Endoscopic sinus surgery improves pulmonary function in patients with asthma associated with chronic sinusitis. The annals of otology, rhinology, and laryngology 108 (4):355–359. https://doi.org/10.1177/000348949910800407
10. Dhong HJ, Jung YS, Chung SK, Choi DC (2001) Effect of endoscopic sinus surgery on asthmatic patients with chronic rhinosinusitis. Arch Otolaryngol Head Neck Surg 124(1):99–104. https://doi.org/10.1067/mhn.2001.111596
11. Batra PS, Kern RC, Tripathi A, Conley DB, Ditto AM, Haines IGK, Yarnold PR, Grammar L (2003) Outcome analysis of endoscopic sinus surgery in patients with nasal polyps and asthma. Laryngoscope 113(10):1703–1706. https://doi.org/10.1097/00005537-200310000-00008
12. Dejima K, Hama T, Miyazaki M, Yasuda S, Fukushima K, Oshima A, Yasuda M, Hisa Y (2005) A clinical study of endoscopic sinus surgery for sinusitis in patients with bronchial asthma. Int Arch Allergy Immunol 138(2):97–104. https://doi.org/10.1159/000088430
13. Ragab S, Scadding GK, Lund VJ, Saleh H (2006) Treatment of chronic rhinosinusitis and its effects on asthma. Eur Respir J 28(1):68–74. https://doi.org/10.1183/09031936.06.00043305
14. Gulati SP, Chaudhry D, Kalra V, Wadhera R, Garg A (2008) The role of functional endoscopic sinus surgery (FESS) in patients with asthma with chronic sinusitis. Indian J Otolaryngol Head Neck Surg 60(2):152–155. https://doi.org/10.1007/s12070-008-0037-6
15. Nair S, Bhadauria RS, Sharma S (2010) Effect of endoscopic sinus surgery on asthmatic patients with chronic rhinosinusitis. Indian J Otolaryngol Head Neck Surg 62(3):285–288. https://doi.org/10.1007/s12070-010-0086-5
16. Proimos E, Papadakis CE, Chimona TS, Kiagiadaki D, Ferekidis E, Yiotakis J (2010) The effect of functional endoscopic sinus surgery on patients with asthma and CRS with nasal polyps. Rhinology 48(3):331–338. https://doi.org/10.4193/Rhin09.123
17. Razmpa E, Saedi B, Safavi A (2010) The effect of functional endoscopic sinus surgery on pulmonary improvement of controlled asthmatic patients with chronic sinusitis. Iran J Allergy Asthma Immunol 9(4):231–236. (09.04/ijaai.231236)
18. Ehnhage A, Olsson P, Kölbeck KG, Skedinger M, Stjärne P (2012) One year after endoscopic sinus surgery in polyposis: asthma, olfaction, and quality-of-life outcomes. Otolaryngol Head Neck Surg 146(5):834–841. https://doi.org/10.1177/0194599811435638
19. Chen FH, Zuo KJ, Guo YB, Li ZP, Xu G, Xu R, Shi JB (2014) Long-term results of endoscopic sinus surgery-oriented treatment for chronic rhinosinusitis with asthma. Laryngoscope 124(1):24–28. https://doi.org/10.1002/lary.24196
20. Dinakar C, Chipps BE, Section On A, Immunology SO, Pediatric P, Sleep M (2017) Clinical tools to assess asthma control in children. Pediatrics. https://doi.org/10.1542/peds.2016-3438
21. Vashishta R, Soler ZM, Nguyen SA, Schlosser RJ (2013) A systematic review and meta-analysis of asthma outcomes following endoscopic sinus surgery for chronic rhinosinusitis. Int Forum Allergy Rhinol 3(10):788–794. https://doi.org/10.1002/alr.21182
22. Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis JPA, Clarke M, Devereaux PJ, Kleijnen J, Moher D (2009) The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. J Clin Epidemiol 62(10):e1–e34. https://doi.org/10.1016/j.jclinepi.2009.06.006
23. Manoharan A, Anderson WJ, Lipworth J, Ibrahim I, Lipworth BJ (2014) Small airway dysfunction is associated with poorer asthma control. Eur Respir J 44(5):1353–1355. https://doi.org/10.1183/09031936.00082314
24. van den Berge M, Ten Hacken NHT, Cohen J, Douma WR, Postma DS (2011) Small airway disease in asthma and COPD: clinical implications. Chest 139(2):412–423. https://doi.org/10.1378/chest.10-1210
25. Alfieri V, Aiello M, Pisi R, Tzani P, Mariani E, Marangio E, Olivieri D, Nicolini G, Chetta A (2014) Small airway dysfunction is associated to excessive bronchoconstriction in asthmatic patients. Respir Res 15:86. https://doi.org/10.1186/s12931-014-0086-1
26. Bjermer L (2014) The role of small airway disease in asthma. Curr Opin Pulmon Med 20(1):23–30. https://doi.org/10.1097/MCP.0000000000000018
27. Virchow JC (2009) [Asthma–a small airway disease: concepts and evidence]. Pneumologie 63(2):S96–S101. https://doi.org/10.1055/s-0029-1214715
28. Siroux V, Boudier A, Dolgopoloff M, Chanoine S, Bousquet J, Gormand F, Just J, Le Moual N, Nadif R, Pison C, Varraso R, Matran R, Pin I (2016) Forced midexpiratory flow between 25% and 75% of forced vital capacity is associated with long-term persistence of asthma and poor asthma outcomes. J Allergy Clin Immunol 137(6):1709–1716 e1706. https://doi.org/10.1016/j.jaci.2015.10.029
29. Tepper RS, Wise RS, Covar R, Irvin CG, Kercsmar CM, Kraft M, Liu MC, O'Connor GT, Peters SP, Sorkness R, Togias A (2012) Asthma outcomes: pulmonary physiology. J Allergy Clin Immunol 129(3 Suppl):S65–S87. https://doi.org/10.1016/j.jaci.2011.12.986
30. Goldberg S, Springer C, Avital A, Godfrey S, Bar-Yishay E (2001) Can peak expiratory flow measurements estimate small airway function in asthmatic children? Chest 120(2):482–488
31. Braunstahl GJ, Fokkens W (2003) Nasal involvement in allergic asthma. Allergy 58(12):1235–1243
32. Braunstahl GJ (2005) The unified immune system: respiratory tract-nasobronchial interaction mechanisms in allergic airway disease. J Allergy Clin Immunol 115(1):142–148. https://doi.org/10.1016/j.jaci.2004.10.041
33. Stirling RG, van Rensen EL, Barnes PJ, Chung KF (2001) Interleukin-5 induces CD34(+) eosinophil progenitor mobilization and eosinophil CCR3 expression in asthma. Am J Respir Crit Med 164(8 Pt 1):1403–1409. https://doi.org/10.1164/ajrccm.164.8.2010002
34. Braunstahl GJ, Overbeek SE, Kleinjan A, Prins JB, Hoogsteden HC, Fokkens WJ (2001) Nasal allergen provocation induces adhesion molecule expression and tissue eosinophilia in upper and lower airways. J Allergy Clin Immunol 107(3):469–476. https://doi.org/10.1067/mai.2001.113046