

Systematic Review

Olfactory Dysfunction in People with Cystic Fibrosis: A Systematic Review and Meta-Analysis [†]

Jessa E. Miller ^{1,‡,§}, Lorena M. Ayoub ^{2,‡}, Maria Skolnick ² , Edith Zemanick ³ , Jennifer L. Taylor-Cousar ⁴ 
and Daniel M. Beswick ^{1,*} 

¹ Department of Head and Neck Surgery, University of California, Los Angeles, CA 90095, USA

² Larner College of Medicine, University of Vermont, Burlington, VT 05405, USA

³ Department of Pediatrics, University of Colorado Medicine, Aurora, CO 80045, USA;
edith.zemanick@childrenscolorado.org

⁴ Departments of Medicine and Pediatrics, National Jewish Health, Denver, CO 80206, USA

* Correspondence: dbeswick@mednet.ucla.edu; Tel.: +1-310-206-8457

[†] This work was presented at the Triological Society Combined Sections Meeting in January 2022 in Coronado, CA, USA.

[‡] These authors contributed equally to this work.

[§] Current address: Department of Otolaryngology-Head and Neck Surgery, University of Michigan, Ann Arbor, MI 48109, USA.

Abstract

Background: Olfactory dysfunction (OD) is prevalent in people with cystic fibrosis (PwCF); however, its overall impact in this population is understudied. No systematic review on this topic is currently available. **Objective:** The objective of this study was to systematically review the existing literature on OD in PwCF. **Methods:** A systematic review was performed using PRISMA guidelines. Inclusion criteria consisted of articles that examined OD in PwCF using psychophysical olfactory testing. PubMed, Ovid Medline, Google Scholar, Cochrane Library, MedRxiv, and Web of Science databases were searched on 13 June 2022. The Newcastle–Ottawa Scale was used to assess the quality and determine risk of bias for the studies included in the meta-analysis. **Results:** A total of 87 articles were initially identified; ten were ultimately included. All ten studies were prospective and observational. A total of 420 PwCF were included in these studies (209 females, mean age = 26 years). Psychophysical olfactory testing was performed via the 40-Question Smell Identification Test (n = 4 studies), Sniffin’ Sticks Testing (n = 4 studies), and other odor identification tests (n = 2 studies). The mean prevalence of OD was 61% (range 10–88%), while rates of anosmia ranged from 5 to 14. The meta-analysis demonstrated that PwCF had lower threshold, discrimination, and identification scores compared to controls, with a very large effect size (Hedges’ $g = -1.57$, 95% CI = -2.51 to -0.63). Five studies revealed impairment in odor identification. Five studies assessed potential associations between OD and body mass index. **Conclusions:** OD is common in PwCF. Most PwCF have hyposmia, while anosmia is less common. Olfactory limitations have not been well characterized in pediatric patients. Understanding how OD affects PwCF is critical to optimization of disease management and quality of life.

Keywords: smell disorders; hyposmia; olfactory dysfunction; chronic rhinosinusitis; cystic fibrosis; olfaction; sense of smell; anosmia; quality of life; sinus disease



Academic Editor: Andrew J. Wood

Received: 2 April 2026

Revised: 11 June 2026

Accepted: 2 July 2026

Published: 9 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and

conditions of the [Creative Commons](#)

[Attribution \(CC BY\)](#) license.

1. Introduction

Cystic fibrosis (CF) is an autosomal recessive disorder caused by mutations in the CF transmembrane conductance regulator (CFTR) gene, which results in deranged ion transport [1,2]. CF affects multiple organ systems, including the upper and lower respiratory tracts, pancreas, liver, and gastrointestinal and reproductive systems. The majority of people with CF (PwCF) have chronic rhinosinusitis (CRS), which is associated with nasal obstruction, nasal congestion, rhinorrhea, and olfactory dysfunction (OD) [3]. OD has a significant adverse impact on quality of life (QOL) and has been associated with increased rates of depression and loneliness [4].

Despite its substantial QOL impact and prevalence, OD in PwCF is understudied [3]. Prior studies have reported rates of olfactory loss in adults with CF, with limited investigation into this complication among children with CF. The congenital and slowly progressive nature of CF may make it difficult for PwCF to perceive their olfactory deficits. Additionally, the severe pulmonary and systemic features of CF may cause PwCF to minimize their olfactory symptoms [5]. CFTR modulators are a new class of drugs that impact the basic CF defect and improve CF sinus symptoms; however, these medications have not been shown to improve OD [6]. Objective psychophysical olfactory testing is a critical component to evaluate OD in PwCF. The aim of this study was to systematically review and analyze the evidence regarding OD in PwCF to better understand the prevalence and severity of this disease complication and to identify areas in need of further study.

2. Methods

2.1. Search Strategy

This study was conducted using the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines (see Supplementary File S1: PRISMA Checklist). A comprehensive literature search of PubMed, Ovid Medline, Google Scholar, Cochrane Library, MexRxiv, and Web of Science was completed on 13 June 2022. The search strategy included keywords in titles and abstracts, as well as subject headings (MeSH terms) related to the concepts of olfactory dysfunction, cystic fibrosis, and/or nutrition. Titles and abstracts were first screened and then followed by a thorough manuscript review. References cited in these articles were also screened and considered. Two authors (L.M.A. and J.E.M.) independently reviewed the articles for eligibility. Any potential discrepancies were resolved via discussion with a third author (D.M.B.). The review was not registered in a public registry as data extraction had already commenced prior to initiation of registration. Consequently, retrospective registration was not feasible in accordance with registry policies.

2.2. Selection Criteria

Studies included in this systematic review required articles to report findings of psychophysical olfactory testing in PwCF of any age. Studies involving non-human subjects were excluded.

2.3. Data Extraction

For articles that met all inclusion criteria, the following information was collected: authors, year of publication, study design, number of subjects, patient demographics (age and gender), and measurement tools used to assess olfaction. OD prevalence was recorded, as well as any other information related to the quality or quantity of olfactory loss. When available, the impact of OD on nutrition and ideal body weight (IBW) was also recorded. Studies with insufficient data, including those lacking information on olfactory dysfunction or its effects on health and quality of life, were excluded.

2.4. Data Presentation

The prevalence of OD in PwCF was calculated based on data collected from studies that reported numerical values for normosmia, hyposmia, and anosmia using psychophysical olfactory testing. The obtained hyposmia percentages were combined to create a mean and range for OD in PwCF. Rates of anosmia were generated similarly using reported anosmia percentages.

2.5. Meta-Analysis

Studies that reported threshold, discrimination, and identification (TDI) scores, standard deviations, and a control group were included in a meta-analysis. The TDI score is a sum of three subtests based on the Sniffin' Sticks (SS) results. A score greater than 30.5 is considered normosmic, between 16.5 and 30.5 is considered hyposmic, and less than 16.5 is considered anosmic [5]. Studies that did not include a control group or that did not report sufficient data, such as mean values, standard errors/standard deviations, or confidence intervals, were excluded. The meta-analysis was conducted using Stata/SE software (version 17). The model assumed random effects and was fit with restricted maximum-likelihood estimation. A forest plot was then generated to compare differences between TDI scores for PwCF and healthy controls. The Newcastle–Ottawa Scale (NOS) was used to assess the quality and determine risk of bias for the studies included in the meta-analysis.

3. Results

3.1. Search Characteristics and Prevalence of Olfactory Dysfunction

The initial search yielded 87 articles; 30 studies underwent a full manuscript review, and 10 articles met all inclusion criteria (Figure 1). Table 1 provides a summary of each study included in this systematic review [5–14]. The range of OD across studies was 10–88% (mean 61%). Rates of anosmia ranged from 5–14%. The majority of studies included a wide age range of PwCF, and two studies focused specifically on children/adolescents with CF. Psychophysical olfactory testing that was employed in these ten studies included the 40-Question Smell Identification Test (SIT-40, $n = 4$), Sniffin' Sticks Testing ($n = 4$), and other odor identification tests ($n = 2$). Two studies included participants on CFTR modulator therapy [6,12].

3.2. Rates of Hyposmia and Anosmia Are Increased in People with Cystic Fibrosis

Data from five studies reporting rates of normosmia, hyposmia, and anosmia were available and analyzed. High rates of olfactory impairment were found in PwCF and, in studies that included a control group, rates of OD in the CF population were higher than those in control participants (Figure 2) [5,6,8,10,12]. In a study by Lindig et al. that compared 35 PwCF with 35 age-matched controls, hyposmia was reported at a higher frequency in the CF group compared to the non-CF group (63% versus 37%, respectively) [10]. Furthermore, none of the controls had anosmia, while 9% of PwCF were anosmic [10]. In a study by Di Lullo et al., a total of 71 PwCF were studied and compared to 50 age-matched controls [5]. Among PwCF, 82% with nasal polyps (NP) and 88% without NP were hyposmic, and 13% with NP and 5% without NP were anosmic [5]. In the control group, 96% were normosmic, 4% were hyposmic, and none were anosmic (Figure 2) [5]. Similar rates of OD were obtained by Beswick et al., who found 63% of PwCF to be dysosmic and 37% normosmic [12]. A study by Bacon et al. found 27% of PwCF to be normosmic, 66% hyposmic, and 9% anosmic [6]. In a study by Aitken et al., olfaction was found to be normal in 44% of PwCF [8]. Among the remaining participants, 40% exhibited hyposmia, while 14% were found to be anosmic.

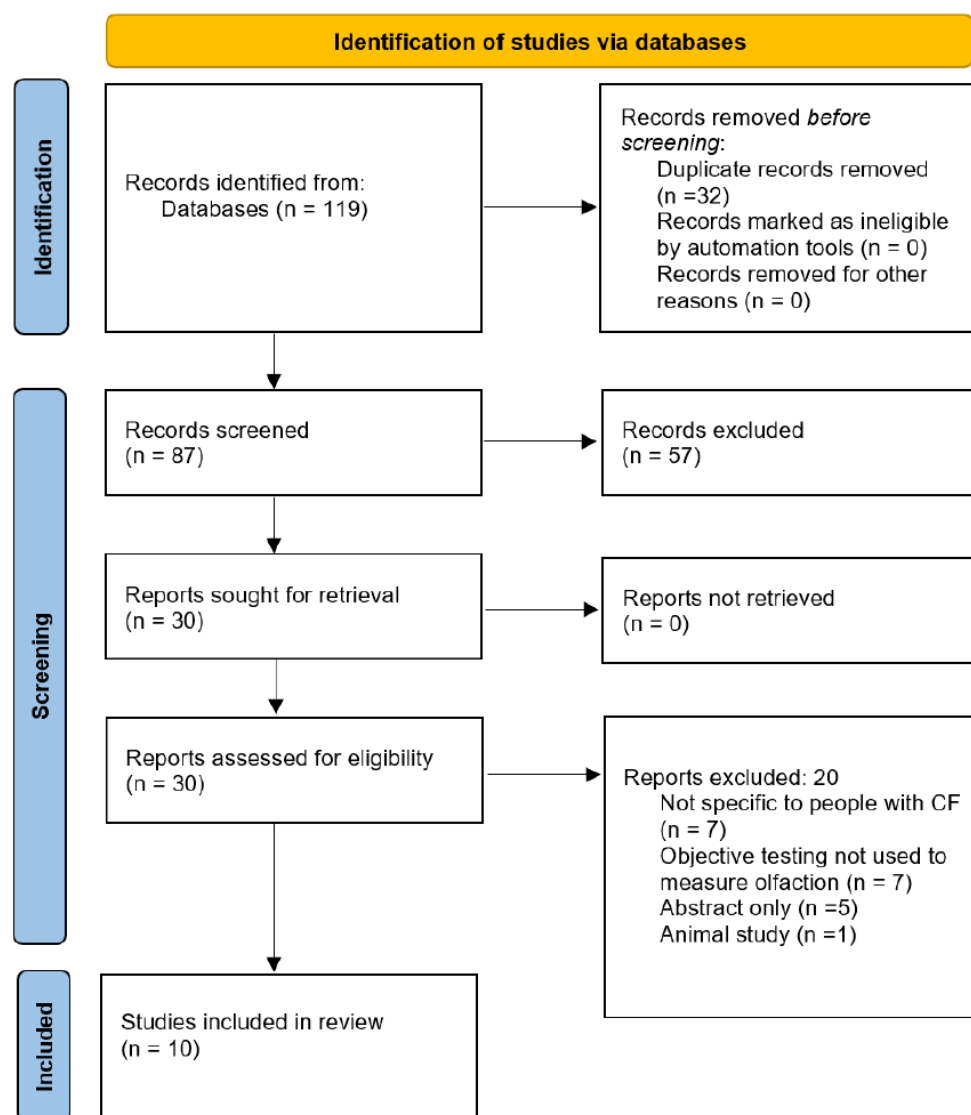


Figure 1. Flow diagram of search results.

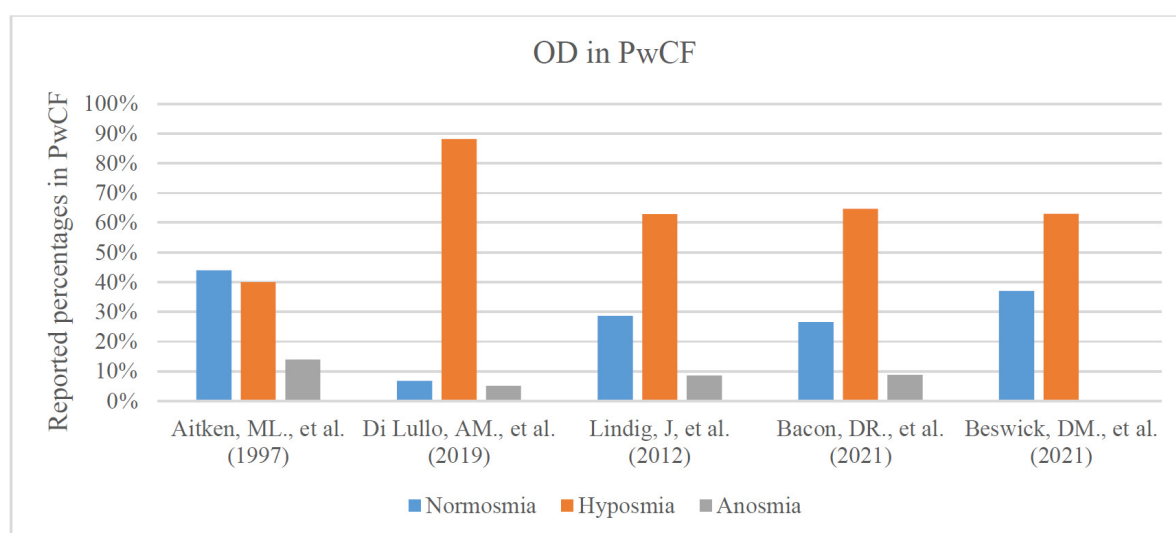


Figure 2. Prevalence of olfactory dysfunction in individuals with cystic fibrosis based on psychophysical olfactory testing results [5,6,8,10,12].

Table 1. Summary of articles on olfactory dysfunction in people with cystic fibrosis.

Author	Type of Study	Study Population	Age Group	Olfactory Assessment Tools	Olfactory Findings	Olfactory Testing Scores	Associated Findings	Nutritional Impact	Level of Evidence	% of Participants with a Copy of F508del
Bacon et al. [6] *	Prospective Observational Study	31 (13 F and 18 M)	12–60 years (median age 28)	SIT-40	26.5% (n = 9) of participants exhibited normosmia, 17.6% (n = 6) exhibited mild microsmia, 20.6% (n = 7) exhibited moderate microsmia, 26.5% (n = 9) exhibited severe microsmia, and 8.8% (n = 3) exhibited total anosmia.		Baseline UPSIT score did not differ significantly by sex, allergic rhinitis, genotype, or CF-related diabetes status. No correlation with age was found.		Level III	100% of participants
Beswick et al. [12] *	Prospective Observational Study	30 (18 F and 10 M)	Mean age 34 years	SIT-40	Most CF patients were hyposmic. 19/30 (63%) individuals were dysosmic and 11/30 (37%) were normosmic.		F508del heterozygosity and CF-related diabetes were associated with worse olfaction.	No association between OD and BMI	Level III	100% of participants
Di Lullo et al. [5]	Prospective Observational Study	71 (36 F and 35 M)	21–39 years (mean age 30.1)	SS and SNOT-22 and VAS	Nasal polyp group: 4/71 (5.63%) were normosmic, 58/71 (81.69%) hyposmic, and 9/71 (12.68%) anosmic. Non-nasal polyp group: 4/59 (6.78%) were normosmic, 52/59 (88.14%) were hyposmic, and 3/59 (5.08%) anosmic.	Mean TDI score: 23.28. Olfactory threshold score was significantly lower than controls.	Sex did not affect the prevalence of OD. Low olfactory threshold values were mainly attributable to CRS with or without nasal polyps.	Negative correlation found between OD and BMI	Level III	63% of participants
Lindig et al. [10]	Prospective Observational Study	35 (22 F and 13 M)	5–70 years (mean age 22.5)	SS and SNOT-20	Normosmia was found in 28.6% of CF patients. 62.9% of them were hyposmic, and 8.6% functionally anosmic.	Mean TDI score was 25.8. Olfactory threshold score was significantly lower than controls.	Sinonasal pathogen colonization, gender, pulmonary function, allergy, and sinonasal surgery did not have significant effects on olfactory function.	Positive correlation found between olfactory function and IBW (not statistically significant)	Level III	
Laing et al. [9]	Prospective Observational Study	42 (18 F and 24 M)	5.5–17.9 years (median age 10.5)	Three-choice 16-item odor identification test 94-item questionnaire	Hyposmia was found in 9.5% of patients; none were anosmic. CF patients had a poorer ability than controls to identify odors, particularly cheesy, grassy, sour, and spicy odors.	Mean identification score for CF subjects (14.36 SD: 1.42) was significantly lower than that of controls (15.31 SD: 1.07).	No correlation between age and odor identification ability.	No significant relationship between BMI and odor identification scores	Level III	83% of participants

Table 1. Cont.

Author	Type of Study	Study Population	Age Group	Olfactory Assessment Tools	Olfactory Findings	Olfactory Testing Scores	Associated Findings	Nutritional Impact	Level of Evidence	% of Participants with a Copy of F508del
Henriksson et al. [14]	Prospective Observational Study	111 (58 F and 53 M)	2–57 years (mean age 17.1)	Smell Identification Test 28	CF patients with or without nasal polyps presented a slightly reduced score in comparison to controls.		Nasal polyps have no significant impact on OD.		Level III	
Aitken et al. [8]	Prospective Observational Study	50 (26 F and 24 M)	14–53 years (mean age 28)	SIT-40	Olfaction was normal in 22/50 (44%), partially abnormal in 20/50 (40%), completely lost in 7/50 (14%).		Objective loss of olfaction is common in CF (56%) and increases with age.	No correlation between olfaction and patients' IBW was found	Level III	96% of participants
Weiffenbach et al. [11]	Prospective Observational Study	20 (10 F and 10 M)	13–53 years	SIT-40	Some CF patients have severe OD.	Olfactory thresholds were significantly higher than controls (PEMEC threshold $U = 48$, $p < 0.002$). Odor identification was also impaired. UPSIT $U = 84$, $p < 0.05$.			Level III	
Hertz et al. [13]	Prospective Observational Study	19 (7 F and 12 M)	7–18 years (median age 11)	SS	Children with C/F have at best normal olfactory sensitivity. There was no indication of hypersensitivity but some indication of hyposensitivity.	Significant difference in threshold scores between CF (2.0×10^{-3} M range: 2.5×10^{-4} to 3.5×10^{-1}) and the control group (3.6×10^{-4} M range: 4.3×10^{-5} to 2.8×10^{-3} M).	Negative correlation between age and threshold concentration ($r = -0.22$). Antibiotics may increase sensitivity slightly.		Level III	
Henkin and Powell [7]	Prospective Observational Study	11 (1 F and 10 M)	6–20 years (median age 9)	SS	Olfaction in CF patients was roughly 10,000 times that of normal subjects.	10/11 CF subjects showed a markedly increased ability to detect all substances.	No significant change was noted in OD after treatment with carbohydrate-active steroids.		Level III	

* These studies included participants on CFTR modulator therapy. SIT-40—40-Question Smell Identification Test; SS—Sniffin' Sticks; SNOT-22—22-Question Sinonasal Outcome Test; SNOT-20—20-Question Sinonasal Outcome Test; TDI—threshold discrimination identification; IBW—ideal body weight; BMI—body mass index.

Multiple studies comparing PwCF to age-matched controls showed differing rates of OD. In general, a significant portion of PwCF exhibited some form of olfactory impairment, with percentages ranging from 27% to 82%. Controls generally had better olfactory function, with most having normal olfaction. These studies highlight the variability in olfactory dysfunction among PwCF [5,6,8,10,12].

3.3. Threshold, Discrimination, and Identification Scores in People with Cystic Fibrosis

Four studies utilized SS testing to assess olfactory TDI [5,7,10,13]. All but one study demonstrated reduced detection abilities in PwCF. The study by Di Lullo et al. showed significantly weakened odor detection in PwCF compared to individuals without CF [5]. Specifically, PwCF identified n-butanol at dilution steps of 2.97 ± 2.89 and 3.25 ± 2.96 (mean), while healthy controls detected it at 7.29 ± 1.61 steps ($p < 0.0001$). PwCF had overall lower TDI scores (23.28 ± 6.02 and 24.61 ± 4.95) compared to controls (33.31 ± 2.45 , $p < 0.0001$) [5]. Similar outcomes were reported by Lindig et al. [10]. In their study, PwCF only recognized n-butanol at 2.95 ± 1.60 dilution steps (mean), while healthy controls could identify it at 7.78 ± 2.95 steps ($p < 0.001$) [10]. The TDI score was again lower in PwCF than controls (mean score 25.8 vs. 31.8 points, $p < 0.001$) [10]. Both studies demonstrated no differences in odor discrimination or identification between PwCF and control groups [5,10]. In the study conducted by Hertz et al., the average butanol threshold concentrations for PwCF were 2.0×10^{-3} M (range: 2.5×10^{-4} to 3.5×10^{-1} M), while for people without CF, it was 3.6×10^{-4} M (range: 4.3×10^{-5} to 2.8×10^{-3} M) [13]. The difference between PwCF and those without CF was statistically significant at the 0.01 level (t -test) [13].

Contrary to other research findings, Henkin and Powell's historical study showed that PwCF (median age 5.5) exhibited significantly heightened detection abilities for all substances [7]. PwCF could identify substances at concentrations 40 to 13,000 times more diluted than detectable by normal volunteers. However, the study indicated reduced smell thresholds in PwCF [7].

3.4. Odor Identification Testing

Five studies investigated odor identification using SIT-40 and a three-choice 16-item odor identification test [6,8,9,11,12]. In a study by Bacon et al., PwCF exhibited a median baseline UPSIT score of 29 (interquartile range = 24–34) [6]. Beswick et al. reported that PwCF had an average SIT score of 30.6 [12]. Additionally, Laing et al. found a statistically significant difference in mean identification scores between PwCF (14.36/16, SD 1.42) and controls (15.31, SD 1.07), with PwCF scoring lower ($p = 0.001$) [9]. Consistent with these findings, Weiffenbach et al. demonstrated a significant difference between PwCF and control groups using the Mann–Whitney U test ($U = 84$) [11]. PwCF displayed severe olfactory deficits, evident in elevated detection thresholds and impaired odor identification. Aitken et al. also reported a significant difference in the objective sensation of smell between PwCF and controls [8].

3.5. Meta-Analysis of Combined Threshold, Identification, and Discrimination Scores

Two studies presented data that were amenable to inclusion in a meta-analysis [5,10]. The pooled estimate revealed that PwCF had lower TDI scores on average than control patients across all studies with a very large effect size (Hedges' $g = -1.57$, 95% CI = -2.51 to -0.63 , Figure 3). This effect is equivalent to the TDI score being 8.14 units lower in PwCF versus controls. Heterogeneity was large ($I^2 = 87.41\%$), likely due to the small number of studies included. The difference in overall effect size was statistically significant ($p = 0.001$). Based on the NOS, both studies had six stars, consistent with moderate-quality studies with some risk of bias (Supplementary Table S1, [5,10]).

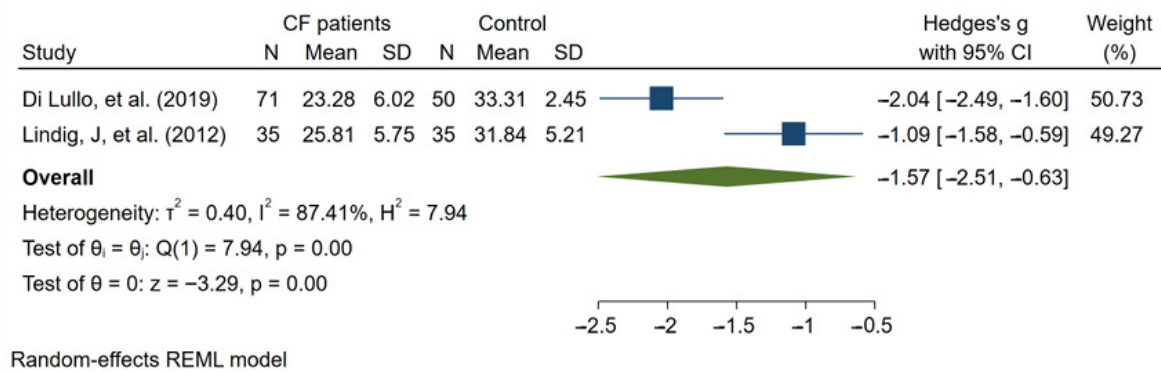


Figure 3. Forest plot of the meta-analysis comparing differences between threshold, discrimination, and identification (TDI) scores for both experimental and control groups [5,10]. Diamond = overall effect estimate; square = point estimate of the study; blue line = 95% confidence interval.

3.6. Association of Olfactory Dysfunction with Nutritional Status

Five studies investigated the potential association of OD on nutrition and body mass index (BMI) [5,8–10,12]. Two adult studies and one pediatric study that included children aged 5 to 18 years old failed to identify any association between OD and nutritional status [8,9,12]. Olfactory function did not show a significant difference between PwCF who were below their ideal body weight (IBW, calculated using the %IBW method, which assumes the ideal weight to correspond to the same percentile ranking as the individual's height-for-age percentile) and those with an IBW, as indicated by the SIT-40 results [8]. One study showed that PwCF had the same affinity for high- and low-fat foods compared with non-CF individuals [9]. While two other studies found a potential correlation between olfactory loss and low BMI, these did not reach statistical significance [5,10].

3.7. Factors Associated with Olfactory Dysfunction

Nine studies evaluated factors associated with OD in PwCF. In one report, F508del heterozygosity and CF-related diabetes were strongly correlated with OD [12]. OD was also shown to potentially increase with advancing age in another report, although this association did not reach statistical significance [8]. Pulmonary function, allergies, sinonasal surgery, and medication use were not associated with OD [10]. Two studies included participants on CFTR modulator therapy and did not identify an association between modulator use and OD [6,12].

Three studies included data on QOL outcomes. One reported a mean 22-question Sinonasal Outcome Test (SNOT-22) score of 32.1 and a mean questionnaire of olfactory disorders (QOD) score of 5.5; smell identification was correlated with QOD scores but not with SNOT-22 scores [12]. Another study reported worse 20-question Sinonasal Outcome Test (SNOT-20) scores among PwCF with hyposmia (11.1) and anosmia (28.3) compared to PwCF with normosmia (7.2); however, this was not statistically significant [10]. The third study reported a mean SNOT-22 score of 38.1 among PwCF; however, they did not evaluate for an association with olfactory function [5].

3.8. Olfactory Dysfunction in Children with Cystic Fibrosis

In one study, 25% of children aged 5 to 18 years with CF correctly identified odorants in a three-choice 16-item odor identification test, whereas 60% of age-matched controls correctly identified all odors [9]. A study from 1962 by Henkin et al., paradoxically, found an increased sensitivity of smell in children with CF (median age: 5.5 years) [7]. However, these findings were later refuted in a study by Hertz et al. and other studies in adults, which found decreased olfactory function in individuals with CF [7,13].

4. Discussion

Findings from this systematic review demonstrate that the majority of PwCF have olfactory loss. Based on the existing evidence, the prevalence of hyposmia ranges from 10 to 88%, while anosmia occurs in 5–14% of PwCF. When compared to the general population, in which the estimated prevalence of OD is 22%, olfactory loss is much more common in PwCF [15].

Based on data from people without CF, one of the most concerning consequences of OD is its potential impact on nutrition [5,10]. It has been theorized that olfactory loss may be a contributing factor to the lower BMI in PwCF, as olfaction, gustation, and appetite are closely intertwined [10]. Overall, five studies explored this question. Three studies (mean age 27 years) failed to show any correlation between olfaction and BMI, although these studies had modest sample sizes, which may explain the lack of association [8,9,12]. PwCF with a low BMI had similar olfactory function to those with normal BMI [8]. Food preferences also did not differ, and PwCF were shown to enjoy high-fat foods as much as non-CF individuals [9]. In contrast, two studies found a potential association between increasing severity of OD and decreasing BMI; however, this was not statistically significant. Ultimately, the potential link between OD and nutritional status was not clearly established by previous studies in CF, and further research is needed in this area, particularly in the era of early initiation of highly effective CFTR modulators [5].

This review analyzed specific components of olfactory testing when those findings were reported, including TDI. Olfactory threshold testing measures the minimal amount of stimulus needed to elicit odor detection, while identification and discrimination testing measure higher-order cognitive processing [5]. Four studies evaluated olfactory thresholds, discrimination, and identification using SS testing [5,7,10,13]. The majority of these studies indicated diminished detection abilities in PwCF, with only one historical pediatric study (median age 9 years) showing an exception [7]. The six studies conducted prior to 2012 warrant careful consideration, given the recent emergence of specific sinus treatments and systemic therapies that address the basic defect in CF, although a study in adults with CF who used one of these therapies did not show post-therapy improvement in OD [16,17]. As these treatments are relatively new, there exists a strong inclination to posit that anosmia may manifest progressively over time. Consequently, it is possible that individuals in the earlier studies, predominantly comprising children, may not have lived long enough to exhibit substantial disease development.

The meta-analysis demonstrated that PwCF also exhibited significantly lower TDI scores than controls, indicating reduced olfactory function [5,10]. However, it is important to note that only two studies could be included in the meta-analysis, which introduces a risk of bias due to the limited number of studies. Additionally, both studies were of moderate quality, with some risk of bias according to the NOS. Across five studies examining odor identification using SIT-40 and a three-choice 16-item odor identification test, PwCF generally exhibited lower identification scores [6,8,9,11,12]. These findings suggest that olfactory loss might result from impairment at the level of the olfactory periphery rather than higher-order centers. This finding could be due to the blockage of molecules reaching olfactory receptors by the thick, viscous mucus that is often present in the sinonasal cavities of PwCF [18]. However, it could also be attributable to a functional lesion of peripheral nerves that develops over time due to chronic inflammation [12].

The final aspect of this systematic review was to investigate factors related to OD in PwCF. One included study showed that F508del heterozygosity and CF-related diabetes were associated with OD [12]. One study found that increasing age was associated with worse olfactory function; however, this correlation was not found in other studies [8]. This

finding may be due to the effects of sinonasal disease progression, sinus surgery, or the decreased turnover rate of olfactory bipolar neurons that occurs with advancing age [8].

5. Conclusions

OD is common in PwCF and has an estimated prevalence of up to 88%. Olfactory thresholds and odor identification are affected significantly in PwCF. Study results on the relationship between OD and nutritional status are mixed, and additional research on this topic is needed.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/sinusitis10020017/s1>, Table S1: Newcastle-Ottawa Scale—Case-Control Star Template; File S1: PRISMA Checklist.

Author Contributions: Conceptualization, D.M.B.; Methodology, J.E.M., L.M.A., M.S. and D.M.B.; Formal Analysis, L.M.A. and M.S.; Data Curation, J.E.M., L.M.A., and M.S.; Validation, J.E.M., L.M.A. and M.S.; Visualization, J.E.M., L.M.A., M.S., and D.M.B.; Writing—Original Draft, J.E.M. and L.M.A.; Writing—Review & Editing, J.E.M., L.M.A., M.S., E.Z., J.L.T.-C. and D.M.B.; Supervision, E.Z., J.L.T.-C. and D.M.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in the preparation of this article. Data sharing is not applicable to this article.

Conflicts of Interest: E.Z.: In the last 36 months, she has received grants to her institution from the Cystic Fibrosis Foundation, National Institutes of Health, and Vertex Pharmaceuticals Incorporated; has received fees from the Cystic Fibrosis Foundation and Vertex Pharmaceuticals Incorporated related to consultation, participation on advisory boards, and grant review committees. She served as chair of the CFF Therapeutics Development Network steering committee, reviewed grants for CF Canada, and received travel support from the European CF Society Clinical Trials Network for speaking at their annual meeting. J.L.T.-C.: In the last 36 months, she has received grants to her institution from the Cystic Fibrosis Foundation, the National Institutes of Health, Vertex Pharmaceuticals Incorporated, Eloxx, Recode, Splisense and 4DMT; her institution has received fees from Vertex Pharmaceuticals Incorporated and 4DMT related to consultation on clinical research design; she has served on advisory boards and/or provided clinical trial design consultation for Kither Biotech and AbbVie. She served on a DMC for AbbVie. She serves as the adult patient care representative to the CFF Board of Trustees, and on the CF Foundation’s Clinical Research Executive Committee, Clinical Research Advisory Board, as immediate past chair of the CF TDN’s Sexual Health, Reproduction and Gender Research Working Group, and served as Co-Chair of the Health Equity Team Science Awards study section. She also serves on the scientific advisory board for Emily’s Entourage and served on the ATS Respiratory Health Awards Working Group. She currently serves as Chair-Elect of the International Conference Committee. She is an Associate Editor for the Journal of Cystic Fibrosis and a member of the International Advisory Board for the Lancet Respiratory Medicine Journal. She serves on the Clinical Trials Review (CTLR) Study section and as a member of the Data and Safety Monitoring Board for Gene/Cell Therapy for the National Institutes of Health/National Heart, Blood, Lung Institute. D.M.B.: In the last 36 months, D.M.B. has received grant support from NIH/NHLBI, Cystic Fibrosis Foundation, International Society of Inflammation and Allergy of the Nose and the American Rhinologic Society/CORE grant program; honoraria from sources including from National Jewish Health, Trinity, and Rockpoint; consulting fees from Medtronic, Amgen, on medicolegal cases and from Garner Health (equity); and served as an Associate Editor for International Forum of Allergy and Rhinology.

References

1. O’Sullivan, B.P.; Freedman, S.D. Cystic Fibrosis. *Lancet* **2009**, *373*, 1891–1904. [[CrossRef](#)] [[PubMed](#)]
2. Mall, M.A.; Galietta, L.J. Targeting Ion Channels in Cystic Fibrosis. *J. Cyst. Fibros.* **2015**, *14*, 561–570. [[CrossRef](#)] [[PubMed](#)]

3. Hassanzad, M.; Derakhshan, K.F.; Ghaffaripour, H.; Naeini, A.S.; Emami, H.; Velayati, A.A. Evaluation of Quality of Life in Terms of Sinonasal Symptoms in Children with Cystic Fibrosis. *Biomol. Concepts* **2019**, *10*, 91–98. [[CrossRef](#)] [[PubMed](#)]
4. Sivam, A.; Wroblewski, K.E.; Alkorta-Aranburu, G.; Barnes, L.L.; Wilson, R.S.; Bennett, D.A.; Pinto, J.M. Olfactory Dysfunction in Older Adults is Associated with Feelings of Depression and Loneliness. *Chem. Senses* **2016**, *41*, 293–299. [[CrossRef](#)] [[PubMed](#)]
5. Di Lullo, A.M.; Iacotucci, P.; Comegna, M.; Amato, F.; Dolce, P.; Castaldo, G.; Cantone, E.; Carnovale, V.; Iengo, M. Cystic Fibrosis: The Sense of Smell. *Am. J. Rhinol. Allergy* **2020**, *34*, 35–42. [[PubMed](#)]
6. Bacon, D.R.; Stapleton, A.; Goralski, J.L.; Ebert, C.S., Jr.; Thorp, B.D.; Nouraie, M.; Shaffer, A.D.; Senior, B.A.; Lee, S.E.; Zemke, A.C.; et al. Olfaction Before and After Initiation of Elexacaftor-Tezacaftor-Ivacaftor in a Cystic Fibrosis Cohort. *Int. Forum Allergy Rhinol.* **2022**, *12*, 223–226. [[PubMed](#)]
7. Henkin, R.I.; Powell, G.F. Increased Sensitivity of Taste and Smell in Cystic Fibrosis. *Science* **1962**, *138*, 1107–1108. [[CrossRef](#)] [[PubMed](#)]
8. Aitken, M.L.; Martinez, S.; McDonald, G.J.; Seifert, C.C.; Burke, W. Sensation of Smell does not Determine Nutritional Status in Patients with Cystic Fibrosis. *Pediatr. Pulmonol.* **1997**, *24*, 52–56. [[CrossRef](#)] [[PubMed](#)]
9. Laing, D.G.; Armstrong, J.E.; Aitken, M.; Carroll, A.; Wilkes, F.J.; Jinks, A.L.; Jaffé, A. Chemosensory Function and Food Preferences of Children with Cystic Fibrosis. *Pediatr. Pulmonol.* **2010**, *45*, 807–815. [[CrossRef](#)] [[PubMed](#)]
10. Lindig, J.; Steger, C.; Beiersdorf, N.; Michl, R.; Beck, J.F.; Hummel, T.; Mainz, J.G. Smell in Cystic Fibrosis. *Eur. Arch. Otorhinolaryngol.* **2013**, *270*, 915–921. [[PubMed](#)]
11. Weiffenbach, J.M.; McCarthy, V.P. Olfactory Deficits in Cystic Fibrosis: Distribution and Severity. *Chem. Senses* **1984**, *9*, 193–199. [[CrossRef](#)]
12. Beswick, D.M.; Humphries, S.M.; Balkissoon, C.D.; Strand, M.; EMiller, J.; Khatiwada, A.; Vladar, E.K.; Lynch, D.A.; Taylor-Cousar, J.L. Olfactory Dysfunction in People with Cystic Fibrosis with at Least One Copy of F508del. *Int. Forum Allergy Rhinol.* **2022**, *12*, 963–966. [[CrossRef](#)] [[PubMed](#)]
13. Hertz, J.; Cain, W.S.; Bartoshuk, L.M.; Dolan, T.F., Jr. Olfactory and Taste Sensitivity in Children with Cystic Fibrosis. *Physiol. Behav.* **1975**, *14*, 89–94. [[CrossRef](#)] [[PubMed](#)]
14. Henriksson, G.; Westrin, K.M.; Karpati, F.; Wikström, A.C.; Stierna, P.; Hjelte, L. Nasal Polyps in Cystic Fibrosis: Clinical Endoscopic Study with Nasal Lavage Fluid Analysis. *Chest* **2002**, *121*, 40–47. [[CrossRef](#)] [[PubMed](#)]
15. Desiato, V.M.; Levy, D.A.; Byun, Y.J.; Nguyen, S.A.; Soler, Z.M.; Schlosser, R.J. The Prevalence of Olfactory Dysfunction in the General Population: A Systematic Review and Meta-Analysis. *Am. J. Rhinol. Allergy* **2021**, *35*, 195–205. [[CrossRef](#)] [[PubMed](#)]
16. Taylor-Cousar, J.L.; Robinson, P.D.; Shteinberg, M.; Downey, D.G. CFTR modulator therapy: Transforming the landscape of clinical care in cystic fibrosis. *Lancet* **2023**, *402*, 1171–1184. [[CrossRef](#)] [[PubMed](#)]
17. Beswick, D.M.; Humphries, S.M.; Balkissoon, C.D.; Strand, M.; Vladar, E.K.; Ramakrishnan, V.R.; Taylor-Cousar, J.L. Olfactory dysfunction in cystic fibrosis: Impact of CFTR modulator therapy. *J. Cyst. Fibros.* **2022**, *21*, e141–e147. [[CrossRef](#)] [[PubMed](#)]
18. Suy, P.; Coudert, A.; Vrielynck, S.; Truy, E.; Hermann, R.; Ayari-Khalfallah, S. Evolution of Sinonasal Clinical Features in Children with Cystic Fibrosis. *Int. J. Pediatr. Otorhinolaryngol.* **2019**, *124*, 47–53. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.