Journal of Current Research in Oral Surgery
2025, Volume 5, Issue 2, Page No: 30-38

Available online at: www.tsdp.net

ISSN: 3062-3480

Original Article

Correlation of Maxillary Sinus Disease with Primary and Persistent Apical Periodontitis: A Cone-Beam Computed Tomography Study

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Received: 11 March 2025; **Revised:** 03 July 2025; **Accepted:** 04 July 2025

ABSTRACT

This investigation aimed to establish the frequency and distribution patterns of maxillary sinus (MS) pathologies originating from periapical (PA) endodontic lesions, to compare the primary and persistent forms of apical periodontitis (AP), and to examine the associations between distinct AP categories and endodontic procedures. A retrospective evaluation of 400 cone-beam computed tomography (CBCT) volumes from individuals referred to the Radiology Department at the College of Dentistry, King Abdulaziz University, was undertaken. The analysis focused on identifying PA lesions in the maxillary posterior dentition, classifying MS disease types, and assessing their spatial relationship with root apices, PA pathoses, and the antral floor. Statistical methods were applied to explore the interrelationships among the investigated variables. PA lesions were detected in 54% of initial infections and 46% of recurrent infections. In 56% of instances, the pathosis was restricted to the bone. MS disease was evident in 28% of cases presenting with persistent infections ($P < 0.05$). Unilateral sinus involvement was noted in 68% of cases, whereas bilateral manifestation accounted for merely 10% ($P < 0.05$). PA mucositis had a markedly higher incidence than PA osteoperiostitis, particularly in cases dominated by primary endodontic infections. These observations yield crucial knowledge regarding the interplay between MS disorders and endodontic pathoses, potentially guiding clinical therapeutic decision-making.

Keywords: Chronic apical periodontitis, Cone-beam computed tomography, Maxillary sinusitis, Mucosal thickening, Odontogenic infections, Periapical lesion

How to Cite This Article: Walker J, Harris O. Correlation of Maxillary Sinus Disease with Primary and Persistent Apical Periodontitis: A Cone-Beam Computed Tomography Study. J Curr Res Oral Surg. 2025;5(2):30-8. https://doi.org/10.51847/vzGBReBiff

Introduction

In endodontics, the long-standing intraradicular infection in teeth previously treated with root canal therapy poses a considerable challenge. Attaining complete bacterial clearance from the root canal space remains problematic despite the use of diverse disinfection protocols. The literature confirms that root canal infections typically harbor multiple microbial strains, making the eradication of all vital organisms an arduous task [1-4]. This polymicrobial essence hinders treatment success and fosters infection tenacity.

An investigation that cultured microbial specimens from 200 endodontically treated teeth demonstrated viable bacteria in every sample, underscoring the near-total impracticality of achieving sterility [5]. Furthermore, bacteriological cultures were positive in 45% and 68% of subjects, respectively, and these cases required retreatment on pathological or technical grounds [6].

Apical periodontitis has also been strongly correlated with defective coronal seals, as select microbial species proliferate in these microenvironments [7]. Among the bacterial taxa implicated in chronic root canal pathoses, *Enterococcus faecalis* has drawn substantial scrutiny. With a prevalence reaching 75%, it has been portrayed as the organism most frequently isolated from unsuccessful root canal interventions [8]. Certain

studies suggest that E. faecalis may be eliminated if present solely in negligible inocula, yet upon colonization of the canal system, it displays profound recalcitrance [9]. Persistent lesions are known to arise from periapical (PA) inflammatory responses provoked by extra-radicular infections—a phenomenon recognized since 1972—mediated by microbes adhering to the cemental root surface [10]. *Actinomyces israelii* has been recovered from PA lesions, particularly where non-surgical retreatment protocols have failed [11]. Concurrently, anaerobic bacterial biofilms have been visualized coating the root termini of teeth afflicted with refractory pathologies [12].

Beyond microbial etiology, enduring PA lesions can also originate from foreign body reactions. Cellulose fibers shed by paper points, dietary debris, and extruded root canal sealants have all been located within PA tissues, triggering inflammatory cascades that arrest reparative processes [13, 14]. Cholesterol crystals, liberated from necrotic cells and lysed erythrocytes accumulating in long-standing lesions, have similarly been implicated in foreign body giant cell responses [15]. The existence of PA cystic transformation may be associated with persistent PA radiolucencies. Based on Ramachandran Nair *et al*. [16] histological work, roughly 15% of all PA lesions are cystic in nature, with true cysts constituting 9% of this subset. Simon *et al*. [14] later distinguished these into true cysts and bay cysts.

Such cystic entities rarely resolve following orthodox root canal treatment, often necessitating surgical excision [17].

Imaging modalities play a pivotal role in assessing endodontic therapeutic outcomes. Strindberg [18] originally devised radiographic benchmarks for treatment success. At the same time, Orstavik *et al*. [19] subsequently formulated the widely adopted periapical index (PAI), furnishing a five-tiered ordinal scale to quantify apical tissue destruction [18-20]. Conventional two-dimensional radiographs suffer from inherent shortcomings, namely geometric distortion and anatomic superimposition [21-23]. Orthopantomographic projections, despite their common use, can introduce measurement discrepancies, particularly those attributable to variable magnification factors [24, 25]. Cone-beam computed tomography (CBCT), owing to its volumetric image acquisition, has emerged as a diagnostically superior modality for intricate endodontic conditions, thereby circumventing these limitations [26, 27]. Tailored for endodontic diagnostics, CBCT delivers enhanced spatial resolution through the employment of reduced voxel dimensions and limited field-of-view acquisitions [28-32].

CBCT technology also significantly aids in identifying maxillary sinusitis, a condition accounting for 10%–12% of all sinusitis cases and often traced to odontogenic sources [33, 34]. Pathologic processes breaching the sinus floor can manifest as a spectrum of findings, ranging from osseous deposition to mucosal hyperplasia [35-37]. Both periapical osteoperiostitis (PAO) and periapical mucositis (PAM), entities intimately tied to PA inflammation encroaching upon the antral cavity, are discernible via CBCT imaging—a prerequisite for rendering a precise diagnosis of dentally derived maxillary sinusitis [34-39].

The precise diagnostic workup and therapeutic management of maxillary sinusitis hinge on a thorough appreciation of the nexus between PA lesions and sinus pathology. The goals of this study were to contrast pathological findings with those of contralateral healthy sinuses, to quantify the prevalence of maxillary sinus (MS) disease within a cohort with endodontic infections, and to scrutinize the correlation between discrete forms of sinus pathology and endodontic infection types.

Materials and Methods

Subject screening

CBCT records were utilized in this study to investigate the occurrence of mucosal thickening adjacent to root-canal-treated teeth. The King Abdulaziz University Research Ethics Committee issued ethical clearance, and rigorous adherence to patient confidentiality and ethical principles was observed throughout the study.

The requisite sample size was derived from an earlier publication by Nascimento *et al*. [40]. A retrospective audit of CBCT volumes for patients referred from the endodontic service to the oral radiology unit at the College of Dentistry, King Abdulaziz University, was conducted.

Eligible participants were those aged 18 to 65 years whose scans included maxillary second premolars, first molars, or second molars. After a surveillance window of at least 1 year, the designated teeth had to exhibit non-healing persistent PA radiolucencies, apical bone resorption, and a pulpal diagnosis of necrosis or prior endodontic intervention. When root canal treatments (RCTs) were present, their technical quality had to satisfy the sufficiency standards defined by Estrela *et al*. [41].

Cases were excluded if they showed cystic lesions or tumors, PA radiolucencies with signs of repair at one year, any background of MS trauma or surgery, or more

than one posterior tooth on the same side harboring a PA lesion.

Image processing and data collection

All CBCT acquisitions were captured on an i-Cat Next Generation platform (Imaging Science International, Hatfield, PA) with parameters set at 120 kV, 37 mAs, and a voxel resolution of 125 µm. Image interpretation was performed on OnDemand3D software (CyberMed, Seoul, South Korea). Two calibrated observers—a practicing endodontist and a board-certified oral and maxillofacial radiologist—evaluated the scans independently for PA and MS pathology.

Study variables

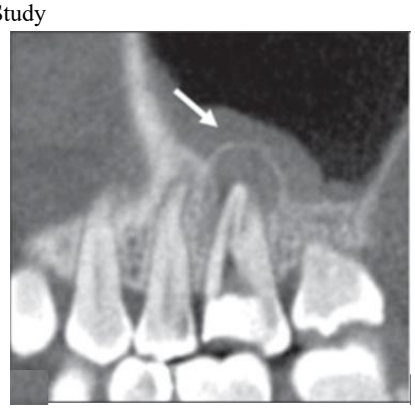
The following characteristics were extracted from the CBCT datasets: the nature of the endodontic infection (designated primary or persistent), the cortical plate condition (eroded or destroyed), and the CBCT-PAI grade, allocated according to the 0–5 ordinal scheme outlined below:

• 0 – Uncompromised PA bone architecture
• 1 – PA bone destruction spanning 0.5–1 mm in diameter
• 2 – PA bone destruction spanning 1–2 mm in diameter
• 3 – PA bone destruction spanning 2–4 mm in diameter
• 4 – PA bone destruction spanning 4–8 mm in diameter
• 5 – PA bone destruction greater than 8 mm in diameter.

The addition of the suffix (E) to the numerical score signals expansion of the cortical plate, whereas the suffix (D) signals its destruction. Where applicable, the quality of RCT was assessed and categorized as absent, substandard, or adequate. The analyzed tooth types included first molars, second molars, and second premolars.

The spatial interplay between the root apices and the MS was stratified into five configurations: the MS floor lying entirely above the root level; the MS floor descending between the roots; the buccal root(s) penetrating the MS; the palatal root penetrating the MS; or both buccal and palatal roots penetrating the MS. The relationship of the PA lesion to the MS was grouped into three scenarios relative to the absence or presence of sinus involvement: a clear buffer zone between the PA lesion and the sinus floor; the PA lesion abutting the sinus floor; or the PA lesion extending directly into the sinus cavity.

In parallel, the contralateral MS was categorized as either healthy or diseased, and the sinus pathology subtype was recorded as either PAM or PAO **(Figures 1 and 2).**



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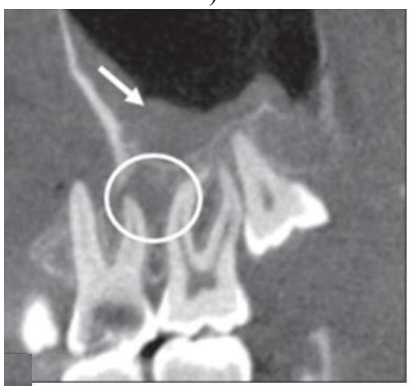

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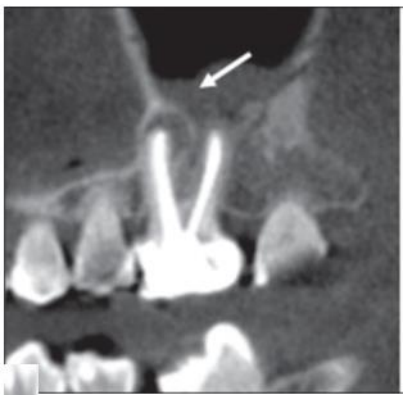
Figure 1. Correlation between periapical infection type (primary infection) and maxillary sinus pathology. Two CBCT images are provided with cropped panoramic reconstruction at 0 thickness: (a) Primary infection linked to periapical osteoperiostitis, (b) Primary infection linked to periapical mucositis. Abbreviations: PAO = Periapical osteoperiostitis, and PAM = Periapical mucositis. Arrows highlight the MS pathology, and the circle demarcates the PA lesion.



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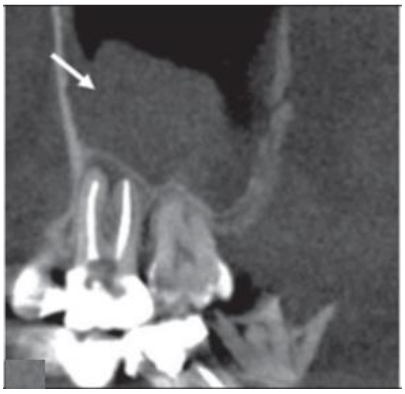

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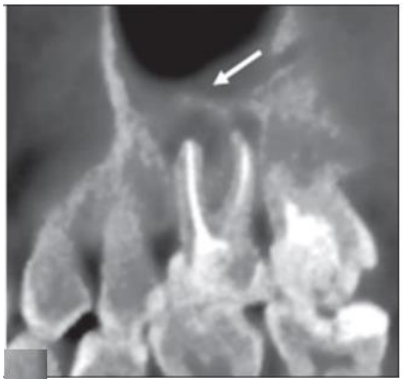

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Figure 2. Correlation between periapical infection type (persistent infection) and maxillary sinus pathology. Three CBCT images are provided with cropped panoramic reconstruction at 0 thickness: (a) Persistent infection linked to periapical osteoperiostitis (PAO), (b) Persistent infection linked to periapical mucositis, and (c) Incomplete PAO bone deposition encircling the lesion of a persistent infection. Abbreviations: PAO = Periapical osteoperiostitis, and PAM = Periapical mucositis. Arrows highlight the MS pathology.

Statistical analysis

Categorical variables were summarized using frequencies and percentages. Descriptive statistics were employed to characterize the dataset, while associations between variables were tested using the Chi-square test and Fisher's exact test. A threshold of $P < 0.05$ was set for statistical significance. Interrater reliability was quantified through Cohen's Kappa coefficient and the Intraclass Correlation Coefficient; a Kappa value exceeding 0.8 and an intraclass correlation coefficient above 0.75 signified subs tantial concordance between the examiners. All statistical computations were executed using STATA software, version 16.0 (StataCorp, College Station, Texas, USA). The prevalence of MS pathologies was analyzed per tooth type, separately delineating cases of PAM and PAO. Notable distinctions between groups were highlighted with asterisks.

The spatial interplay between PA lesions or root apices and the sinus floor was examined, yielding perspectives on the anatomical determinants shaping the emergence of MS disorders in the setting of endodontic infections.

Results and Discussion

A total of 400 teeth comprised the study sample, divided into two cohorts: primary infections accounted for 54%, while persistent infections accounted for 46% **(Table 1).**

Table 1. Characteristics of the assembled cases (400 teeth).

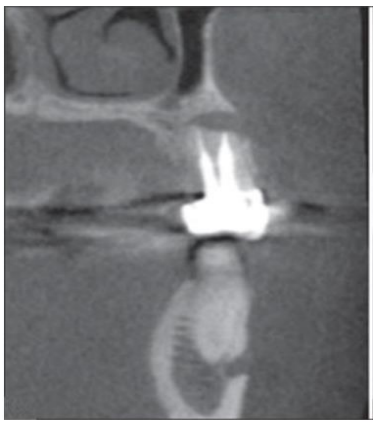
Category	Subcategory	Frequency, n (%)
Gender	Males	154 (38.5)
Gender	Females	246 (61.5)
Gender	Total	400 (100)
Tooth type	Second premolar	102 (25.5)
Tooth type	First molar	215 (53.75)
Tooth type	Second molar	83 (20.75)
Tooth type	Total	400 (100)
PA lesion type	Primary infection	216 (54)
PA lesion type	Persistent infection	184 (46)
PA lesion type	Total	400 (100)

Abbreviation: PA lesion = Periapical lesion

Upon evaluating the categories of PA infections and their association with MS, a significant intergroup difference emerged. MS pathology was identified in 28% of persistent infection cases and in 41% of primary infection cases ($P < 0.05$). Moreover, bilateral sinus involvement was limited to merely 10% of instances, in contrast to unilateral sinus disease, which accounted for 68% ($P < 0.05$).

Regarding PAO, no statistically meaningful difference was observed between the primary and persistent infection groups ($P > 0.05$), and PAO manifested at a moderate frequency overall.

The connection between PA lesions and MS pathology also varied according to sex, with female patients demonstrating a stronger association than male patients ($P < 0.05$), as revealed by the analysis. Lesions situated in the t and second molars coincided more often with diseased sinuses ($P < 0.05$). In contrast, those affecting second premolars were more commonly associated with healthy sinuses, underscoring that tooth location was a meaningful determinant **(Figure 3; Table 2).** The distribution of MS disease alongside the PA infection category is depicted in the study **(Figure 4).**



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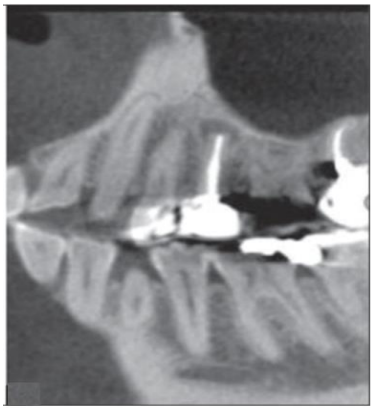

b)

Figure 3. Variables shaping the classification of maxillary sinus pathology (tooth type). Two cone-beam computed tomography views illustrate how tooth position influences maxillary sinus pathology: (a) A cropped coronal slice and (b) a cropped panoramic reconstruction at 0 thickness depict the spatial relationship between premolar teeth bearing apical lesions and the maxillary sinus. With increasing posterior location, the roots of the teeth approach the maxillary sinus more closely. In the presented images, the periapical lesions of the second premolars are demarcated from the sinus by a substantial barrier of cortical bone.

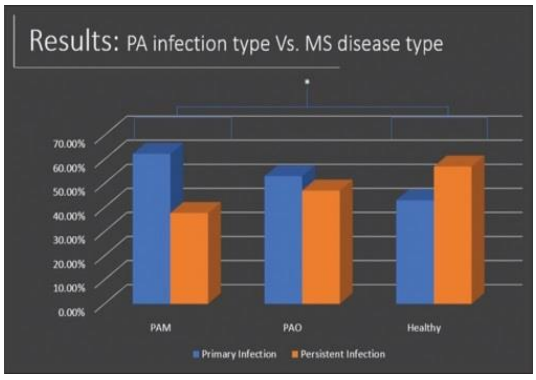

Figure 4. Proportional representation of periapical infection status and maxillary sinus pathology. Primary endodontic infections were accompanied by a significantly higher count of affected maxillary sinuses (40%) relative to persistent infections (27.25%) ($P < 0.05$). Post hoc comparisons pinpointed a significant distinction between the periapical mucositis (PAM) subgroup and the healthy maxillary sinus subgroup. Primary infection was associated with a substantially greater proportion of PAM cases, while persistent infection tended to coincide more frequently with sinus health. The frequency of periapical osteoperiostitis fell in the middle tier and did not reach statistical significance. highlights a significant difference between the groups.

Table 2. The effect of tooth type on the categorization of maxillary sinus pathology.

Tooth type	PAM, n (%)	PAO, n (%)	Healthy n (%)	P
Second premolar	40 (21)	14 (17)	48 (73)	0.002
First molar	111 (59)	45 (54)	59 (46)	
Second molar	37 (20)	24 (29)	22 (17)	
Post hoc	*	**	*/**	

Identical asterisks point to significant differences between groups. Abbreviations: MS = Maxillary sinus, PAM = Periapical mucositis, PAO = Periapical osteoperiostitis.

A clear relationship emerged between CBCT-PAI scores and MS disease categories, with score 4 being the most frequently observed. PAO was strongly tied to this score ($P < 0.001$), while PAM or healthy sinus presentations were predominantly linked to the lower end of the scoring spectrum (1 and 2).

According to the study, buccal plate expansion remained a rare finding across both groups, yet cortical plate breakdown was markedly more common among individuals classified with PAO ($P = 0.01$). Looking at the full sample, 35.75% of PA lesions were accompanied by cortical destruction, 7.75% by expansion, and 56.5% showed no discernible change to the buccal plate ($P < 0.05$). How cortical plate status and CBCT-PAI scores related to the various MS subtypes was examined **(Table 3),** and the spread of CBCT-PAI scores across MS disease categories was assessed **(Figure 5).**

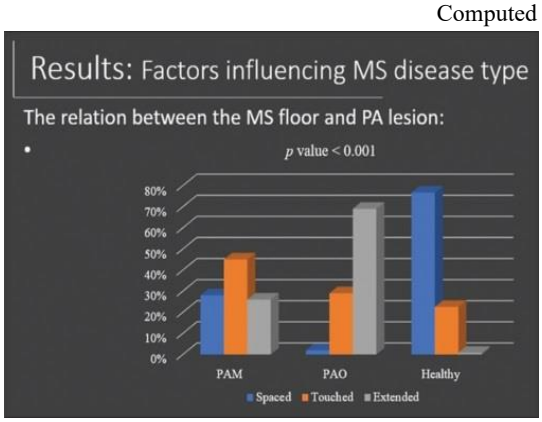

Figure 5. Contributors to maxillary sinus disease subtype (cone-beam computed tomography-periapical index [CBCT-PAI]). This graph maps the association between CBCT-PAI scores and maxillary sinus disease classification. Higher scores (3–5) tracked with a growing prevalence of periapical osteoperiostitis, whereas lower scores (1–2) most often accompanied periapical mucositis or a healthy sinus state. These patterns highlight how the intensity of periapical infection and the resulting sinus pathology are connected. Abbreviations: MS = Maxillary Sinus, PA = Periapical infection, PAM = Periapical mucositis, PAO = Periapical osteoperiostitis, CBCT-PAI = Cone-beam computed tomography-periapical index

Table 3. The role of (CBCT-PAI) in determining maxillary sinus disease subtype.

Factor	PAM (n = 188), n (%)	PAO (n = 83), n (%)	Healthy (n = 129), n (%)	P
CBCT-PAI score				
Score 1	27 (14)	0	18 (14)	< 0.001
Score 2	28 (15)	2 (3)	19 (15)	
Score 3	60 (32)	16 (19)	33 (26)	
Score 4	52 (28)	50 (60)	43 (33)	
Score 5	21 (11)	15 (18)	16 (12)	
Post hoc	**	*/**	*	
Cortical plate status				0.01
Expansion	15 (8)	6 (7)	10 (8)	
Destruction	55 (29)	43 (52)	45 (35)	
NA	118 (63)	34 (41)	74 (57)	
Post hoc	*	*		

Identical asterisks mark significant differences between the groups. Abbreviations: MS = Maxillary Sinus; PAM = Periapical Mucositis; PAO = Periapical Osteoperiostitis; CBCT-PAI = Cone-beam Computed Tomography Periapical Index; NA = Not Applicable (no change)

The results underline a consequential intersection between MS pathology and PA endodontic infections, pointing particularly toward primary infections posing a greater risk for sinus complications than persistent ones. The data showed that primary infections coincided far more often with PAM than with periapical osteitis (PAO). However, neither infection form showed a clear tendency to provoke one entity over the other. The infection category and its resultant MS disease proved tightly intertwined, with PAM surfacing at a much higher rate in primary infection cases.

The study observed that score 4 accounted for the majority of the PAI (CBCT-PAI) distribution, a finding that echoes earlier investigations of PA lesions in postthe erior maxillary teeth [4]. The comparatively wide span of this score (4–8 mm), set against the narrower 2 mm increments of lower scores, likely contributes to its overrepresentation and further suggests that more expansive lesions predominate in such clinical scenarios.

These data agree with prior reports showing that CBCT tends to exaggerate membrane thickness relative to histological measurements of the Schneiderian membrane [42]. Membrane thickness ranged from 0.5 to 27 mm in this series, operated well above the voxel resolution limit of 0.125 mm^3, making appreciable measurement error unlikely. The findings also align with studies associating thicker Schneiderian membranes with the proximity of teeth and PA lesions, especially in cohorts undergoing apical microsurgery [43].

Unlike some research reporting lower rates, this investigation found MS diseases—PAM included—to have a prevalence reaching 47%, a number that resonates with earlier literature [7-9, 44]. The larger sample pool and finer voxel size in this study, when compared with others, may partly explain the higher detection rate. The nature of the infection likely also shaped the lower observed frequency of PAO [11, 12, 14]. Because endodontic infections are usually high-grade processes driven by aggressive anaerobic bacteria, the slow-developing, low-grade infectious milieu needed for PAO formation is less common, potentially accounting for its reduced prevalence [6, 42].

Conversely, some research proposes that the intensity of endodontic infections may correlate not with the bacterial species present, but rather with the overall microbial load within the root canal system [45, 46]. Additionally, the relatively low frequency of PAO cases may be attributed to a more robust host immune response, which may reduce the likelihood of PA lesion progression [47, 48]. Nonetheless, further investigation is warranted to fully elucidate the pathogenesis of PAO.

Taken together, this study represents the first to explore the relationship between MS pathology subtypes and endodontic infection categories. The results imply that PAO formation may depend more heavily on the patient's immunological status than on the infection type itself, even while acknowledging that the prevailing literature has largely substantiated the association between PA lesions and PAM [2, 4, 38].

This work underscores the link between PA endodontic pathosis and MS disorders. When arriving at a diagnosis and formulating a treatment plan, a comprehensive clinical evaluation, combined with CBCT analysis before any intervention, is essential to determine the intimate spatial relationship between maxillary molar teeth and the sinus. It became apparent that endodontic infection exerts a direct influence on MS health, thereby impacting the patient's quality of life [49]. Addressing these endodontic infections is fundamental to either preventing or resolving such sinus pathologies [47]. Moreover, post-treatment clinical follow-up with these patients is vital to gauge the regression of these conditions following root canal therapy.

The investigation revealed that 10% of cases exhibited MS disease on the contralateral side, lending support to the notion that factors beyond endodontic infections—such as periodontal disease or dental implants—may also contribute to sinus pathology [2, 49, 50].

Conclusion

The findings indicate that primary endodontic infections stand as the most probable trigger for any MS pathology, particularly PAM. In addition, the proximity of PA lesions to the antral floor seems to constitute a critical determinant in disease development; lesions situated at or encroaching upon the sinus floor demonstrated a heightened propensity for causing PAO, whereas those positioned more apically were often associated with entirely healthy sinuses. Effective management of endodontic infections should consequently facilitate the resolution of related MS diseases. Clearly, additional studies are needed to unravel the intricate interplay between endodontic infections and MS disorders, incorporating anatomical and microbiological factors, and to conduct prospective cohort studies to assess therapeutic outcomes.

Acknowledgments: The authors would like to express their thanks to the staff of the Department of Oral Radiology for providing cone beam CT data from King Abdulaziz University Dental Hospital.

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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