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REVIEW ARTICLE

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A literature review of the maxillary sinus with special emphasis on its anatomy and odontogenic diseases associated with it

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Abstract

Maxillary air sinus (MS) is the largest and clinically most important air sinus because of its anatomical relationship with the nasal cavity and especially with teeth of the upper jaw. Periapical dental infection frequently spreads to the maxillary sinus leading to its secondary infection. The occurrence of maxillary sinusitis due to the odontogenic causes is one of the common clinical conditions which is frequently encountered by the endodontists. While handling such cases, the gross anatomy and structure of MS are visualized using various radiological images. However, most of the time, it is challenging for dentists to understand the MS due to its complicated morphology. Keeping this in mind, this literature review is done to comprehensively compile the details on MS from anatomy, radiology, and endodontic importance point of view. The articles were selected from databases like PubMed, Scopus, Embase, and Google Scholar using the keywords "maxillary sinus," "maxillary sinusitis," "Endo antral syndrome," "periapical surgery," and "odontogenic infections." In addition, a literature survey was also done using phrases like "roots extending into maxillary sinus," "foreign bodies in maxillary sinus," etc. Anatomical variation of sinus could be of clinical importance and the knowledge about the same could come in handy in treatment planning of upper teeth. Extruded materials from the root of a tooth into the sinus can make it prone to infection. The dentist should carefully evaluate the root of a tooth during root canal treatment.

Keywords Paranasal air sinuses, Maxillary teeth, Conservative dentistry, Periapical surgery, Sinusitis

Background

Maxillary air sinus (MS) is the largest of the paranasal air sinuses, and its structure, blood supply, and relationship with the teeth are considered clinically important [1]. Nathanial Highmore was the first person to report the drainage of an infected maxillary sinus through the extracted socket of a canine tooth [1]. The spread of periapical tooth infection to MS has also been reported [2]. Stafne has estimated that about 15–75% of maxillary sinusitis occurs due to odontogenic causes [3]. Despite the availability of advanced radiological techniques, most of the time, it is challenging for dentists to understand the MS due to its complicated morphology. Though there are many reports on the normal and variant anatomy of the MS, its clinical importance, and its significance in endodontic and conservative dentistry, a comprehensive discussion of the MS from the endodontic management point of view is lacking. Hence, the objective of this literature review is to present a comprehensive literature

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review including anatomy, radiology, and endodontic literature.

Materials and methods

The articles were selected from databases like PubMed, Scopus, Embase, and Google Scholar using the keywords "maxillary sinus, maxillary sinusitis, endoantral syndrome, periapical surgery, and odontogenic infections." In addition, phrases like "roots extending into the maxillary sinus, foreign bodies in the maxillary sinus, etc.," were also used.

Anatomy of the maxillary sinus

Maxillary sinuses are a pair of air-filled cavities occupying most of the body of the maxilla bone. It is a pyramidal-shaped cavity measuring about 3.5 cm in height opposite the first molar tooth, about 2.5 cm in transverse breadth, and about 3.2 cm in anteroposterior breadth. Its rectangular base forms the medial wall of the sinus and the lateral wall of the nasal cavity. It shows a small deficiency called maxillary hiatus in its anterosuperior part [4]. The size of the maxillary hiatus is minimized into a small ostium in the living by the approximation of the uncinate process of the ethmoid bone, the lacrimal bone, the descending part of the inferior nasal concha, the perpendicular plate of the palatine bone, and the overlying mucosa [5]. Through this, the sinus opens into the lowest part of the hiatus semilunaris below the bulla of the middle meatus in the lateral wall of the nasal cavity. A second opening is frequently present in 15 to 40% of cases in or just below the hiatus. Both the openings are nearer the roof than the floor of the sinus (Fig. 1). This position of the opening is disadvantageous for the natural drainage of the sinus [5]. The apex of MS is directed laterally into the zygomatic process of the maxilla. It sometimes forms a zygomatic recess by extending into the zygomatic process of the maxilla and reaching up to the zygomatic bone [4, 5]. The roof of MS is the floor of the orbit. Often, it is ridged by an infraorbital groove and canal on the floor of the orbit containing infraorbital nerve and vessels [6] (Fig. 2). Here, the nerve is vulnerable in 14% of individuals and it may be injured during surgical procedures. The posterior wall of the sinus is formed by the infratemporal plate of the maxilla [4]. Pterygopalatine and infratemporal fossae are posterior to it [4]. The floor of the MS is formed by the alveolar and palatine processes of the maxilla. It is usually about 1.5 cm below the level of the floor of the nasal cavity at the level of the lower border of the ala of the nose, and it normally extends from the mesial surface of the first premolar tooth to the distal surface of the third molar tooth with its lowermost part at the

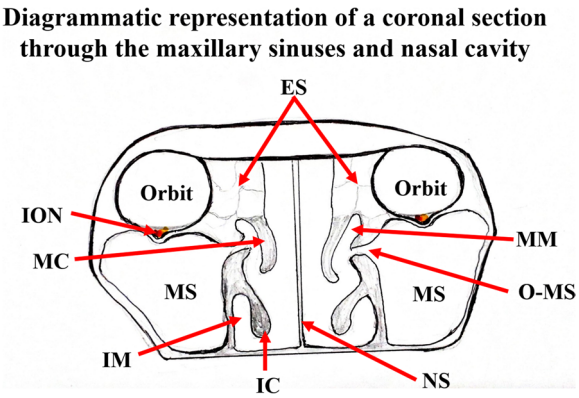

Fig. 1 Diagrammatic representation of a coronal section through the maxillary sinus and nasal cavity. Opening (O-MS) of the maxillary air sinus (MS) into the nasal cavity at the middle meatus (MM) has been indicated. It can be noted here that the maxillary sinus opening (O-MS) is located close to the roof of the sinus relations. ION infraorbital nerve, MC middle nasal concha, IM inferior nasal meatus, IC inferior nasal concha, NS nasal septum, ES ethmoidal air sinus

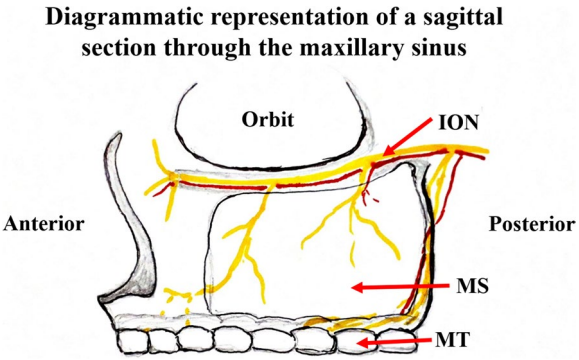

Fig. 2 Diagrammatic representation of a sagittal section through the maxillary sinus showing its anatomical relations. The course of the infraorbital nerve (ION) in the roof of the maxillary air sinus (MS) has been shown. MT maxillary teeth

first and second molar teeth. In children, the floor of the MS is 4 mm superior to the level of the floor of the nasal cavity. However, in adults, it lies 4 to 5 mm inferior to the nasal cavity floor [7]. The alveolar recess formed by its projection into the alveolar process may be seen in 50% of the population. A thin layer of compact bone separates the molar dentition from the floor of the antrum. The roots of the first and second molars project into the antral floor forming several conical elevations [8] (Fig. 3). The 1st and 2nd premolar and third molar roots, rarely canine roots, may also project into the sinus [8]. These roots may perforate the floor of the sinus. The size of the sinus varies, even on the two sides of an individual. Computerized

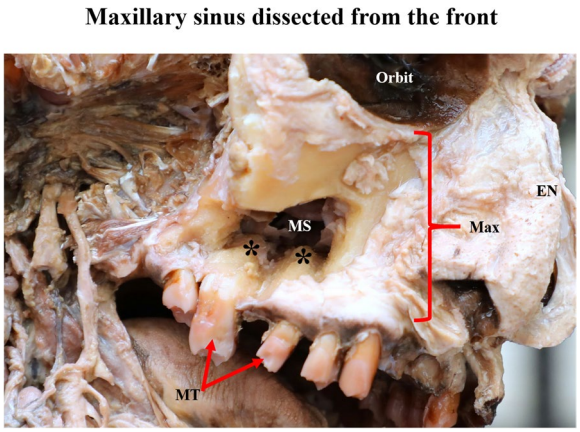

Fig. 3 Anterior wall of the maxillary sinus (MS) has been removed to expose the cavity of MS. Roots of the maxillary teeth (MIT) projecting into the floor of the sinus (marked *) can be seen

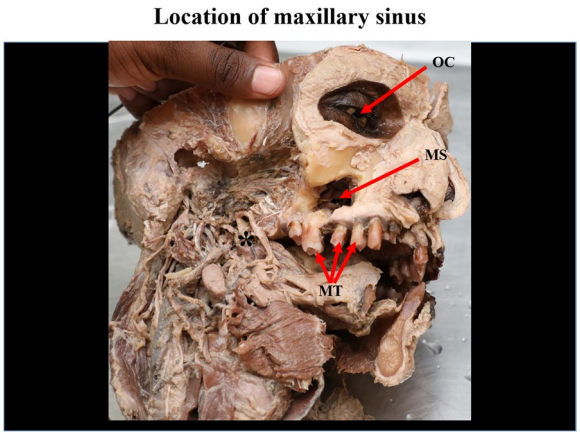

Fig. 5 Dissection of the maxillary sinus (MS). The anterior wall of the MS has been removed to expose the cavity of MS. Maxillary teeth (MIT) along the floor of the sinus and orbital cavity (OC) related to the roof of the MS can also be seen

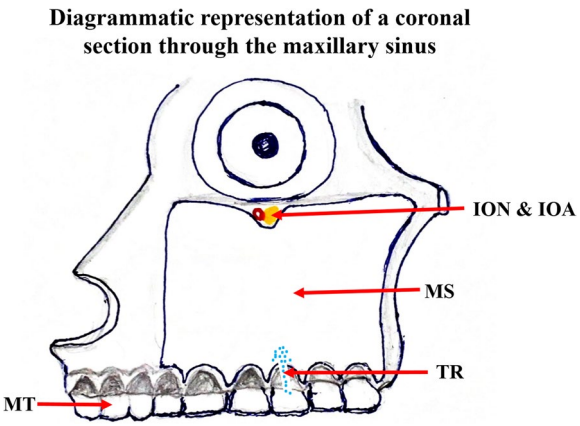

Fig. 4 Diagrammatic representation of a coronal section through the maxillary sinus showing its anatomical relations. A maxillary tooth root (TR) has been shown representatively and a possible route of entry of foreign material into the sinus from the root has been indicated. ION infraorbital nerve, *IOA* infraorbital artery, *MS* maxillary air sinus, *MT* maxillary teeth

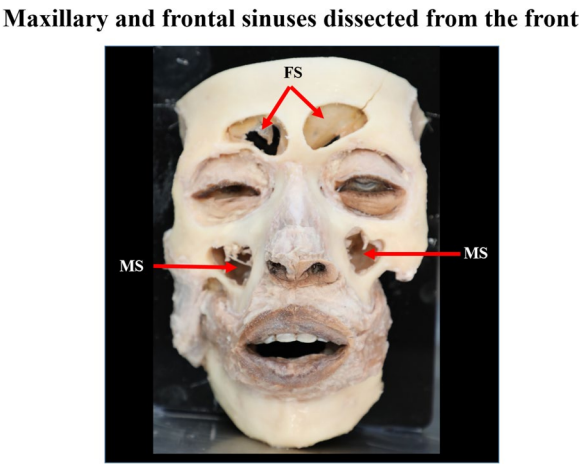

Fig. 6 Dissection of the maxillary sinus (MS) and frontal sinus (FS) from the front

tomography (CT) studies have shown that the average thickness of the gap separating upper molar teeth and antral floor is 1.97 mm [9]. In about 40% of cases, the 1st and 2nd molar roots possess an intimate association with the antral floor which they pierce in 2.2% and 2.0% of cases, respectively [10]. Sometimes, as a result of extensive pneumatization, 3rd molar, premolar, and canine teeth may also get exposed to the MS [7]. This can create a risk to the dental neurovascular bundle at the time of MS curettage. When posterior teeth are lost as a result of the reduction of their function, antrum may extend into the alveolar bone, rarely into the alveolar ridge [11] (Figs. 4, 5, 6, and 7).

Development of the maxillary sinus

Embryologically, MS is the first paranasal air sinus to develop during fetal life. It appears during the 10th week of intrauterine life as mere mucosal invaginations at the deeper cranial tip of the ethmoidal infundibulum into the adjacent mesoderm [12]. Such projections unite in the eleventh week of embryonic life to form one space indicating primitive MS [12]. The initial configuration of the sinus is somewhat oviform and is characterized by smooth walls [12]. From its initial oval shape, the sinus grows rapidly in 2 phases during the 4th to 5th month and later during the 6th to 7th month. Osteogenesis of its wall starts in the 4th month of fetal life, and at birth,

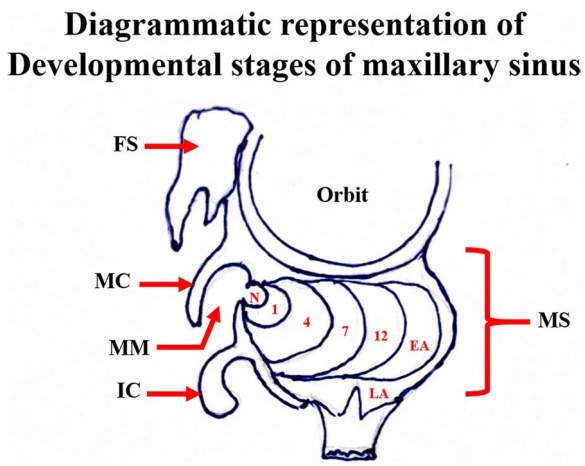

Fig. 7 Diagrammatic representation of various developmental stages of maxillary sinus after birth. N, size of MS in the newborn baby; 1, size of MS at the 1st year, 4, size of MS at the 4th year; 7, size of MS at the 7th year; 12, size of MS at the 12th year; EA, size of MS at early adulthood; LA, size of MS at late adulthood; FS, frontal air sinus (adult size); MC, middle nasal concha; MM, middle meatus; IC, inferior nasal concha; MS, maxillary air sinus

MS is rudimentary and measures about 10 mm × 3 mm × 4mm; it continues to grow slowly until 7 years of age and enlarges appreciably during the eruption of permanent teeth and after puberty markedly altering the size and shape of the face. It reaches its full size after the eruption of all the permanent teeth. In adults, it measures about 40 mm × 26 mm × 28 mm with 15 mL aggregate capacity [7].

Functions of the maxillary sinus

Maxillary sinus increases moisture content and temperature of inspired air, helps to regulate pressure inside the nasal cavity, enhances the surface area of the olfactory epithelium, reduces the weight of the skull to maintain a proper head balance, adds resonance to the voice, acts as a shock absorber to the head, and assists in the facial growth [7]. It may probably allow the enlargement of the local mass of the skull while minimizing a corresponding increase in bony mass. Such growth-related changes serve to strengthen the alveolar process of the maxilla when secondary dentition erupts. Proper drainage of MS depends on the patency of the maxillary ostium to the nasal cavity, its ciliary action, and the standard of secretions by the mucous and serous glands [7]. The overall well-being of the nose and sinuses is dependent primarily on effective mucociliary clearance which is considered as a primary defense mechanism of the respiratory tract to protect against pollutants, allergens, and pathogens [13]. The maxillary sinus is one of the anterior sinuses and any blockage in its osteomeatal unit results in anterior sinus disease [13].

Septa in the maxillary sinus

Septa in the MS are the bony processes that develop in various manners, and they are believed to challenge various surgical procedures involving the maxillary sinus [14]. One of the most common surgical complications is perforation of the Schneiderian membrane, which is believed to be due to the presence of maxillary sinus septa [15]. Augmentation of the maxillary sinus is a surgical procedure used to increase the lost height of the ridge in the posterior maxilla. During such procedures, the presence of septa in the MS may severely impact the outcome [16]. Many CT studies have reported the presence of septa within the MS in 16 to 58% of cases. However, complete partition is rare ranging from 1.0 to 2.5% [6]. There are congenital primary septa, formed during maxillary development, and are above the teeth [17]. A study conducted among the Lebanese population revealed at least one septum in the MS in about 36.27% of cases. Anteroposteriorly oriented septa were found in a greater number of cases, and most of them were in the lower part of the sinus [14]. Al-Zahrani et al. have discovered a significant positive association between the age of an individual and the presence and number of septa in the MS. They have also reported that the occurrence of septa in the MS is significantly more in males when compared to females [18]. A study among the Indian population has reported that MS septa are more frequently in the bucco-palatal direction and on the floor of the sinus and are commonly seen in the region of molars [16]. Jung et al. have proposed a safe floating septum technique for managing such palatally located septum during sinus lifting procedures [19].

Lining of the maxillary sinus

There is no periosteum forming the inner lining of MS. It is lined solely by respiratory epithelium with mucous-secreting goblet cells. The epithelium shows increased ciliary density near the maxillary ostium [20]. Lathiya et al. have observed that the mean thickness of mucosa of MS in healthy people is significantly greater than that of the periodontal bone disease group. They have also observed an association between periodontal bone loss and the thickening of the Schneiderian membrane at the floor of the sinus [21]. Since the opening of MS is more commonly situated in the upper part of the base of the sinus, mucous drainage depends principally on the mucociliary escalator with the cilia beating towards the ostium [4]. The spiral ciliary movement towards the ostia directs the mucous flow secreted from glands with any contaminants to the cavity of the nose for elimination. A case of absence of a primary or accessory maxillary ostium resulting in painful "recurrent acute sinusitis" has

also been reported [22]. A scanning electron microscopy study showed the presence of diplococci-like and streptococci-like bacterial colonies in the MS under normal homeostatic body conditions. The bacteria were found in single microcolonies of the biofilm on the border of the mucous covering the ciliary epithelium of the sinus [23].

Blood supply of the maxillary sinus

Arterial supply to the MS is by the radicals of maxillary and facial arteries and is supplied by endosseous and periosteal vessels [24]. The posterior superior dental or the infraorbital artery (buccally) and the palatine artery (palatally) supply the sinus membrane that provides the periosteal supply [24]. There is 100% intraosseous anastomosis and 90% extraosseous anastomosis in the anterior and lateral walls of the maxillary sinus between the branches of the posterior superior alveolar artery and the infraorbital artery. The posterior superior alveolar artery was divided into a gingival and a dental branch. The gingival branch is anastomosed with the terminal extraosseous branch of the extraosseous anastomosis and the dental branch with the intraosseous branch of the intraosseous anastomosis. Venous drainage is by the facial vein, the sphenopalatine vein, and the pterygoid venous plexus. Some veins drain upward through ethmoidal and frontal sinuses into the cavernous sinus. The spread of MS infection via this route can result in serious complications [24].

Nerve supply of the maxillary sinus

Sensory innervations to MS are provided by branches of the maxillary nerve and greater palatine nerve (GPN). Its posterior and middle superior alveolar branches supply the posterior sinus wall, while the anterior sinus wall is innervated by the anterior superior alveolar nerve [24]. These branches pass through the sinus wall and innervate the related teeth [25]. This can pose difficulty in differentiating pain of dental origin from that of sinus origin. An endodontic surgical approach through the buccal route, involving the sinus, does not generally produce bleeding problems, but it can cause nerve damage and may induce paresthesia [25]. The area of the MS opening is innervated by GPN and the infundibular region by the anterior ethmoidal nerve. Preganglionic secretomotor fibers to sinus mucosa pass through the sensory root of the 7th cranial nerve to synapse in the sphenopalatine ganglion from where postganglionic fibers proceed to the sinus mucosa with sensory trigeminal fibers [5].

Age changes in the maxillary sinus

At birth, the maxillary sinus is less than 7 mm in anteroposterior width, less than 4 mm in height, and less than 2.7 mm in transverse width [5]. Development of sinus height depends on the pressure against the orbit wall from the eyeball, traction on the lower part of the maxilla by the pull of facial muscles, and the eruption of permanent dentition [6]. MS grows very rapidly from 1 year to 8 years of age [5]. Traction on maxillary bones by facial muscles continues till three years of age [6]. Inferolateral sloping sinus roof in childhood takes a more horizontal position in adults due to the progression of pneumatization [5]. The sinus floor is below the level of the inferior nasal concha (INC) at the end of the second year of life. It lies at the level of INC at 7 years of age and at the level of the nasal floor at 9 years of age. In some cases, the floor of the sinus forms a palatine recess by its extension into the hard palate. A study has revealed that the volume of MS decreases as the age of the individual increases. They have also reported that the volume of the sinus in males in the age group of 18–24 years was higher than that in females [25].

Primary dentition has no impact on MS because about 1.5- to 2-mm-thick layer of bone separates the follicles of primary dentition from the sinus floor. The volume of adult MS ranges from 5 to 22 ml size with a mean volume of 12.5 ml, and the mean length, width, and height are 27.96 mm, 19.57 mm, and 25.33 mm, respectively [26]. It is also reported that there is no significant difference in the volume of MS between the right and left sides, and sinus volume in males is higher than that of females [25].

Maxillary sinus in radiographs

Many radiological imaging techniques such as computed tomography (CT), magnetic resonance imaging (MRI), and dentascan (cone beam CT) can be used to measure the maxillary sinus volume. In radiographs, usually MS appears as if the molar teeth roots are penetrating the sinus floor and protruding into the antrum. But in reality, MS is very close to molar roots, and it extends between the molar roots. During periapical surgery, for the prediction of maxillary sinus perforation, dentascan or cone beam CT (CBCT) is recommended instead of periapical radiographs [27]. The correlation of sinus mucosal thickening with carious of upper posterior teeth and periodontal disease has been shown by CBCT study analysis [28]. For the diagnostic confirmation of maxillary sinusitis, radiographs, and computed tomography are mandatory [29], but computed tomography is the best choice for sinusitis evaluation.

Ultrasound examinations are useful for evaluating mucosal thickening and sinusal fluids, although it is operator-dependent and sometimes do not clarify a diagnosis. One of the important signs of the sinus infection is nasal discharge. A detailed association of the sinus floor with the dental roots could be obtained by panoramic radiography which also helps in the diagnosis of the size

of periapical lesions and cysts as well as radio-dense foreign bodies, local swelling, and opaque areas of the sinus membrane [30]. However, some believe that the cone beam is highly useful for the analysis of anatomical structures during any sinus or dental surgery [31]. Commonly, unilateral sinusitis is observed in patients suffering from odontogenic sinusitis when subjected to radiographical examination. More than 70% of maxillofacial CT scans depicting unilateral maxillary sinusitis may be due to odontogenic causes [32].

Significance of maxillary sinus in endodontic treatment

Maxillary posterior teeth are in close approximation with the maxillary sinus floor which is an important anatomical relationship during the endodontic treatment of upper posterior teeth [33]. Iatrogenic perforation and the spread of periapical infection can also lead to maxillary sinusitis. The thickness of the alveolar cortical plate of bone and roots of maxillary molars affect the spread of odontogenic infection which plays a major role in deciding the treatment plan [34]. A case of formation of orbital abscess has been reported due to rapid exacerbation of periapical inflammation of the upper 1st molar. From the periapical lesions of involved teeth, microorganisms and their toxins may infiltrate the maxillary sinus through porous maxillary bone. Therefore, the periodontal lesions and maxillary sinus mucosal thickening exhibit a positive correlation between them [35, 36]. Eberhardt et al. have observed a close relationship between the mesiobuccal roots of the maxillary second molar and the MS floor [9]. A study of Kilic et al. has shown that the distobuccal root of the upper 2nd molar is close to the MS floor [10]. Studies showed that the buccal root of the upper molars is close to the buccal cortical plate [37, 38].

Maxillary sinusitis (MSS)

Maxillary sinusitis can be caused by many entities and bacterial or fungicidal sinusitis which usually results from dental problems and may result in many different symptoms like nasal obstruction, nasal discharge/purulence, smell disorders, facial pain/pressure, dental pain, halitosis, and headache. Epidemiologic surveys indicate that odontogenic infections cause about 10 to 12% of maxillary sinusitis, and solving dental problems usually leads to the cure of sinusopathy [38]. Investigation on pulp testing and periodontal evaluation is essential to differentiate a sinus infection from an odontogenic infection.

Sometimes dental cysts, tumors, and inflammatory lesions may extend into the MS [39]. Foreign bodies during dental procedures can enter the MS leading to sinusitis. These foreign bodies can be tooth root filling material during endodontic treatment and rarely burs and bone grafts of oral surgery [40].

MSS affects about 35 million people in North America annually, resulting in an estimated 2 to 3 billion dollars in health care costs annually and approximately 150 million for patients to buy products prescribed or for the treatment of the disease. Despite this, it is very commonly wrongly diagnosed and misunderstood disease in clinical practice. A dentist is expected to have a very profound knowledge of the various diseases of the MS and their clinical features. Chronic orofacial pain or atypical odontalgia may be caused by MSS and would require an appropriate medical referral [41–43]. Incidence of sinusitis of an odontogenic origin is reported in about 10% of cases [44]. Ideally, odontogenic maxillary sinusitis patients should be referred to orofacial surgeons. Some of the common causes of odontogenic MSS are periodontal disease, periapical infection, perforation of the floor of the MS and its mucosa during tooth extraction, and displacement of roots of maxillary teeth or foreign objects into the maxillary sinus during a dental procedure. MSS may also result from odontogenic cysts and tumors and certain metabolic diseases affecting the maxilla. The proximity of the root apices of the posterior maxillary teeth to the maxillary sinus floor may lead to symptoms of dental diseases [45]. Maxillary sinusitis results in sensitivity of upper molars on percussions. However, when pulpal testing is done, if there is no corresponding pulpal involvement, these teeth will show a negative response. In addition, in cases of sinusitis, pain varies with changes in the head position of the individual [45].

From the above discussion, it is evident that any dentist must be very careful about odontogenic sinusitis, producing symptoms of both dental and sinus diseases. When infections are localized in the lower part of the antrum, sinus infection may be asymptomatic. Potential for considerable pain and discomfort may be there after the blockage of its ostium obstructing the free flow of fluid and gas leading to increased pressure within the sinus. When there is MSS, symptoms such as unilateral facial paresthesia, anesthesia, and midface fullness, altered vision, double vision, altered positioning of the eyeball, epiphora, epistaxis, allergic rhinitis, and postnasal drip may be observed in the patient. Generally, maxillary referred pain is felt in the region of the face, eye, nose, and oral cavity. Further, in addition to the tooth pain and sensitivity in the oral cavity, gingival and mucosal anesthesia or paresthesia, a feeling of alveolar expansion or malocclusion, may also be experienced by the patient.

Odontogenic maxillary sinus diseases

According to an earlier report, 15–75% of sinusitis cases have a dental reason behind them [3]. "Endoantral syndrome" [EAS] is a clinical condition where a pulpal disease spreads into the sinus [46]. The characteristics of

EAS are the disease of the pulp of the tooth that penetrates the MS floor; radiolucencies of periapical parts of pulpally diseased teeth, radiographic disappearance of lamina dura over the pulpally diseased tooth, and a faintly radiopaque mass bulging into the maxillary sinus above the affected tooth apex and radiopacity of the surrounding sinus space [46]. The variable presentation of EAS can create diagnostic and therapeutic difficulties, because all five features are not always evident, and the presentation of EAS can vary [47]. The maxillary sinus of a patient affected by a disease of odontogenic origin may be very tender to tapping or palpation [47]. The teeth affected by the sinusitis show sensitivity to palpation but respond normally to routine pulp sensitivity tests. Pain radiates to all the posterior teeth of the affected quadrant, which becomes tender to percussion. There may be blockage of the nasal passage of the affected side. Nasal discharge is an important sign of sinus infection. Fever is not commonly seen in severe acute or subacute sinusitis. However, very high temperatures and some degree of sickness can be observed in severe fulminating sinusitis cases. During the percussion test, if only one tooth shows tenderness, that tooth itself could be the source of trouble and sinusitis may be excluded [48]. Radman suggested that a cotton swab saturated with 5% lidocaine can be placed in the nostril of the affected side as a differential diagnostic test. He suggested that if the pain is modified or eliminated within 1 to 2 min, the diagnosis of maxillary sinusitis can be confirmed [49].

The MS floor is in close relationship with the upper molar and premolar roots, specifically the 2nd premolar, 1st first, and 2nd permanent molars. Very rarely, the floor of the MS can extend up to the region of the canine root [30]. Projection of the sinus floor between the adjacent teeth or between the individual roots of teeth forms recesses. As age advances, alveolar bone thins out, especially around the root apices. As a result of this, root tips extending into the sinus are covered only by a very thin bony lamina and a sinus membrane. The sinus floor is deepest in the molar root region. However, increased pneumatization of the sinus can lead to exposure of the 3rd molar, premolars, and canine teeth into it [7]. Studies have shown that the frequency of close proximity (0.5 mm or less) of roots of posterior maxillary teeth to the sinus floor is second molars (45.5%), first molars (30.4%), second premolars (19.7%), and first premolars (0%). Two radiographic studies classified the relationship between the roots of the maxillary teeth and the inferior wall of MS [50]. In a study, Kwak et al. used the denta scan reformatted cross-sectioned images and suggested 5 vertical relationships [50]. Root over-filled paste may protrude into the alveolar recess of the sinus floor, leading to chronic maxillary sinusitis [50]. Partial or complete blockage of nasal passage on the affected side may occur [30]. Most cases of EAS will respond satisfactorily to nonsurgical root canal treatment.

The presence of fungal balls in the MS is considered as a subtype of non-invasive fungal infection which is a common variety of unilateral maxillary sinusitis. Occasionally, MS fungus ball has been reported to be caused by root-filling material [51]. Stammberger et al. have reported that in more than 50% of cases, the typical radiopaque appearance of MS concretions seen as sinus fungus ball consisted of endodontic materials that iatrogenically entered the sinus [52]. Eighty-five percent of the 85 reported cases of MS fungus ball were related to the extrusion of root canal sealer in upper teeth [53]. Pathogenesis of sinus fungus ball, because of zinc oxide–eugenol containing root filling materials has been explained by Stammberger et al. This "dental" hypothesis suggests that sinus fungus ball is generated by overfilling of the root canal, with the zinc oxide containing root filling material which is inducing the infection [51]. It is said that about 0.8- to 7-mm-thick bony layer separates the sinus from teeth apices of lateral maxillary segments [9]. Following the apicectomy of maxillary premolar and molar teeth, cases of MS perforations have been reported [53]. Ericson et al. have observed oro-antral communications in 40% of molars, 26.1% of second premolars, 8.8% of first premolars, and 7.7% of canines [54]. Results of operation in the oroantral communication group, with ruptured sinus mucosa and intact mucosa did not differ [55]. The important thing to remember here is, in these cases, there is only limited involvement of the maxillary mucosa, as compared with extensive mucosal stripping of the maxillary sinuses, as seen in the Caldwell-Luc sinus operations, which may be followed by extensive fibrosis and occasionally, massive osteitis.

All the posterior teeth have referred pain and usually become tender to percussion. Partial or complete blockage of nasal passage and nasal discharge are significant signs of antrum infection. The existence of prominent sinusitis is improbable in the absence of a discharge. Thickened sinus mucosa, presence of air-fluid levels, or complete opacification of the sinus are the changes observed in radiographs of sinusitis patients [56]. There is a wide degree of variations in the odontogenic pain accompanied by regional swelling and cellulitis. The odontogenic source of the disease can also be suspected by routine pulp tests, where normal responses eliminate dental causes in a diagnosis of sinusitis. There are also reports of tooth infections causing pathological destruction of both periapical and adjacent sinus tissues [2]. It has been reported that 4.6 to 47% of all sinusitis cases are of dental origin [57]. In cases where the apex of a pulpally infected tooth is closer to the MS floor, the

chances of greater impact on sinus tissues are higher [58]. Incidences of the spread of periapical infection along blood vessels and lymphatics through the bone marrow have been reported. Sinus can be infected faster and can undergo more destruction by a rapidly spreading acute infectious disease of the pulp. Swift spreading of dental infections to the MS followed by periorbital cellulitis, blindness, and deadly conditions like cavernous sinus thrombosis have been reported in patients suffering from EAS [59]. Other characteristic features of EAS are (i) proximity of pulpally diseased tooth to the MS floor, (ii) periapical radiolucencies on pulpally involved teeth, (iii) radiographic absence of the lamina dura sinus separating the floor of MS from the pulpally involved tooth, (iv) a slightly radiopaque mass projecting into the cavity of the sinus over the affected tooth apex without any connection to the tooth or to the lamina dura of the tooth socket (this represents a localized swelling and thickening of the sinus mucosa), and (v) varying degrees of radiopacity of the sinuses around the MS in comparison with the that of the opposite side [47]. The absence of all the above features in EAS can lead to diagnostic and therapeutic problems. About 80% of teeth with periapical osteitis present hyperplasia of the mucosal sinus [60]. Mucosal swelling, cyst formation, hypertrophy, and mucosal granulation tissue can be observed in MS in such cases. Before, it was believed that in cases of such sinus mucosal changes, and the teeth involved should be extracted. This idea was supported by the study of Ericson and Welander who observed the inflammation of the lateral sinus wall due to periapical osteitis and their disappearance after the affected teeth extraction [60].

Local mucosal hyperplasia of the MS due to dental infection could be eliminated by conservative root canal treatment [61]. After treating the 1st and 2nd premolar periodontal-endodontic lesions, Selden and August managed to retain teeth and achieve resolution of sinusitis [2]. Studies indicate that most of the EAS cases respond well with satisfactory outcomes to root canal treatment. It has been hypothesized that increased incidences of iatrogenic causes for sinusitis may be due to the increased number of dental surgeries over the last few years [62]. Normally, the patients do not complain of tooth pain in odontogenic sinusitis cases. In other words, the presence of tooth pain in the absence of other nasal symptoms is not specific to sinusitis [63]. According to an estimation, 10% of chronic maxillary sinusitis cases are odontogenic in origin, but this can go up to 75% in patients with unilateral maxillary diseases [64].

Odontogenic sinusitis is most common among the age groups of 40–60 years, and it is slightly more common in females [65]. Among these, about 50% of patients had a history of preceding tooth problems, but only one third complained of tooth pain [66]. There are reports of misplaced foreign bodies causing odontogenic sinusitis [64]. Dental caries can lead to pulpitis, apical infection, and chronic periodontitis resulting in chronic tooth socket infection. These conditions may also lead to inflammation which can disrupt the Schneiderian membrane resulting in sinusitis. Maxilla bone trauma, odontogenic cysts, and neoplasms can also lead to sinusitis [67]. A recent study of 674 patients of odontogenic sinusitis showed that an iatrogenic etiology accounted for 65.7% of cases, apical periodontal pathology accounted for 25.1% of cases, and marginal periodontitis accounted for 8.3% of cases [65, 66]. A study showed a radiopaque foreign body in 94% of the cases out of 85 cases of aspergillosis of the maxillary sinus. Of this group, 85% of cases were due to endodontic dental paste [53]. Multi-rooted teeth are considered as the most common source of odontogenic sinusitis, and it can be noted here that periapical radiography has some limitations in the evaluation of multi-rooted teeth. In cases of odontogenic sinusitis, the involvement of the ostiomeatal unit may result in an extension of sinusitis into adjacent paranasal sinuses, which may amount to be about 27 to 60% of extra maxillary extension [67]. In such cases, about 20% of odontogenic sinusitis patients may show bilateral involvement [68]. Therefore, clinicians should invariably suspect an odontogenic cause of maxillary sinusitis. As the MS floor is closest to the mesiobuccal root of the upper 2nd molar tooth, there is an increased risk of disruption of the Schneiderian membrane. Despite this, the palatal root of the upper 1st molar is most associated with perforation of the sinus floor. This may be due to the earlier eruption of the upper first molar than the 2nd molar, which could result in greater susceptibility to various dental lesions over time [66]. Further endodontic root canal treatment, apicectomy, or tooth extraction may be involved in the management of odontogenic MS disease [66]. It is suggested that successful management of odontogenic sinusitis may be achieved by a combination of medical treatment involving dental surgery and/or endoscopic sinus surgery [66].

Ericson et al. have performed periapical surgery in 159 maxillary premolar and molar apices of which 18% of cases were protruding into the sinus by creating an opening in the wall or floor of the maxillary sinus [54]. They reported that during operative procedures, the foreign objects introduced into the sinus may cause thickening of the sinus lining with symptoms of sinusitis [54]. Jerome and Hill recommended the use of gauze to block the MS to prevent penetration of foreign bodies [68]. Watzek et al. after 146 apicectomies reported that there is no statistically significant difference in sinus mucosal healing between the patients with and without intraoperative membrane perforations [24]. Advanced devices

like surgical microscopes and endoscopes can be used to enhance magnification and visibility to identify perforations, isthmuses, micro-fractures, and accessory canals to check the marginal adaptation of root filling during dental procedures [69, 70].

During osteotomy of periapical surgery of the first and second maxillary molars, accidental perforation of the MS floor has been described due to the closeness of the roots of these teeth to the sinus floor [25]. Garcia et al. created a window through the lateral wall of MS with ultrasonics to permit the apical surgery through MS [70]. They reported that when compared to a conventional technique, this technique helps in reducing the risk of perforating the sinus lining, improves visibility, gives better accessibility to surgical areas, and also gives more conservative and required bone cuts [71]. Chronic periapical disease-causing maxillary sinusitis can be treated using different options which include conventional endodontic retreatment like drainage of the maxillary sinus, trans-antral periapical surgery, Caldwell-Luc procedure [25], root-end resection, extra-oral root-end filling, and intentional replantation of the tooth [72]. Trans-antral periapical surgery helps in maxillary sinus drainage, in filling the canals with root end fillings, and also in the prevention of periapical lesions [72]. Starkey and Mortman have stressed on importance of a medical and dental collaboration when determining treatment for patients who present with maxillary sinusitis of odontogenic origin with effective usage of CBCT technique while evaluating the MS and its associated odontogenic conditions [73].

Conventional endodontic treatment involving maxillary sinus

During the normal endodontic treatment, procedural errors, instrumentation, and medicaments pass beyond the apical foramen leading to periapical tissue inflammation that can involve sinus mucosa [74]. Extrusion of debris from apical foramen, overfilling of the canals, and slipping of antigens from inflamed pulp or infected root canal can result in inflammation of periapical tissue extending onto MS. It can lead to the formation of granuloma or cysts. Excess sodium hypochlorite irrigation extending beyond the apical foramen into the periapical tissues can elicit inflammatory reactions and can be toxic to the cells. It can result in damage to MS leading to sinusitis when the affected tooth is very close to its floor. Extrusion of intracanal medicaments can damage the periapical tissue and lead to sinusitis. Calcium hydroxide paste used for dressing between appointments has an immediate degenerative effect on tissues and results in sinusitis. Sealer or solid materials such as gutta percha or silver cones may invade the sinus during obturation, leading to inflammation of the sinus which persists until the removal of foreign material [75].

There have been very few reports on the extrusion of sealer into the MS. A case of N2 sealer extrusion into the MS was reported by Orlay [75]. There are reports of maxillary sinus aspergillosis caused by root-filling materials [76]. Kopp et al. and Stammberger et al. reported that more than 50% of diagnosed sinus aspergillosis cases were due to iatrogenically placed endodontic materials [51, 52]. If sodium hypochlorite is extruded, it may result in acute sinusitis, bleeding into interstitial tissues leading to ecchymosis [31]. Side vented needle may reduce the extrusion of irrigants. An earlier study reports that about 85% of cases of aspergillosis of the MS are due to over-filling of root canal sealer in maxillary teeth [52]. Two such cases of sinus aspergillomas due to overfilled root canal material in maxillary first molars have been reported also by Khongkhunthian and Reichart [77]. It has been noted that the silver cones pushed beyond the apex of the tooth are highly toxic to the periapical tissue [78]. A step-back technique with lateral condensation has been shown to minimize the extrusion of gutta purcha into the sinus. A root with wide open apices provides risks when obturation is done with the thermo-plasticized gutta purcha technique. During such a procedure, accidental extrusion of sealers may result in aspergillosis [78].

Endodontic surgery

Endodontic surgery of maxillary molars is a challenging task due to the proximity of the root apex of the premolar and molar tooth to the sinus floor [31]. The floor of the MS which is exposed to pathological conditions warrants many surgical procedures. Endo-antral connection may not be visualized radiographically [68]. A study of 159 cases of premolar and molar endodontic surgery revealed 18% of cases of perforations [31, 79]. After root resection, there is a probability of invasion of foreign bodies into the MS leading to the thickening of mucosa and sinusitis. It is cumbersome to remove the invaded root apex dentinal shavings and filling materials from the sinus due to limited accessibility and iatrogenic trauma and the surgeons need to carry out the procedure very cautiously [68]. Mostly buccal root of the upper posterior teeth is less complicated. It is advised to cut the bone and approach the apex from the front and below [80]. According to some, it is better to grind the apical part of the root instead of root resection as the latter may displace the apex into the sinus [80]. In contrast, Jerome and Hill have suggested that the sectioning of the root apex as a single piece is much safer than grinding the apex to the required level as the latter may generate more debris [68]. According to them, a hole should be made in the root apex and be secured with a suture before resection,

and this makes it easier to remove the root tip. In case of accidental invasion of the root apex into the sinus, a radiograph is mandatory. Normally, sinus perforation heals by itself, and in a few cases, healing may not occur. Sometimes, the Caldwell-Luc procedure might also cause root fractures, and thus, it is important to have follow-up sessions with such patients before continuing with future endodontic treatment [81, 82]. Broken instruments in the MS during the endodontic procedure can be removed by the Caldwell-Luc procedure.

The roles of nasal endoscopy in the diagnosis and treatment of maxillary sinusitis

Nasal endoscopy is considered as a very handy diagnostic and treatment tool which helps in a detailed and complete evaluation of intranasal normal and pathological features. When compared to observations made with the naked eye using headlight, etc., endoscopic observation provides the surgeon with a great capacity to have a view of the nasal cavity and associated areas at various angles and magnifications with good illumination. This will help in the identification of various anatomical structures precisely during preoperative, intraoperative, and postoperative assessments. In addition, the photographs captured during the process can be used for academic, research, and documentation purposes [82]. Nasal endoscopy has also been extensively used in the diagnosis and the interventions associated with the ailments of the maxillary sinus. It has been reported that the successful management of odontogenic maxillary sinusitis involves a combination of dental surgery and/or endoscopic sinus surgery. Though earlier it was believed that dental surgery is the primary treatment modality for odontogenic maxillary sinusitis, recent reports suggest that endoscopic sinus surgery alone may be an equally effective approach to treatment. While treating maxillary sinusitis, culture-directed therapy is preferred against the empiric antibiotic therapy to avoid the failure of treatment due to antibiotic resistance. However, the collection of culture through traditional antral puncture has poor patient and clinician acceptance. To overcome this issue, endoscopically directed aspiration of culture is being recommended over the antral puncture which will help in organism-specific antibiotic therapy for sinusitis [83]. In addition to its extensive usage in cases of maxillary sinusitis, the endoscope is being used to introduce full-strength intravenous antibiotics, steroids, or antifungal agents by inserting the cannula into the maxillary sinus. Post-surgical procedures such as lysing scar tissue or removing bone chips which remain after the surgery or deflating polyps which occur during the immediate postoperative period [84]. Strek et al. Have reported that radical resection of paranasal sinus osteomas be safely performed using endoscopic techniques with very good cosmetic effects [84].

Conclusion

It is well known that among all the sinuses, an understanding of the fundamentals of anatomy, functions, development, radiology, and various applied aspects of the maxillary sinus and its relationship with the teeth of the upper jaw is essential for clinicians, especially dentists. This compilation of detailed information on axillary sinus will help the clinicians/dentists working in this field.

Abbreviations

MS Maxillary sinus
CT Computed tomography
CBCT Cone beam computed tomography

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