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Abdulkader Yassin-Kassab

Pallavi Bhargava

Robert J. Tibbetts

Zachary H. Griggs

Edward L. Peterson

See next page for additional authors

Authors

Abdulkader Yassin-Kassab, Pallavi Bhargava, Robert J. Tibbetts, Zachary H. Griggs, Edward L. Peterson, and John R. Craig

Comparison of bacterial maxillary sinus cultures between odontogenic sinusitis and chronic rhinosinusitis

Abdulkader Yassin-Kassab, BS[1], Pallavi Bhargava, MD[2], Robert J. Tibbetts, PhD[3], Zachary H. Griggs, DO[4], Edward I. Peterson, PhD[3] and John R. Craig, MD[4]

Background: **Bacterial odontogenic sinusitis (ODS) is distinct from other forms of rhinosinusitis. Diagnosing ODS can be challenging because of nonspecific clinical presentations and underrepresentation in the literature. The purpose of this study was to compare maxillary sinus bacterial cultures between patients with ODS and chronic rhinosinusitis (CRS), to determine whether certain bacteria are associated with ODS.**

Methods: **This was a retrospective case-control study of 276 consecutive patients from August 2015 to August 2019 who underwent endoscopic sinus surgery (ESS) for bacterial ODS, CRS without nasal polyps (CRSsNP), or CRS with nasal polyps (CRSwNP). When present, pus was sterilely cultured from maxillary sinuses after maxillary antrostomy, and aerobic and anaerobic cultures were immediately sent for processing. Demographics and culture results were compared between ODS and CRS patients, and then separately between ODS and CRSsNP, and ODS and CRSwNP. ODS culture results were also compared between different dental pathologies (endodontic vs oroantral fistula).**

Results: **The following bacteria were significantly more likely in ODS compared to CRS: mixed anaerobes, *Fusobacterium* spp., *Eikenella corrodens*, *Streptococcus intermedius*, *Streptococcus anginosus*, and *Streptococcus constellatus*. *Staphylococcus aureus* and *Pseudomonas aeruginosa* were inversely related to ODS. There were no significant differences in cultures between the different dental pathologies.**

Conclusion: **Certain bacteria were more likely to be associated with ODS compared to CRS when purulence was cultured from the maxillary sinus. Physicians should evaluate for an odontogenic source of sinusitis when these ODS-associated bacteria are identified in maxillary sinus cultures.** © 2020 ARS-AAOA, LLC.

Key Words:
odontogenic sinusitis; unilateral sinus disease; maxillary sinusitis; chronic rhinosinusitis; endoscopic sinus surgery

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Bacterial odontogenic sinusitis (ODS) refers to maxillary sinusitis, with or without extension to other paranasal sinuses, secondary to either adjacent maxillary dental infection or iatrogenic injury from dental or other oral procedures.[1] A variety of dental pathologies can lead to ODS, including endodontic disease, periodontitis, oroantral fistula (OAF), or dental treatment-related foreign bodies in the sinus.[2-9] Endodontic disease causing ODS refers to apical periodontitis with or without periapical lesions (PAL) such as abscesses, cysts, or granulomas.

ODS is a distinct type of sinusitis that presents more commonly unilaterally.[5,10-15] Despite multiple studies showing ODS accounting for 45% to 75% of unilateral maxillary sinus opacification,[5,10-15] its diagnosis can be elusive because patients have nonspecific sinonasal symptoms and minimal dental complaints.[8,12,14] Additionally, because radiologists and dentists frequently miss the diagnosis,[8,10,12,15-18] otolaryngologists are often responsible for recognizing ODS. However, ODS has not been discussed in sinusitis guidelines,[12,19,20] and diagnostic protocols have not been established. It would be helpful to determine whether certain clinical variables could help predict an odontogenic

[1]*College of Human Medicine, Michigan State University, East Lansing, MI;* [2]*Department of Internal Medicine, Division of Infectious Disease, Henry Ford Health System, Detroit, MI;* [3]*Department of Public Health Services, Henry Ford Health System, Detroit, MI;* [4]*Department of Otolaryngology, Henry Ford Health System, Detroit, MI*

Correspondence to: John Craig, MD, Department of Otolaryngology, Henry Ford Health System, 2799 W Grand Blvd, Detroit, MI 48202; e-mail: jcraig1@hfhs.org

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source of sinusitis so that ODS is not overlooked, and patients are referred for appropriate dental evaluation.

One possible way to distinguish ODS from other forms of non-odontogenic rhinosinusitis could be through bacterial sinus cultures. Multiple studies have demonstrated anaerobic bacteria and polymicrobial growth to be common in ODS,[5,21-23] but very few studies have directly compared culture results between ODS and rhinosinusitis patients. The purpose of this study was to compare bacterial culture results between ODS and chronic rhinosinusitis (CRS) patients, to determine whether certain bacteria and polymicrobial growth were more common in ODS.

Patients and methods

This was a retrospective case-control study of 276 consecutive patients from August 2015 to August 2019 who underwent endoscopic sinus surgery (ESS) for bacterial ODS, CRS without nasal polyps (CRSsNP), or CRS with nasal polyps (CRSwNP). The study was approved by Henry Ford Health System's Institutional Review Board. All ODS and CRS patients had sinonasal symptoms for over 3 months, nasal endoscopic evidence of sinus inflammation or infection, and at least maxillary sinus opacification on computed tomography (CT). Exclusion criteria included the following: neoplasia, fungal disease, autoimmune disease, and primary or acquired immunodeficiency.

ODS was diagnosed based on a sinus CT demonstrating at least maxillary sinus opacification, plus confirmation of odontogenic pathology by endodontic and periodontal testing, and cone-beam CT imaging. All dental evaluations were performed either by 1 endodontist or 1 periodontist (see Acknowledgments). Only unilateral ODS cases were included.

CRSsNP and CRSwNP were diagnosed according to the 2015 adult sinusitis guidelines,[17] and presented as either unilateral or bilateral disease. All CRS cases demonstrated at least maxillary sinus opacification, and no overt dental pathology on sinus CT. Unilateral CRSsNP and CRSwNP were diagnosed only after having negative dental exams and imaging. Bilateral CRSsNP and CRSwNP patients did not undergo dental evaluations because ODS suspicions were very low.

All ODS and CRS patients were treated with at least 1 course of medical therapy before considering ESS. Medical therapy included at least a 2-week course of oral antibiotics, steroids, or a combination of both, and depended on nasal endoscopy findings. If patients had pus and minimal to no edema in the middle meatus, only oral antibiotics were prescribed. If patients had significant middle meatal edema or polyps but no pus, only oral steroids were prescribed. If patients had pus plus edema or polyps, then both antibiotics and steroids were prescribed. If patients failed medical therapy, ESS was offered. Note that patients did not receive oral or topical antibiotics in the 4 weeks prior to ESS, to allow optimal yields in bacterial cultures.[24-26] Patients underwent varying degrees of ESS, but all underwent at least maxillary antrostomies on the side or sides of maxillary sinus disease. All patients received a single preoperative dose of intravenous clindamycin, or cefazolin in clindamycin-allergic patients. Tissue was sent for histopathologic analysis in all CRS cases, and nearly all ODS cases. Cases were defined as eosinophilic if histopathological analysis revealed ≥10 eosinophils per high-powered field.[27]

If purulence was identified intraoperatively in the maxillary sinus during maxillary antrostomy, it was always cultured. Drainage had to be thick, opaque, and colored to be cultured. If pus was not identified, cultures were not taken. Thin, clear, or eosinophilic-appearing mucin was not cultured. In bilateral CRS cases, cultures were only taken from 1 of the maxillary sinuses demonstrating purulence. Cultures were always obtained sterilely in the same fashion by using a mucus specimen trap (Covidien, Mansfield, MA) attached to a sterile 2.5-mm curved olive-tip suction. The suction tip was advanced into the maxillary sinus lumen before turning on the suction, to minimize the possibility of nasal contamination.

Specimens were immediately submitted to the core microbiology laboratory for routine aerobic and anaerobic culture and identification. For aerobic culture, specimens were plated onto 5% sheep blood agar (BA), chocolate agar (CA), and MacConkey (Mac) agar media (Remel, Lenexa, Kansas) and were incubated overnight in 5% carbon dioxide at 35°C. For anaerobic culture, specimens were plated onto BA, CA, Mac, and pre-reduced BA plates anaerobically (90% nitrogen, 5% carbon dioxide, and 5% hydrogen) at 35°C for 72 hours. After incubation, isolated bacterial colonies were identified either by mass spectrometry using the Vitek-MS Matrix Assisted Laser Desorption Ionization-Time of Flight (MALDI-TOF), or biochemically by using the Vitek-2 automated platform according to the manufacturer (bioMérieux, Durham, NC).

First, presence or absence of maxillary sinus pus was compared between ODS and CRS patients. Next, polymicrobial growth rates were compared between ODS and CRS, with polymicrobial growth being defined as ≥2 bacteria cultured per patient. Then all cultured bacteria were compared individually between ODS and CRS patients. Bacteria were classified as anaerobic, or aerobic gram-positive or negative. Some bacteria were grouped together for comparative analysis between ODS and CRS based on established classifications.[28,29] The following bacterial groups were compared between ODS and CRS: mixed anaerobes (nonspeciated), *Actinomyces* spp. (nonspeciated), and *Fusobacterium* spp. (comprosed of *F. nucleatum*, *F. necrophorum*, or *F. varium*).

Bacterial cultures and polymicrobial growth rates were compared between ODS and all CRS, then separately for ODS vs CRSsNP, and ODS vs CRSwNP. These comparisons were also performed between CRSsNP and CRSwNP patients, and between unilateral and bilateral forms of CRS (both within and between subtypes). Additionally for CRSsNP and CRSwNP, these comparisons were made based on primary vs revision ESS status, but not for

TABLE 1. Frequencies of ODS, CRS, and both CRSsNP and CRSwNP, as well as their unilateral and bilateral presentations*

Sinusitis types	Sample sizes
ODS	62
Eosinophilic	18/51 (35%)
All CRS	214
All CRSsNP	70
Unilateral	28
Bilateral	42
Eosinophilic	14/70 (20%)
Unilateral	2/28 (7.1%)
Bilateral	12/42 (28.9%)
All CRSwNP	144
Unilateral	24
Bilateral	120
Eosinophilic	128/144 (89%)

*Frequencies of tissue eosinophilia are also reported for each type of sinusitis.
CRS = chronic rhinosinusitis; CRSsNP = CRS without nasal polyps; CRSwNP = CRS with nasal polyps; ODS = odontogenic sinusitis.

ODS because nearly all ODS cases were primary. Last, cultures were compared between the 2 types of odontogenic pathologies causing ODS in this study: apical periodontitis with PALs (endodontic disease) and temporary or permanent OAF.

Statistical analyses were performed using SAS v9.4 (SAS Institute, Inc., Cary, NC). Because most variables were binary, comparisons between groups were completed using a chi-square test. The continuous variables were compared using a 2-sample Wilcoxon test. Odds ratios (ORs) along with their 95% confidence intervals (CIs) were generated using a linear logistic regression analysis. Values of $p < 0.05$ were considered statistically significant.

Results

Table 1 shows the frequencies of ODS and CRS types in this study. Of the 276 sinusitis patients, 62 had unilateral ODS (22.5%). ODS represented 54.4% of all unilateral chronic sinusitis cases (62/114). Of the 62 ODS patients, 40 (64.5%) were due to apical periodontitis with PALs (endodontic disease), and 22 (35.5%) were due to temporary or permanent OAF. Of the 214 CRS patients, 70 were CRSsNP (unilateral = 28, bilateral = 42), and 144 were CRSwNP (unilateral = 24, bilateral = 120). The following percentages of cases showed tissue eosinophilia: 89% CRSwNP (128/144), 20% CRSsNP (14/70), and 35% ODS (18/51). Among CRSsNP patients, 7.1% of unilateral cases demonstrated tissue eosinophilia, and 28.9% of bilateral cases demonstrated eosinophilia. Eleven ODS patients did not have pathology results. The differences in eosinophilia were significantly different between CRSwNP and CRSsNP ($p = 0.001$), and between CRSwNP and ODS ($p = 0.001$), but not between all CRSsNP and ODS ($p = 0.06$). There was a higher incidence of eosinophilia in unilateral ODS compared to unilateral CRSsNP ($p = 0.007$), but no difference between ODS and bilateral CRSsNP ($p = 0.490$).

Table 2 shows demographic and clinical data compared between ODS and all CRS, CRSsNP, and CRSwNP. Primary vs revision surgery status was significantly different between ODS and CRS patients. Nearly all ODS patients underwent primary ESS (98.4%), compared to 58% of all CRS patients (54% of CRSsNP, 60% of CRSwNP). Intraoperatively, pus was identified in 100% of ODS patients, but in only 42% of all CRS patients ($p = 0.001$). Among CRS patients, pus was identified in 57% of CRSsNP, and 35% of CRSwNP, and this difference was significant. Pus was still more likely in ODS when compared to both CRSsNP and CRSwNP. When pus was present, 100% of cultures resulted in microbial growth.

Among ODS and CRS patients with purulence, the majority of both ODS and CRS patients showed polymicrobial bacterial growth, with 71% of ODS and 64% of all CRS ($p = 0.400$). There were no significant differences in frequencies of polymicrobial bacterial growth between ODS and CRSsNP, or between ODS and CRSwNP (Table 2).

Table 3 shows frequencies of all bacterial species cultured, and their associations between ODS and all CRS. Table 4 shows only ODS-associated bacteria with their associated ORs. The following bacteria were significantly more likely in ODS compared to CRS: mixed anaerobes, *Fusobacterium* spp., *Eikenella corrodens*, *Streptococcus intermedius*, *Streptococcus anginosus*, and *Streptococcus constellatus*. The following bacteria were inversely correlated with ODS: *Pseudomonas aeruginosa* and *Staphylococcus aureus*. A high percentage of coagulase-negative staphylococci as well as corynebacteria were isolated in both ODS and CRS patients. These same bacterial culture associations were demonstrated when comparing them between ODS and CRSsNP, and between ODS and CRSwNP.

On CRS subgroup culture comparisons, there were no significant differences in bacterial cultures between CRSsNP and CRSwNP, nor between unilateral and bilateral forms of CRSsNP and CRSwNP. There were also no significant differences in culture results based on primary or revision ESS for all CRS patients, or for either CRSsNP or CRSwNP. Therefore, culture results were equivalent across all CRS, regardless of polyp status, unilateral, or bilateral disease, or primary vs revision surgery status. This helped to validate statistical comparisons between ODS and all CRS, and CRS subtypes.

There were also no significant differences in bacterial cultures between the 2 types of dental pathologies causing ODS in this study (endodontic disease and OAF). Table 5 shows comparisons of only the frequencies of ODS-associated bacteria between the 2 dental pathologies.

TABLE 2. Comparisons of demographic and clinical data of patients with ODS to all CRS, CRSsNP, and CRSwNP*

	ODS (n = 62)	All CRS (n = 214)	p	CRSsNP (n = 70)	p	CRSwNP (n = 144)	p
Age (years), mean ± SD	55.1 ± 15.8	50.9 ± 15.6	**0.038**	55.9 ± 15.8	0.827	48.5 ± 15.2	**0.002**
Gender (%)							
Male	59.7	54	0.575	40	**0.024**	58.3	0.857
Female	40.3	46		60		41.7	
Primary ESS (%)	98	58	**0.001**	54	**0.001**	60	**0.001**
Pus present (%)	100	42	**0.001**	57	**0.001**	35	**0.001**
Polymicrobial growth (%)	71	64	0.400	65	0.526	64	0.433

*Bold values are significant at $p < 0.05$.
CRS = chronic rhinosinusitis; CRSsNP = CRS without nasal polyps; CRSwNP = CRS with nasal polyps; ESS = endoscopic sinus surgery; ODS = odontogenic sinusitis; SD = standard deviation.

Discussion

ODS is distinct from other types of rhinosinusitis in that it originates from odontogenic infection or iatrogenic injury from dental or oral procedures. Although ODS management is highly successful when both the odontogenic source and sinusitis are managed,[30-35] treatment success hinges upon identifying the odontogenic source. Unfortunately, diagnosing ODS can be elusive due to nonspecific clinical presentations, missed diagnoses by dentists and radiologists, and a lack of diagnostic recommendations in sinusitis guidelines. Given the potential challenge of diagnosing ODS, it would be helpful to have diagnostic measures that distinguish ODS from other forms of rhinosinusitis, and maxillary sinus bacterial cultures could be 1 such measure.

Prior culture-based ODS studies have generally shown anaerobes to be common in ODS, often with polymicrobial growth.[4,5,21,22] In 2005 Brook[23] reviewed cultures from 48 ODS patients, and showed that about 90% grew anaerobes, and most were polymicrobial. However, there were no comparisons made to non-odontogenic rhinosinusitis patients, nor between the numerous dental pathologies included in the study. Saibene et al.[22] compared culture results of 15 bacterial ODS patients to 16 CRSwNP patients. They reported a higher polymicrobial burden in ODS patients. Their sample sizes were too small to compare presence of anaerobes between ODS and CRSwNP patients, or between different dental pathologies. Puglisi et al.[21] compared sinus culture results between 12 ODS patients and 47 CRS patients, and showed a slightly higher predominance of anaerobes in ODS (43% vs 32%), but no statistical testing was performed. Each of these studies reported a variety of bacterial species being cultured, but none compared frequencies of individual species between ODS and rhinosinusitis patients, and none compared ODS cultures based on odontogenic pathology.

The current study showed some similarities and differences from previous ODS microbiology studies. First, consistent with multiple previous studies,[4,5,22] anaerobic bacteria were identified in most ODS patients. When compared to Brook's[23] findings, *Fusobacterium spp*. were also common among anaerobes. However, the current study showed that multiple oral streptococcal species were significantly more common in ODS compared to CRS, whereas these bacteria were not reported in Brook's study. Zirk et al.[5] also reported a relatively high incidence of *Streptococcus* spp. in 33% of their 40 ODS patients, although they did not report frequencies of individual species. Last, although the high rate of polymicrobial growth in ODS patients in the current study was similar to other studies,[4,5,21,22] there were no significant differences in the polymicrobial burdens between ODS and any CRS patients. These findings would suggest that polymicrobial bacterial growth may not be unique to ODS.

It is also important to note that ODS patients presented with maxillary sinus purulence significantly more frequently than CRS patients (100% vs 42%, $p = 0.001$). Similarly, Saibene et al.[22] showed that only 40% of CRSwNP patients had culture positivity. These findings would support that ODS is distinct from CRS in that it is infectious in nature, whereas CRS is frequently an inflammatory condition, with or without concurrent infection.

Certain bacteria were identified more commonly in ODS patients, and these could help predict an odontogenic source of sinusitis when identified. Mixed anaerobes, *Streptococcus intermedius*, and *Streptococcus constellatus* were significantly more likely in ODS cases, although smaller percentages of them were also found in some CRS patients. Three of the ODS-associated bacteria grew solely in ODS cultures: *Fusobacterium* spp., *Eikenella corrodens*, and *Streptococcus anginosus*. Overall, ODS-associated bacteria in this study were consistent with oral flora, which often colonize subgingival plaques.[28,36] However, one must also consider that the normal oral flora is comprised of hundreds of other bacteria not identified in the current study,[28] and sinus cultures demonstrating these bacteria should also trigger an evaluation for dental pathology. It was also important to show that *Pseudomonas aeruginosa* and

TABLE 3. Comparison of all individual bacteria cultured from maxillary sinuses purulence, in ODS vs non-odontogenic CRS*

Bacteria	ODS (n = 62) (%)	CRS (n = 90) (%)	*p*
Anaerobes (obligate)			
Mixed anaerobes	40.3	22.2	**0.016**
Fusobacterium nucleatum	16.1	0	**0.001**
Fusobacterium necrophorum	1.6	0	0.408
Fusobacterium varium	1.6	0	0.408
Peptostreptococcus micros	3.2	2.2	1.000
Peptostreptococcus magnus	1.6	0	0.408
Propionibacterium acnes	1.6	6.7	0.241
Prevotella denticola	1.6	0	0.408
Actinomyces spp.	1.6	1.1	1.000
Aerobes (gram-positive)			
Streptococcus intermedius	24.2	5.6	**0.001**
Streptococcus anginosus	8.1	0	**0.010**
Streptococcus constellatus	8.1	1.1	**0.042**
Alpha-hemolytic streptococcus	4.8	10	0.361
Streptococcus sanguinis	1.6	0	0.408
Streptococcus mitis	1.6	1.1	1.000
Streptococcus pneumoniae	0	1.1	1.000
Streptococcus Group F	4.8	1.1	1.000
Streptococcus Group G	1.6	0	0.408
Beta-hemolytic Streptococcus	1.6	1.1	1.000
Staphylococcus aureus	9.7	32.2	**0.001**
Staphylococcus lugdunensis	3.2	3.3	1.000
Coagulase-negative staphylococcus	51.6	43.3	0.315
Corynebacterium spp.	22.6	12.2	0.091
Aerobes (gram-negative)			
Eikenella corrodens	14.5	0	**0.001**
Haemophilus parainfluenzae	3.2	3.3	1.000
Aggregatibacter aphrophilus	3.2	1.1	0.567
Moraxella catarrhalis	4.8	3.3	0.688
Neisseria spp.	4.8	1.1	0.305
Pseudomonas aeruginosa	1.6	14.4	**0.008**
Escherichia coli	1.6	6.7	0.241
Klebsiella oxytoca	1.6	1.1	1.000
Haemophilus influenzae	0	4.4	0.146

(Continued)

TABLE 3. Continued

Bacteria	ODS (n = 62) (%)	CRS (n = 90) (%)	*p*
Serratia marcescens	0	1.1	1.000
Klebsiella pneumoniae	0	1.1	1.000
Enterobacter aerogenes	0	4.4	0.146
Stenotrophomonas maltophilia	0	1.1	1.000
Enterobacter cloacae	0	2.2	0.514
Proteus mirabilis	0	1.1	1.000

*Bold values are significant at $p < 0.05$.
CRS = chronic rhinosinusitis; ODS = odontogenic sinusitis.

Staphylococcus aureus were inversely related to ODS. When these bacteria are identified in the absence of ODS-associated bacteria, CRS should be considered more likely. Also of note, coagulase-negative staphylococci and corynebacteria grew in significant numbers in both ODS and CRS groups. Whether these were pathogenic cannot be determined with certainty, but based on previous literature, it is more likely they represented commensal flora.[37-39]

Although it may be intuitive that oral bacteria are associated with ODS, very few studies have discussed the pathophysiologic spread of bacteria during ODS. Brook et al.[40] in 1996 compared culture results from 5 ODS patients who underwent concurrent aspirations of periapical molar abscesses and maxillary sinuses. He showed 100% culture concurrence between the aspirates, suggesting direct spread from the dental infection to the sinus. No other studies have directly analyzed bacterial spread during ODS, but some have discussed how ODS can be due to either primary odontogenic infection spread into the maxillary sinus, or secondary rhinosinusitis due to maxillary sinus inflammatory edema and ostial obstruction in response to underlying odontogenic infection.[23,40,41] The current study suggested that direct spread of dental bacteria into the maxillary sinus was more likely because there were no significant differences in culture results between patients with apical periodontitis (intact sinus mucosa), and patients with OAF (violated sinus mucosa. However, one cannot determine this definitively without comparing concurrent aspirates from infected dentition, so future studies will be needed to study this more methodically.

There are clinical scenarios where sinus cultures could prove beneficial for predicting an odontogenic source of sinusitis, after which the diagnosis could be confirmed by appropriate dental evaluation. First, as was reported by Pokorny and Tataryn,[15] some ODS patients have subtle to absent dental pathology on CT scans. It is also possible for clinicians to overlook overt dental pathology on CT, as was suggested in a series by Longhini and Ferguson,[12] where 21 ODS patients failed ESS due to

TABLE 4. Comparisons of bacteria found to be significantly different between ODS and non-odontogenic CRS, with OR predicting their associations with ODS*

Bacteria	OR (95% CI)	*p*
ODS-associated bacteria		
Fusobacteria spp.	29.40 (6.00, >1000)	**0.001**
Eikenella corrodens	20.64 (4.08, >1000)	**0.001**
Streptococcus anginosus	10.36 (1.84, >1000)	**0.010**
Streptococcus constellatus	7.81 (0.89, 68.55)	**0.042**
Streptococcus intermedius	5.43 (1.86, 15.87)	**0.001**
Mixed anaerobes	2.37 (1.16, 4.81)	**0.016**
Non-odontogenic bacteria		
Pseudomonas *aeruginosa*	0.10 (0.01, 0.76)	**0.008**
Staphylococcus aureus	0.23 (0.09, 0.59)	**0.001**

*Bold values are significant at $p < 0.05$.
CI = confidence interval; CRS = chronic rhinosinusitis; ODS = odontogenic sinusitis; OR = odds ratio.

TABLE 5. Frequencies of ODS-associated bacteria compared between endodontic and OAF pathologies causing ODS

ODS-associated bacteria	Endodontic (n = 40) (%)	OAF (n = 22) (%)	*p*
Mixed anaerobes	40.0	40.9	0.944
Fusobacteria spp.	15.0	27.3	0.242
Eikenella corrodens	10.0	27.3	0.675
Streptococcus intermedius	22.5	27.3	0.675
Streptococcus anginosus	5.0	13.6	0.337
Streptococcus constellatus	7.5	9.1	1.000

OAF = oroantral fistula; ODS = odontogenic sinusitis.

unrecognized odontogenic sources. In these scenarios, identifying ODS-associated bacteria from sinus cultures could provide the diagnostic information necessary to direct subsequent dental evaluation. Alternatively, some patients with sinonasal complaints could present without a sinus CT. If ODS-associated bacteria were cultured from pus in the middle meatus or maxillary sinus, one could consider further workup for an odontogenic source, rather than treating repeatedly like rhinosinusitis. However, it should also be noted that some of the ODS-associated bacteria were found in CRS patients' cultures, albeit in significantly smaller proportions. This highlights that sinus cultures are not 100% diagnostic of ODS, but could be used to increase or decrease one's suspicion of an odontogenic source. Some sinus culture results could also potentially help to rule out ODS if patients grow bacteria associated with non-odontogenic rhinosinusitis. For example, sinus cultures demonstrating *Staphylococcus aureus* or *Pseudomonas aeruginosa*, and no ODS-associated bacteria, could suggest rhinosinusitis based on the current study. In these situations, perhaps a dental evaluation would be less prudent. However, larger prospective studies will be necessary to determine whether sinus cultures accurately predict which sinusitis patients warrant dental evaluation.

There were multiple strengths of the current study when compared to previous studies. First, all diagnostic data were collected prospectively by both a rhinologist and either an endodontist or periodontist. Second, culture accuracies were optimized by holding oral antibiotics for at least 1 month preoperatively,[24,25] obtaining cultures only if frank purulence was identified in maxillary sinuses intraoperatively, and obtaining all cultures in the same sterile fashion. The 100% microbial growth rate, and isolation of fastidious organisms suggested that the study's culture method was optimized. Additionally, this was the first ODS study utilizing MALDI-TOF for more accurate identification of most organisms to the species level. Last, and very importantly, culture comparisons were made between ODS and both CRSsNP and CRSwNP, as well as between the different dental pathologies causing ODS.

Study limitations also deserve mention. First, although this was the largest study to date comparing culture results between ODS and CRS patients, the sample size was still not large enough to generalize the findings to the entire population. Another important consideration with regard to the sample size was that many bacteria were not present in high enough frequencies for adequate statistical comparison. However, some of these species could very well be unique to either ODS or CRS. For example, *Streptococcus sanguinis* and *Streptococcus mitis* are both part of oral flora, and could be associated with ODS, but their frequencies were very small. This could be true of other bacteria as well. Likewise, other bacteria could have been associated with CRS such as *Escherichia coli* and other aerobic gram-negative organisms. A larger multicenter study would be ideal to achieve adequate sample sizes of various bacteria for comparisons. Bacterial antibiotic susceptibilities were also not reported in this study. This was intentional, because the purpose of the study was to compare culture results between ODS and CRS for diagnostic, not therapeutic purposes. However, future studies would be beneficial in comparing antibiotic resistance patterns between ODS and CRS patients. Additionally, the single preoperative doses of intravenous antibiotics could have potentially altered microbial growth. However, there is literature reporting preoperative antibiotics having no significant effects on intraoperative cultures,[42,43] and this coupled with the robust microbial growth shown in the current study suggested that the antibiotics were unlikely to have significantly affected the culture results. Another limitation was that medical comorbidities were not analyzed, and whether this confounded culture results will require further study.

Complete structured histopathology reports were also not directly compared between ODS, CRSsNP, and CRSwNP, as was done by Raman et al.[44] Tissue eosinophilia did not appear to affect culture results in this study based on eosinophilia being similar between ODS and CRSsNP, but different between ODS and CRSwNP, while ODS cultures were different from both CRS types. Interestingly, unilateral ODS showed greater tissue eosinophilia than unilateral CRSsNP. Future larger studies will be beneficial to determine whether tissue eosinophilia can distinguish ODS from certain forms of unilateral sinusitis. Another potential limitation was that bilateral CRS patients did not undergo dental evaluations, and therefore it is possible that some of them had an odontogenic source of infection on 1 or both sides of their sinusitis. This was unlikely overall given their lack of dental pathology on sinus CT, but it is possible, and could explain why some ODS-associated bacteria were identified in the CRS group. Last, the culture results shown in this study only represented patients with chronic symptoms, and further study will be necessary to compare bacterial cultures between ODS and acute rhinosinusitis.

Conclusion

Certain bacteria were more likely to be associated with ODS compared to CRS when purulence was cultured from the maxillary sinus. Physicians should evaluate for an odontogenic source of sinusitis when these ODS-associated bacteria are identified in maxillary sinus cultures.

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