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Review

Imaging of odontogenic sinusitis

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The aetiological relationship between dental disease and procedures and mucosal disease within the maxillary sinus has received extensive attention in the recent otolaryngological and dental literature. In contrast, the concept of an odontogenic cause for sinusitis is not well appreciated by radiologists. Review of the maxillary dentition, the alveolar process, and the relationship of the tooth roots to the floor of the maxillary sinus should be an integral part of interpretation of imaging of the paranasal sinuses. The pathogenesis, clinical presentation, and imaging features of rhinogenic and odontogenic sinusitis are discussed and compared. Clinical definitions of rhinosinusitis are explained and the huge impact on healthcare of this disease is briefly discussed. Periapical inflammatory lesions, post-extraction oroantral communication, and procedures used to augment the alveolar process prior to placement of dental implants are the commonest causes of odontogenic sinusitis. Current estimates are that an odontogenic cause for maxillary sinusitis is present in 25–40% of cases. The incidence of odontogenic sinusitis is rising, extension outside the maxillary sinus is common, and the diagnosis is often delayed, resulting in inappropriate and failed treatment. Differentiation of rhinological and odontogenic causes of sinusitis is usually difficult on clinical grounds and imaging plays a key role in the distinction.

Introduction

Chronic rhinosinusitis (CRS) is a common, multifactorial inflammatory disorder, which causes extensive morbidity and enormous healthcare costs. There is increasing recognition in the otolaryngological and dental literature of the contribution of maxillary dental disease and surgical procedures to the aetiology of mucosal thickening (MT) and sinusitis within the maxillary sinus. It is estimated that 25–40% of maxillary sinusitis is odontogenic in origin[1,2] and extensive opacification of a maxillary sinus on imaging is dental in aetiology in 75% of cases.[3] The incidence of odontogenic sinusitis (OS) is increasing in the UK and USA, due to dental neglect amongst those who cannot afford treatment,[4] but also to the significant increase in complex reconstructive dentistry, including maxillary bone grafts and implants, being performed in those who can.[5] Extension from the maxillary sinus to other anterior sinuses is common, being seen in 60–70% of cases. Bilateral involvement occurs less frequently and mimics CRS due to other causes.[6,7]

OS has received scant attention in the imaging literature covering CRS. There have been five articles written by radiologists describing the relationship between dental and maxillary sinus disease in the last 22 years.[8,9,11,23,25] Several articles in the otolaryngological literature mention the

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absence of comment on the maxillary dentition in sinonasal computed tomography (CT) reports and the poor performance of radiologists in diagnosing dental pathology and suggesting possible OS.[1,5,10,39,40] Two of these articles acknowledge that the absence of a thorough clinical examination by a dentist was a contributing factor to the failure of recognition of dental pathology, in addition to the imaging report; however, in the last 10 years, no major review article concerning the imaging of CRS, reporting sinonasal CT, or imaging anatomy of the sinuses mention the maxillary dentition, dental disease, or OS.[13,21,41,42]

Recognition of an odontogenic cause for sinusitis is vital to initiate the best treatment. The clinical setting is usually non-specific and dental pain is reported in only 29% of OS.[2] Dental (rather than respiratory) bacterial sepsis is due to a mixed flora, with anaerobes predominating. Different antibiotics are therefore required to treat OS in comparison to other forms of CRS. Surgical treatment of the dental cause should be undertaken, and sinus surgery is also frequently required.[4]

Intra-oral radiographs and especially dental panoramic tomography provide suboptimal assessment of the posterior maxillary teeth. The radiologist reporting CT of the paranasal sinuses should play a key role in diagnosing OS. For this to occur, the scan coverage and reporting checklist should always include the maxillary dentition and alveolar process. Unilateral opacification of a maxillary sinus on imaging is dental in origin unless proven otherwise.[7,8]

Materials and methods

Optimal reporting of sinonasal CT scans by radiologists requires an understanding of anatomy and physiology, including the maxillary dentition and alveolar process. The importance of mucociliary clearance and patent sinus drainage channels is fundamental to complete aeration of the sinuses and absence of mucosal disease. The intimate relationship of the posterior maxillary teeth to the maxillary sinus is reviewed.

Terminology used in radiology reports should correlate with that used by referring clinicians. Acute and chronic rhinosinusitis are defined according to current clinical guidelines and the aetiology is briefly discussed.

The relevant literature concerning OS and mucosal disease in the maxillary sinus related to dental disease and intervention from the year 2000 was reviewed. The vast majority of articles were in journals aligned to otolaryngology and dentistry, including dental and maxillofacial radiology. Two articles were located in the imaging literature and the only review article on this topic, from 1996,[11] was also reviewed.

Functional anatomy and physiology of the maxilla, maxillary sinus, and ostiomeatal unit

The principal functions of the sinonasal cavity are to filter, humidify, and warm inspired air in preparation for optimal gas exchange in the alveoli. Mucus produced by the lining of the respiratory mucosa acts as a “fly-trap” to capture inhaled viruses, bacteria, allergens, and other particles. This is propelled towards the sinus ostia by ciliary action: mucociliary clearance. The anterior ethmoid, maxillary, and frontal sinuses drain into the nasal cavity via the ostiomeatal unit (OMU; Fig 1) and the mucus is subsequently swallowed.[12,13] If exogenous irritants, including infective agents, are not dealt with by these protective mechanisms, they can cause nasal inflammation (rhinitis). Mucosal inflammation spreads to the anterior ethmoid air cells; mucosal swelling and impaired mucociliary clearance results in obstruction of the OMU and the contiguous frontal recess. Without treatment, maxillary and frontal sinusitis may result.

Each tooth consists of a crown, which is covered by enamel, and a root or roots covered by cementum: enamel is radiographically denser than cementum, allowing visualisation of the cemento-enamel (amelocemental) junction, which should normally lie within 1–2 mm of the crest of the alveolar ridge (Fig 2). The dentine, which makes up the bulk of the substance of both crown and roots, is of identical radiographic density to cementum and cannot be distinguished from it. The soft tissue of the pulp chamber within the crown is radiolucent, and contiguous with the root canal, which opens at an apical foramen at the apex of the root. The root is surrounded by a periodontal ligament allowing minimal movement of the tooth within its supporting alveolar bone: this is visible radiographically as a radiolucent periodontal ligament space, in turn surrounded by a thin layer of cortical bone visible as a linear density, the lamina dura. Several different systems are available for numbering the teeth. The most widely used is the International Standards Organisation (ISO) system (based on the International Dental Federation, FDI, system), and this is used in the figures in this article. Each tooth is identified by a two digit number, in which the first digit represents the quadrant (starting upper right, which is quadrant 1, and continuing clockwise from the observer's point of view, so that upper left is quadrant 2, lower left quadrant 3, and lower right quadrant 4). The second digit represents the tooth in that quadrant, numbering from the midline distally (1–8) and assuming a full complement of dentition. Thus, for example 25 (pronounced “two five”) is the upper left second premolar; 17 is the upper right second molar. This system has the merit that the second digit always means the same type of tooth, for example, a canine[3] or a third molar.[8] Deciduous (primary) teeth are labelled with the first digit as quadrants 5–8 (upper right, proceeding clockwise) rather than 1–4; the second digit is again numbered from the midline distally.[1–5] Other systems to be aware of are the Palmer notation (still widely used, especially in the UK) and the Universal system (which is mainly used in the United States).

The roots of the maxillary teeth are embedded within the alveolar process of the maxilla, which forms the inferior margin, or floor, of the maxillary sinus. The height of the alveolar process reduces from mesial to distal (anterior to posterior) in the premolar and first molar region. Depending on the length and degree of divergence of the roots of the molars and the degree of pneumatisation of the

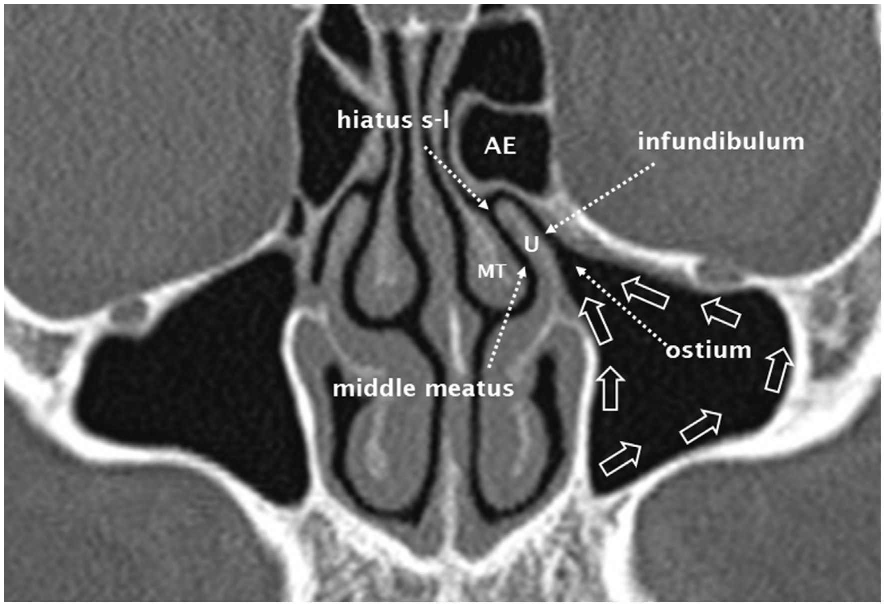

Figure 1 The OMU or ostiomeatal complex (OMC). Coronal reconstruction from multidetector CT of the sinuses. The frontal, anterior ethmoid, and maxillary sinuses drain into the OMU, which is a functional unit consisting of the maxillary sinus ostium, the ethmoid infundibulum, and the hiatus semilunaris (s-l), as well as the middle meatus and frontal recess (not shown). The terms OMU and OMC are used interchangeably. Mucociliary clearance (open arrows) propels mucus towards the ostium. The adjacent uncinate process (U), middle turbinate (MT), and largest anterior ethmoid (AE) air cell are indicated.

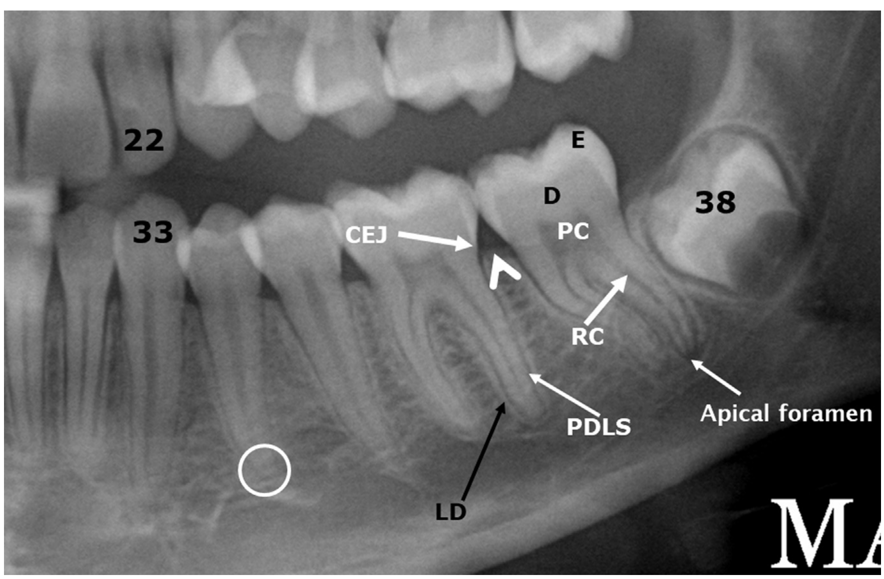

Figure 2 Radiographic dental anatomy and dental numbering. Cropped view from a dental panoramic tomograph showing the teeth in the left lower quadrant. Enamel (E) is very dense and covers the crown. Dentine (D) is less dense and can be distinguished from enamel, but not from the thin layer of cementum covering the root: the cemento-enamel junction (CEJ) can be inferred from the margin of the enamel and is normally within 1–2 mm of the alveolar ridge crest (arrowhead). The pulp chamber (PC) contains the soft tissues in the centre of the crown and is contiguous with the root canal (RC) within the root, which opens at the apical foramen at the apex (circle) of the root: infection commonly reaches the periapical region via necrotic pulp and the root canal and apical foramen. The radiolucent periodontal ligament space (PDLS) separates the surface of the root from the dense radiopaque line of the lamina dura (LD). The crowns of the lower upper left lateral incisor[22] lower left canine,[33] and the unerupted lower left third molar[38] are numbered as examples of the ISO dental numbering system, described in the text.

maxillary sinus, there is a variable relationship[14] of the apices of the roots of the molars to the sinus floor (Fig 3). The thinnest bone usually overlies the apices of the first (53%) and second molars (38%) with an average thickness of 2 mm. If a tooth apex or other portion of the root projects into the sinus lumen, the mucosal lining of the maxillary

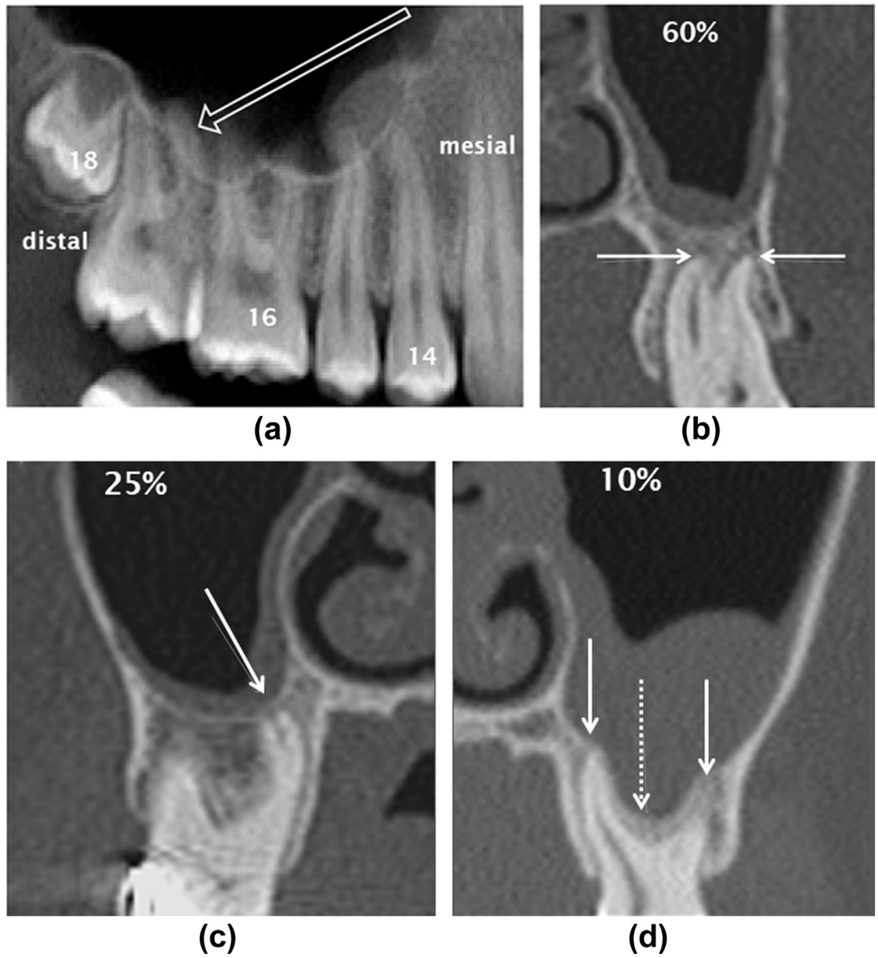

Figure 3 The relationship of the roots and apices of the posterior maxillary teeth to the floor of the maxillary sinus. (a) A cropped panoramic reconstruction from CBCT demonstrates reduction in height of the alveolar process from mesial to distal in the premolar and molar region of the right maxilla (open white arrow). (b,c,d) The variable relationship of the root apices of the first and second molars on radial reconstructions from CBCT. (c,d) In 35% of cases, the apices are intimately related to the floor of the maxillary sinus. (b) The roots apices are separate from the sinus floor: 60%. (c) The root apices abut the sinus floor: 25%. (d) The sinus floor descends between (dotted arrow) or around the apices and roots: 10%. Mild MT is present in (b) and (c) with moderate inferior MT in (d).

sinus (Schneiderian membrane) may be separated from that root by only the thin cortex of the lamina dura.[15,16]

Since the advent and frequent use of cone-beam (CB)CT imaging in dentistry, extremely high-resolution imaging (cubic voxels of length 0.1–0.2 mm) of the maxillary dento-alveolar process and maxillary sinus are commonplace. Numerous articles address the issue of what cut-off measurement should be used to distinguish between normal mucosa and pathological MT; 2 mm is most commonly used.[15]

Rhinosinusitis: definition and aetiology

Sinusitis of rhinogenic origin (originating in or transmitted by the nose) is termed rhinosinusitis. It represents contiguous inflammation of the respiratory mucosa of the nose and paranasal sinuses.[17] Acute viral rhinosinusitis (i.e., the common cold) is self-limiting, with complete resolution of symptoms within 10 days. The entity of acute post-viral rhinosinusitis describes worsening of symptoms after 5 days or persistence of symptoms after 10 days with resolution within 12 weeks. In 0.5–2% of cases, viral-induced mucosal oedema and decreased mucociliary function may be complicated by occlusion of the OMU and secondary bacterial infection.[18] The common pathogenic bacteria are aerobes of respiratory tract origin. Acute bacterial rhinosinusitis is suggested by three or more of the following symptoms: purulent nasal discharge, severe localised facial pain/toothache/focal sinus tenderness, high fever, elevated inflammatory markers, or “double sickening” (deterioration within 10 days after initial improvement). Imaging is indicated if complications of acute bacterial sinusitis develop; initially using CT, with magnetic resonance imaging (MRI) used if intracranial sepsis is suspected.

CRS is a clinical diagnosis made when two or more of the four key symptoms of nasal obstruction (congestion)—nasal discharge (rhinorrhoea)-facial pressure (or pain or fullness), and anosmia (or hyposmia) are present for at least 12 weeks. Supportive evidence is provided by findings at rhinoscopy (mucosal oedema, pus, polyps) and imaging (mucosal disease). It is of multifactorial aetiology; contributing factors include infection with bacteria and fungi, bacterial biofilms, allergens, smoking, pollution, abnormal host immunity, and obstructed sinus drainage channels. CRS is a debilitating, chronic inflammatory disease, which affects 10% of the adult population in the UK. It is associated with significant reduction of quality of life, high healthcare utilisation, and absenteeism from work.[19] CRS is subcategorised by the presence or absence of nasal polyps (Fig 4).

Treatment of CRS requires a multipronged approach incorporating nasal saline irrigations, topical steroids, selective use of oral steroids, and antibiotics. Surgery is performed in refractory cases.[19,20] Low-dose multidetector CT is the primary investigation used to evaluate patients with CRS, both to assess the severity and pattern of disease and to evaluate anatomical variants, which may contribute to obstruction of sinus drainage channels and be of relevance to endoscopic sinus surgery. Post-surgical assessment can be performed using the same technique (Fig 5). Radiologists

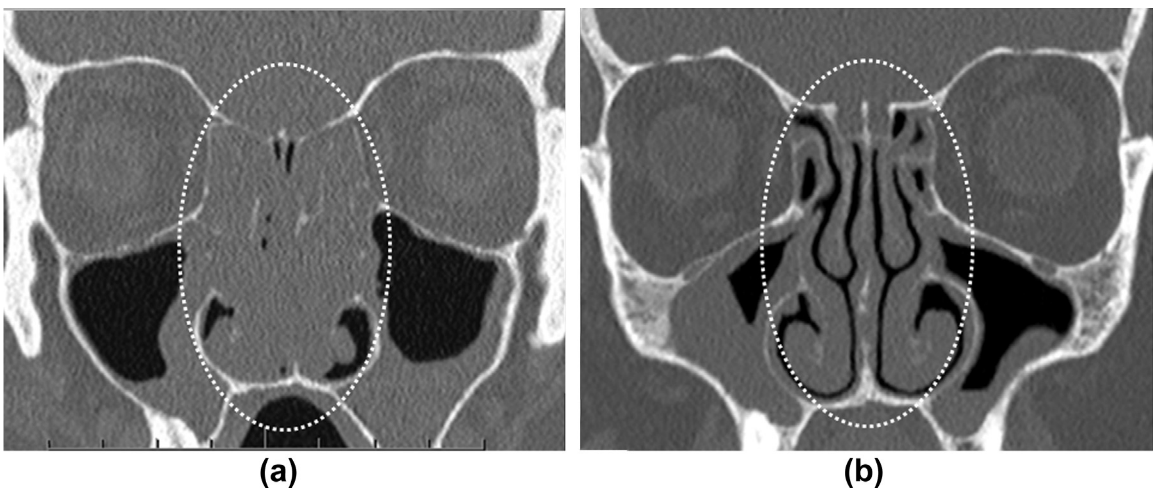

Figure 4 CRS with (a) and without (b) polyps. Coronal CT reconstructions from two patients. (a) Extensive nasal polyps opacify the nasal cavity (white dotted oval) with confluent opacification of the ethmoid air cells and bilateral occlusion of the OMUs. (b) There is hypertrophy of the inferior turbinates, but no nasal polyps (white dotted oval). Mild to moderate MT is present in the ethmoid and maxillary sinuses and the infundibulum of the OMU is diseased and occluded bilaterally. The two categories of CRS have different immune mechanisms. Medical treatment is similar for both, but surgery is more commonly indicated for CRS with polyps.

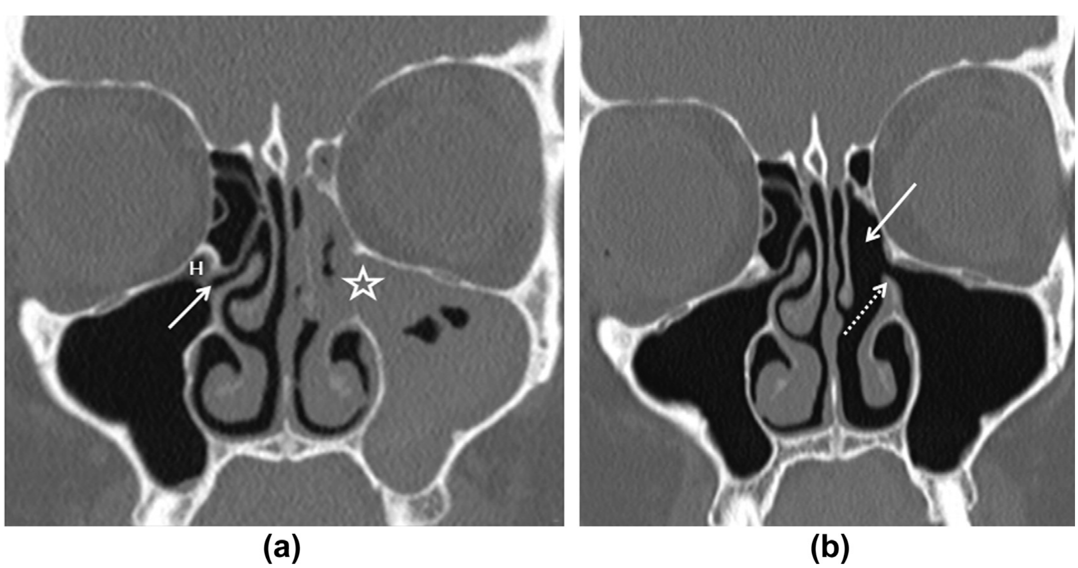

Figure 5 Left anterior sinus group (OMU pattern) of sinusitis treated by endoscopic sinus surgery (ESS) after failed medical management. Coronal CT reconstructions from the same patient before and after endoscopic sinus surgery. (a) Marked left ethmoid and maxillary opacification with occlusion of the OMU (open white star). There was no odontogenic cause. The right maxillary and ethmoid sinuses are clear and the OMU is patent on this side (white arrow); there is a small right Haller cell (H). (b) An anterior ethmoidectomy (white arrow) and uncinectomy (white dotted arrow) have been performed. The OMU is now patent and the maxillary and ethmoid sinuses are clear.

should evaluate and report these scans in a systematic fashion to avoid errors and to provide optimal information for the clinician.[21]

Dental disease and MT in the maxillary sinus

Retrospective reviews of sinus CT or maxillary CBCT images with no history or symptoms of sinusitis shows a prevalence of MT in the maxillary sinuses of 29–53%.[15,22] MT is more common with increasing age, overlying edentulous regions, and dental disease.[15] In addition, the presence of restorations in the maxillary teeth correlates strongly with MT in the inferior aspect of the maxillary sinuses on routine sinonasal CT.[23] In contrast, retention cysts are not related to dental pathology or treatment.[15,22]

Inflammation or perforation of the Schneiderian membrane secondary to dental infection or surgical procedures results in MT. The commonest dental diseases are periapical inflammatory pathology and periodontitis. A consensus in the dental literature was reached that MT >10 mm in thickness was graded as severe and it was further subdivided as focal or generalised and flat (smooth-surfaced) or lobular.

Dental disease

Periapical inflammatory pathology develops at the apex of a tooth which is devitalised, usually by caries in the case of molars or premolars. Subtle widening of the apical periodontal ligament space (>0.5 mm) is the first manifestation of involvement by inflammation when sepsis extends from the pulp chamber via the root canal to the apical foramen.[15] This can be appreciated on CBCT with a spatial resolution of <0.2 mm.[17,22]

Focal expansion of the apical periodontal ligament space can be due to a granuloma, abscess, or cyst and can be clearly visualized on multidetector CT as well as CBCT.[9] Multiplanar evaluation is required and an oblique sagittal reconstruction plane along the line of the posterior maxillary teeth optimally demonstrates the lucency as well as its relationship to the floor of the maxillary sinus and overlying

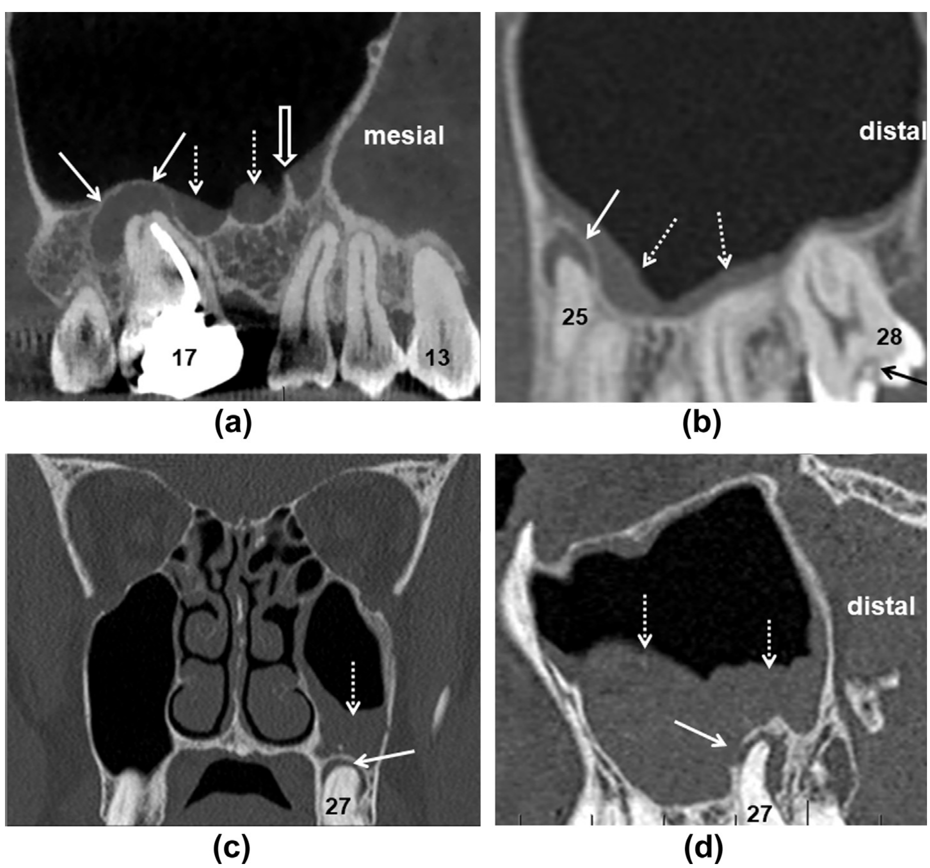

Figure 6 MT in the inferior aspect of the maxillary sinus in response to PIL. Oblique sagittal reconstruction of the right maxilla from a CBCT scan (a). There is a 10 mm PIL (white arrows) associated with the root-filled 17 elevating the floor of the maxillary sinus and associated with mild MT (white dotted arrows). Given the size of the lesion and its corticated margin, it probably represents an apical radicular cyst; 16 is absent and there is a short inferior sinus septum (white open arrow). Oblique sagittal reconstruction from multidetector CT of the left maxilla (b). There is mild MT (white dotted arrows) overlying a 4 mm PIL (white arrow) associated with the non-vital 25. Occlusal caries is present in 28 (black arrow). Coronal (c) and sagittal (d) reconstructions from a MDCT showing a 7 mm PIL associated with the non-vital 27. The sagittal reconstruction (d) demonstrates focal elevation and a small perforation of the sinus floor (white arrow). MT is >10 mm in thickness and is therefore graded as marked (white dotted arrows).

MT (Fig 6). These lesions are not reliably distinguished by imaging and the terms periapical inflammatory lucency (PIL) or periapical radiolucency of inflammatory origin (PRIO) may be used.[24] An acute abscess is often symptomatic whereas granulomas and cysts are usually asymptomatic; apical radicular cysts tend to be larger.[25]

Several studies report a strong correlation of up to 80% between MT and the presence of a PIL,[15,22,26,27] especially in older males. Thickening of the sinus mucosa is almost 10 times more commonly demonstrated in individuals with periapical lesions. Focal, unilateral MT overlying the involved apices is the usual pattern of disease. The severity of MT is related both to the size of the PIL and its proximity to the sinus floor.

Periodontitis represents loss of the osseous and ligamentous supporting structures of the tooth roots secondary to progression of gingivitis. The alveolar crest is normally situated within 1–2 mm from the amelo-cemental junction of the crown. Bone loss may be horizontal or vertical in type. Horizontal bone loss refers to a reduction in height of the alveolar bone surrounding several teeth, the resorbed crest of the ridge remaining parallel to the occlusal plane (i.e., horizontal), whereas vertical bone loss refers to deep pocketing lucencies adjacent to one or two individual teeth (Fig 7). Periodontitis is graded radiologically according to the depth of the periodontal pocket relative to the length of the involved tooth root: mild (coronal third of the root), moderate (middle third of the root), and severe (apical third of the root).

Two large studies evaluating the severity of periodontitis and MT by CBCT demonstrated a strong, statistically significant relationship. In Thai and Chinese patients with periodontitis, the incidence of MT was 42% and 49% respectively; it was much more common in middle-aged males.[28,29] The incidence and severity of MT increased proportional to the severity of periodontitis. Eighty-eight percent of patients with severe periodontitis have MT. Vertical bone loss involving the division of the molar roots (furcation) was also strongly associated with MT. In contrast to periapical

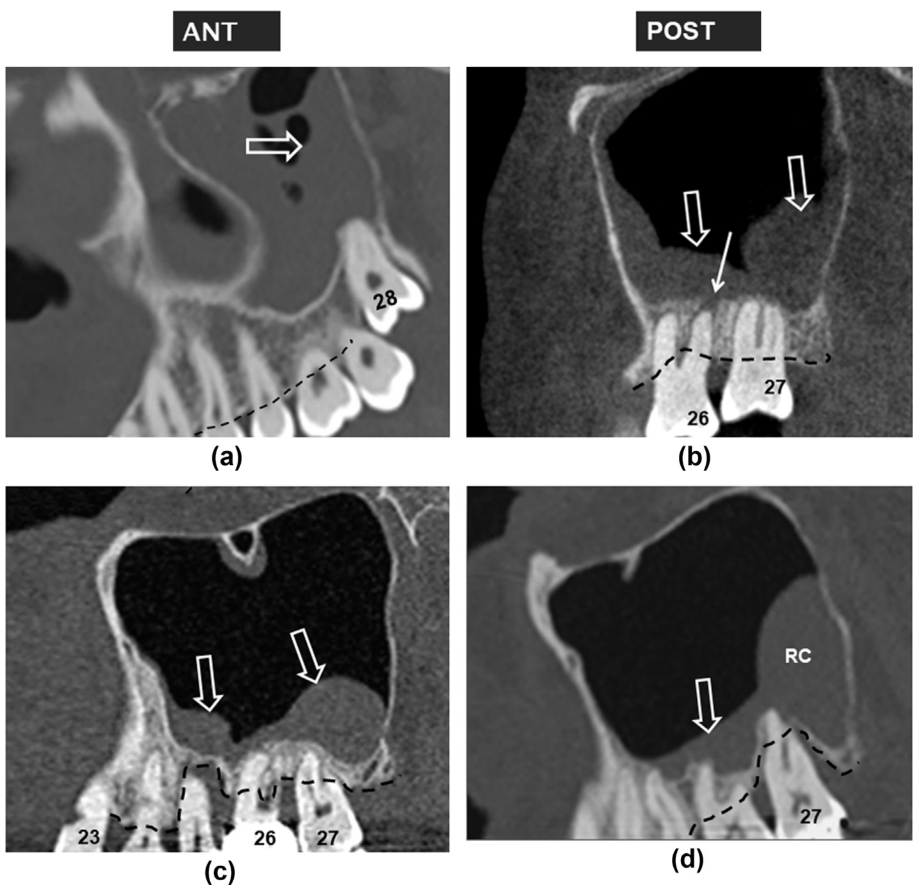

Figure 7 Normal alveolar bone levels and bone loss due to periodontitis. Oblique sagittal reconstructions of the left maxilla from multidetector CT (a,d) and CBCT (b,c). The level of the alveolar crest in each image is shown as a dashed black line. (a) Normal level of the alveolar crest in this young adult who has acute left maxillary sinusitis; no odontogenic cause was evident (the vertically impacted and unerupted 28 is not relevant). Pneumatised secretions are present in the extensively opacified left maxillary sinus (white open arrow). (b) Mild horizontal alveolar bone loss around 27 with bone loss being slightly more marked and vertical around the supra-erupted 26. In addition, there is a small periapical lucency associated with the disto-buccal apex of 26 (white arrow) and moderate lobular MT in the inferior aspect of the maxillary sinus (white open arrow). (c) Alveolar bone loss is graded as mild and horizontal around 23 and 24, marked and vertical around the distal aspect of 25 extending to the apex and of moderate severity and horizontal in type around 26 and 27. There is moderate MT in the inferior aspect of the maxillary sinus (white open arrow). (d) Moderate to marked vertical bone loss around 27 with moderate horizontal bone loss around 26. There is mild smooth-surfaced MT in the inferior aspect of the left maxillary sinus (white open arrow) with a posteriorly situated retention cyst (RC).

pathology, periodontitis is associated with MT, which is usually <10 mm in thickness and frequently bilateral.

Iatrogenic causes

An oro-antral communication following extraction of a maxillary molar or premolar, a sinus lift procedure to augment bone height in a shallow edentulous segment in the maxilla, and subsequent placement of an implant fixture can all result in perforation and inflammation of the Schneiderian membrane and development of MT.

Dental panoramic tomograms are useful as on overview of the jaws and dentition,[30] but are inadequate for evaluation of the posterior maxillary teeth, the relationship of premolar and molar roots to the maxillary sinus and the presence and severity of mucosal disease in the maxillary sinus. Intra-oral periapical radiographs provide high resolution, two-dimensional visualization of posterior maxillary teeth, but have the same limitation as the dental panoramic tomogram: superimposition of air or MT in the maxillary sinus, alveolar bone, and soft-tissues overlying the maxillary tooth roots.[16,31] CT, and especially high-resolution CBCT, overcome this problem. In addition, the volume data set from these studies can be used to evaluate the dento-alveolar unit and maxillary sinus in multiple imaging planes, providing optimal evaluation of the relationships of the roots and apices to the sinus floor as well as the accurate demonstration of periapical pathology, periodontal disease, and complications following dental procedures.[16,31]

OS: definition and aetiology

Although some authors in the dental literature recognise that sinusitis is a clinical diagnosis, several define or describe MT in the inferior aspect of the maxillary sinus associated with dental disease or treatment as OS.[15,22,32] The basic physiological requirements of mucociliary clearance and patent drainage channels in maintaining a clear and healthy sinus are rarely mentioned. It is more accurate to regard mucosal disease of dental aetiology as a spectrum varying from: (a) asymptomatic MT in the inferior aspect of the maxillary sinus; (b) subtotal opacification of the maxillary sinus; this is dental in origin in 75% of cases[3]; (c) occlusion of the maxillary sinus ostium resulting in absence of mucociliary clearance, stasis, bacterial overgrowth, and a predisposition to acute sinusitis. In the appropriate clinical setting, fluid levels and pneumatised secretions support this diagnosis; (d) occlusion of the OMU and therefore the drainage of the anterior ethmoid and frontal sinuses; (e) maxillary, anterior ethmoid and frontal sinusitis, which can be acute or chronic in nature. Extension of OS from the maxillary to the other anterior sinuses occurs in 60% of cases.[6]

Unilateral sinusitis involving the anterior sinus group should always raise the possibility of a dental aetiology and alert the radiologist to review the posterior maxillary teeth, alveolar process, and floor of the maxillary sinus (Fig 8).

There is a single proposed classification of OS,[33] which is heavily weighted towards surgical and iatrogenic causes rather than common dental diseases as aetiological factors, probably reflecting the specialist nature of the unit from which the research originated. A simpler classification is presented (Table 1) with two categories of aetiology: dental disease and iatrogenic. This should be of practical value to radiologists and clinicians.

Table 1
The common causes of odontogenic sinusitis.

Dental disease
• Periapical inflammatory pathology: most common cause, due to a non-vital premolar or molar
• Periodontitis: less common, usually only severe and vertical bone loss
• Endodontic-periodontic pathology: combination of 1 and 2
Iatrogenic
• Oroantral communication/fistula: post-extraction of a molar
• Sinus lift procedure: to increase bone height for implant placement
• Foreign bodies: misplaced roots, dental restorations and root canal fillings

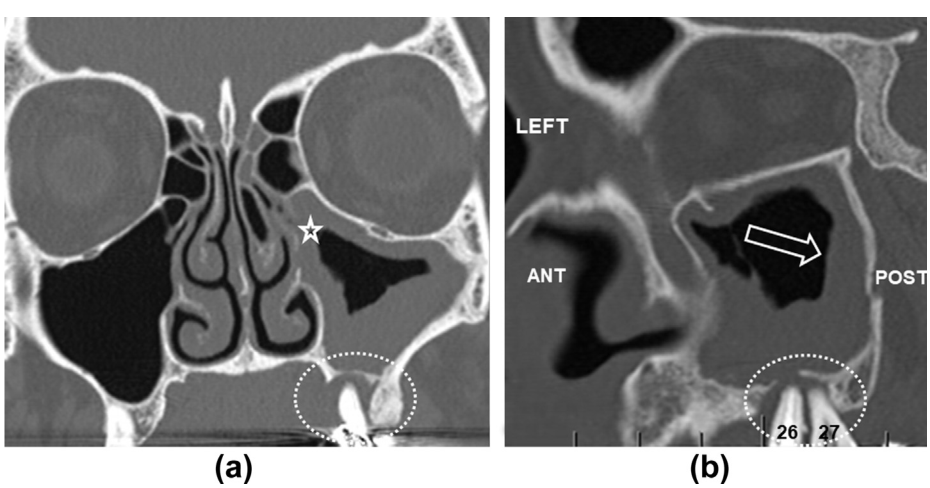

Figure 8 Acute OS. Coronal and left oblique sagittal reconstructions from CT. There is subtotal opacification of the left maxillary sinus due to MT and fluid (white open arrow). The left OMU is occluded (white star) with mild MT in the anterior ethmoid air cells. There is extensive loss of alveolar bone around the roots of root-filled 26 and adjacent 27. Bone loss is due to a combination of marked vertical periodontitis and a PIL (i.e., combined endodontic–periodontic lesion). The sinus floor is thinned, elevated, and perforated (white dotted oval).

Dental disease

Although periodontal disease is a common cause of MT, it is a significantly less common cause of true OS than periapical inflammatory lesions,[15,22,26,27] especially when a PIL markedly thins or perforates the sinus floor (Fig 9). In the single study published from the UK, OS was due to a PIL in 73% and an oro-antral communication/fistula in 23% of cases.[4] Periodontitis was not discussed.

Iatrogenic causes

There are multiple risk factors[32] for the development of an oro-antral communication following extraction of a posterior maxillary tooth: this is especially likely in elderly patients with extensively pneumatised maxillary sinuses and resorbed and osteopaenic alveolar bone and ankylosed and divergent molar roots (Table 2). If the communication becomes epithelialized (which takes about 7 days), it becomes an oro-antral fistula (Fig 10).

Following tooth loss, there is progressive resorption of alveolar bone, with loss of about half of bone height and width after 3 years.[34] Replacement of missing teeth using implants made from titanium (for both functional and cosmetic reasons) is a frequently performed procedure. The implant fixture is shaped like a screw and is placed into a pre-drilled socket or (in the case of immediate placement) in the socket of an extracted tooth. Bone grows progressively into the thread of the surface of the fixture and complete osseointegration takes 3–6 months in the maxilla. Planning of the surgical procedure, with specific reference to the degree of socket healing, the dimensions and quality of alveolar bone in the edentulous segment and the proximity and integrity of the floor of the maxillary sinus, is optimally

Table 2
Risk factors for development of an oro-antral communication.

- Intimate relationship between the root apices and the sinus floor
- Divergent roots of maxillary molars, especially the first molar
- Bulbous roots due to hypercementosis
- Ankylosis: the periodontal ligament space around the roots is lost
- Periapical inflammatory lucency: thins or perforates the sinus floor
- Impaired wound healing: diabetes, smoking, increasing age
- Osteoporosis
- Medication related osteonecrosis of the jaws (MRONJ)

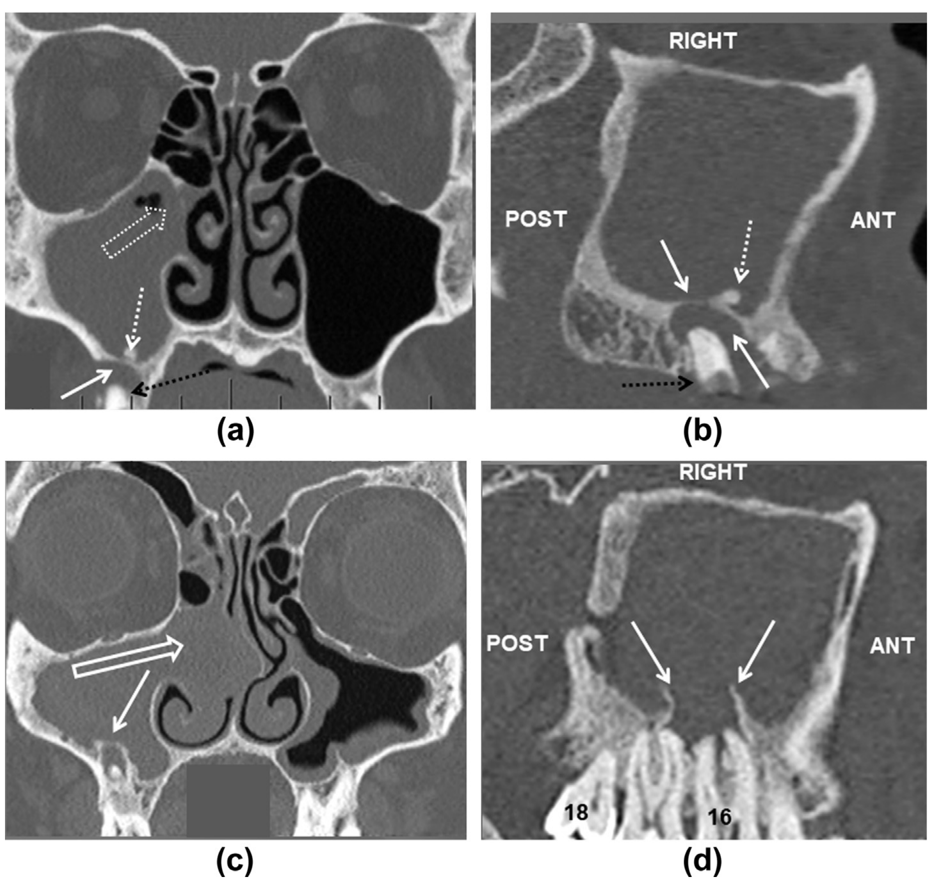

Figure 9 Chronic OS. Coronal and oblique sagittal reconstructions from CT in two patients. (a,b) Case 1: subtotal opacification of the right maxillary sinus with occlusion of the sinus ostium (white open dotted arrow). There is an expansile PIL and marked vertical periodontal bone loss (white arrows) around a carious 16 root remnant (black dotted arrow). The sinus floor is elevated and thin. There is a tiny calcified focus within the opaque sinus overlying the floor and PIL (white dotted arrow) which probably represents a displaced apical root remnant. (c,d) Case 2: subtotal opacification of the right maxillary sinus with a polypoidal mass of inflammatory tissue (white open arrow) filling and expanding the right OMU. This was confirmed after endoscopic sinus surgery. There is mild MT in the right anterior ethmoid air cells and the left maxillary and frontal sinuses. A large PIL is present around the apices of 16 and the mesio-buccal apex of 17 with perforation of the sinus floor (white arrows).

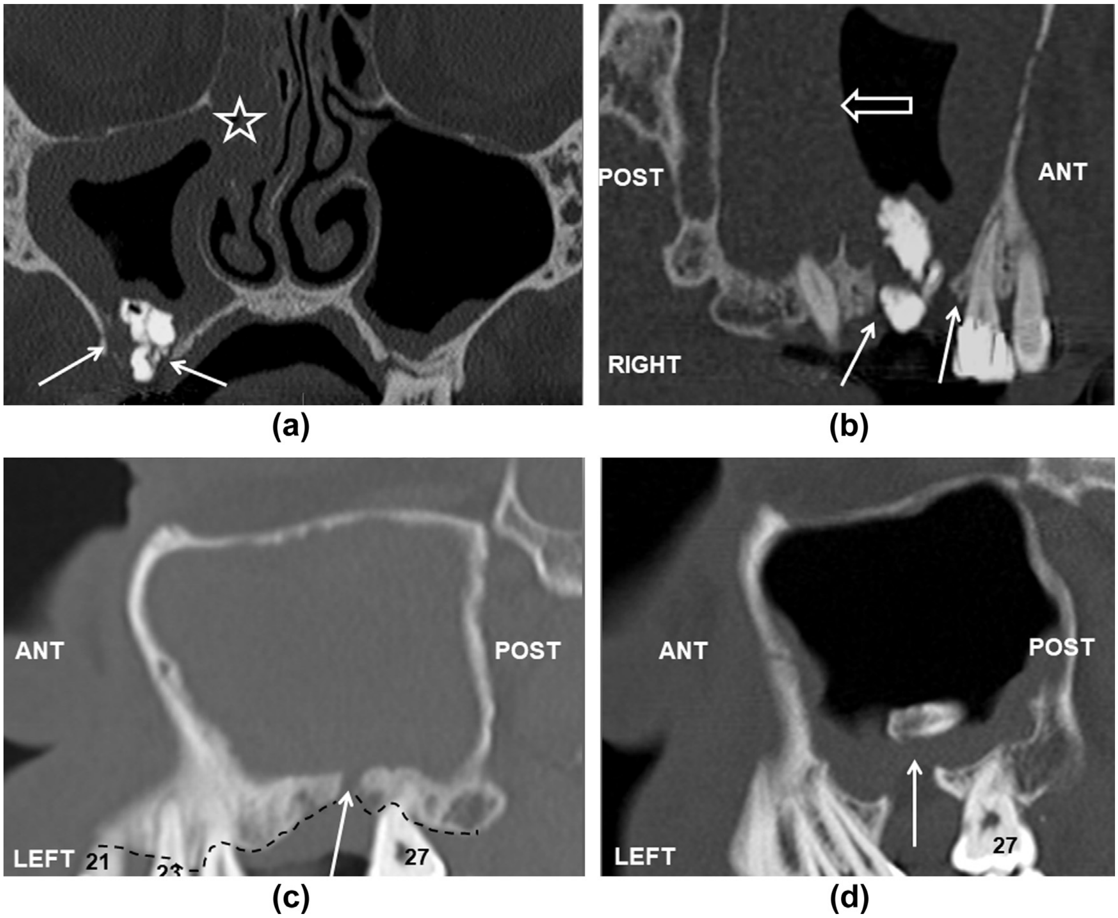

Figure 10 Oro-antral communication causing OS. (a) Coronal and (b,c,d) oblique sagittal reconstructions from CT in three patients. (a,b) Case 1: attempted extraction of 16. Dense fragments of crown restoration and root are seen in a large defect within the right posterior maxilla (white arrows). Moderate peripheral MT and fluid is present in the right maxillary sinus (white open arrow). The right OMU is occluded (white star) with total opacification of the right anterior ethmoid air cells. (c) Case 2: small oro-antral communication in the 26 region (white arrow). Periodontitis is present around the remaining right posterior maxillary teeth (black dotted line) with extensive alveolar resorption following tooth loss in the edentulous 26 region. The left maxillary sinus is totally opaque. (d) Case 3: chronic oro-antral fistula in the 26 region (white arrow). A displaced 26 root remnant lies on the surface of moderate MT in the inferior aspect of the left maxillary sinus.

performed with high resolution CBCT.[25] The appropriate length and width of the implant fixture is chosen to avoid perforation of the floor of the maxillary sinus (Fig 11). It is imperative that CBCT or CT performed for preoperative assessment prior to implant placement in the posterior maxilla cover the maxillary sinus ostium and ethmoid infundibulum. In the majority of reported studies, the reported incidence of OS following placement of implants in the posterior maxilla is very low even if the apical portion of the implant fixture just perforates the sinus floor.[15]

If there is inadequate bone height for implant placement, a “sinus lift” can be performed with augmentation of the ridge using a technique known as guided bone regeneration. This involves placement of particulate bone grafts and/or bone substitutes between the sinus floor and Schneiderian membrane via a bone window (Fig 12a and b) in the inferolateral wall of the maxillary sinus.[25,35] Once the graft has consolidated and healed to the sinus floor, an appropriate-sized implant can be placed. Perforations of the Schneiderian membrane during a sinus lift procedure occur on average in 30% of cases and are usually related to difficulty in elevating the membrane. This is more likely when imaging shows marked loss of alveolar bone, thin mucosa, and inferior sinus septa. Small perforations heal spontaneously; larger perforations pose a risk of OS (Fig 12c and d) and implant failure and require repair and postoperative care including appropriate antibiotics.[35] The risk of OS following these surgical procedures is relatively low (<10%), but strongly associated with the following findings on preoperative CT or CBCT[25,35–37]: (1) occlusion of the maxillary sinus ostium/OMU; (2) opacification of more than half of the maxillary sinus; (3) sepsis associated with teeth adjacent to the edentulous segment.

Foreign bodies, such as root fragments and root canal filling material, may also be introduced into the maxillary sinus following extraction or instrumentation of the root canal respectively (Fig 10d). Maxillary osteotomies for correction of facial deformity at the Le Fort 1 level can lead

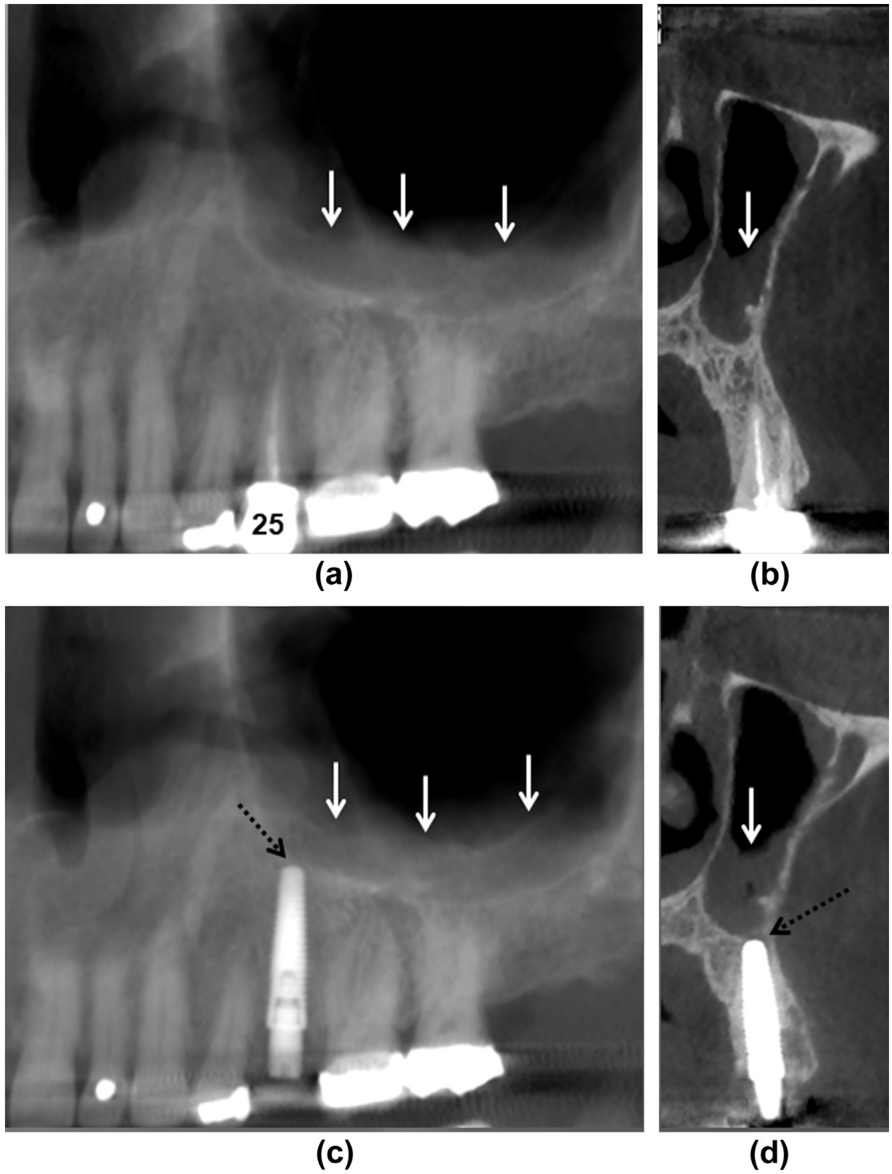

Figure 11 Immediate implant. Pre- and postoperative CBCT image in the same patient with panoramic (a,c) and radial (b,d) reconstructions. (a,b) Preoperatively: 25 is crowned and root-filled; 26 and 27 are also crowned and there is MT in the inferior aspect of the left maxillary sinus (white arrows). The OMU was patent (not shown). Mild inferior MT is associated with previous restorative dentistry. (c,d) Postoperatively: 25 was carefully extracted and replaced with an immediate implant which was longer than the roots of the premolar. There is osseo-integration of the implant fixture the apical portion of which abuts the focally demineralised sinus floor (dotted black arrow). Inferior MT in the maxillary sinus is unchanged, the OMU remained patent, and the patient was asymptomatic.

to acute or chronic sinusitis, especially if there is pre-existing mucosal disease and occlusion of the OMU.[15]

Microbiology, clinical presentation, and treatment of OS

Acute bacterial rhinosinusitis is due to aerobic bacteria found in the respiratory tract. Bacteria can be cultured in only 40% of sinus aspirates in patients with CRS, which is a multifactorial, chronic inflammatory disorder. In contrast, bacterial cultures are positive in 100% of patients with OS[1]; a mixed bacterial flora of aerobes and anaerobes is characteristic, with anaerobes predominating, reflecting the normal oral flora. Foreign bodies within the maxillary sinus can act as a nidus for growth of fungi, especially *Aspergillus* spp., which can also proliferate in an anaerobic environment. If a dental cause for sinusitis is not recognized, antibiotic treatment may be inappropriate and fail.

OS predominates in the fifth and sixth decades of life. The signs and symptoms of OS are similar to rhinogenic sinusitis and do not allow distinction between the two entities. Nasal obstruction, a purulent nasal discharge, facial pain, and a bad taste or smell, are the commonest symptoms of OS. Dental pain is present in less the one-third of OS patients at presentation, probably because dental sepsis has decompressed as it drains into the maxillary sinus. On the

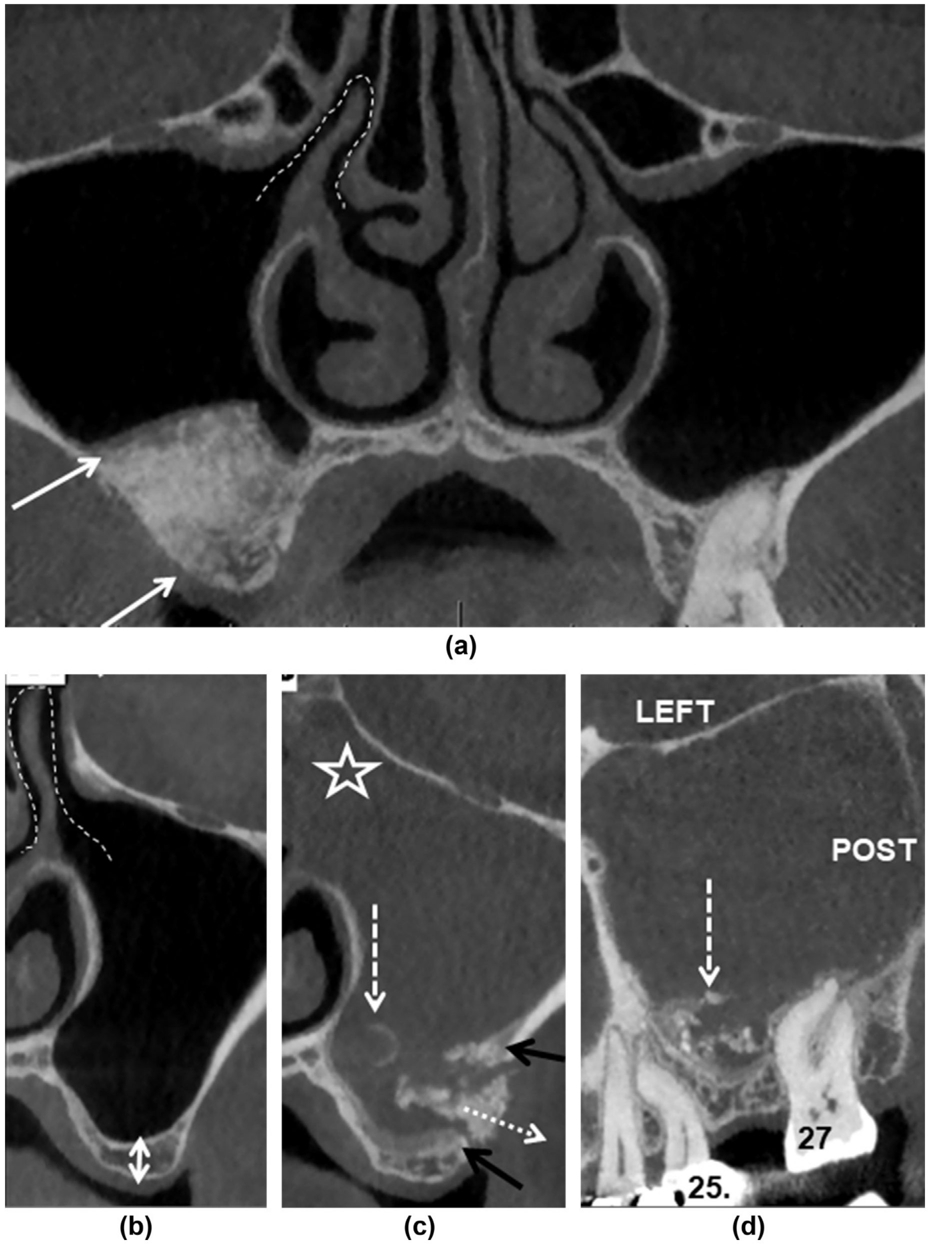

Figure 12 Successful and unsuccessful sinus lift procedures. (a,b,c) Coronal and oblique sagittal (d) CBCT reconstructions in two patients. (a) Case 1: guided bone regeneration has been performed via a window in the infero-lateral wall of the right maxilla. The graft is placed between the sinus floor and the surgically elevated Schneiderian membrane. After an interval of 10 weeks, the bone graft is consolidated and united to the inferior and inferolateral walls of the right maxilla. The sinus is clear and the OMU is patent (white dashed line). (b,c,d) Case 2: preoperative assessment (b) prior to implant placement in the 26 region: there is a minimum bone height of 3 mm, which is inadequate for implant placement (white double arrow). The sinus is clear and the OMU is patent (white dashed line). Several weeks after a left sinus lift procedure to augment the 26 region, the patient was re-scanned (c,d) because of suspected sinusitis and no significant improvement with antibiotics. The left maxillary sinus is totally opaque; the OMU is occluded (white star) and the anterior ethmoid air cells are diseased. The bone graft has extruded buccally (white dotted arrow) through the bone window (short black arrows). Some new bone formation is present in the inferior aspect of the sinus but the majority of the graft (white dashed arrows) is not consolidated or united to the sinus floor or walls. Endoscopic sinus surgery is scheduled.

other hand, maxillary dental pain can be a symptom of true rhinogenic sinusitis, because the inferior aspect of the maxillary sinus and the posterior maxillary teeth share a common neurovascular plexus.[1,32]

Successful treatment of OS requires treatment of the dental aetiological factors and appropriate antibiotics to cover an infection with oral flora. OS is frequently harder to treat than rhinogenic sinusitis and endoscopic sinus surgery will be required in 48–80% of cases, the strongest indications being obstruction of the OMU and an oro-antral communication or fistula.[1,4,38] Postoperative scans should cover the maxilla as well as the paranasal sinuses, and are essential to show the extent of disease, obstruction of the OMU, and complications related to surgery.

Discussion

The intimate relationship of the roots of the posterior maxillary teeth to the floor of the maxillary sinus is the principal factor accounting for the high incidence of mucosal disease related to dental disease and surgery. The application of high-resolution CBCT and multiplanar imaging by the dental profession has produced extensive research and numerous publications on this anatomical and pathological relationship.[14–16,31] The major deficiency of much of this literature is the assumption that MT equates to OS and failure of assessment of the OMU and the other anterior sinuses. Although this, in part, due to the limited field of view used for high-resolution CBCT, the concept and importance of mucociliary clearance and a patent drainage channel is not emphasized. Isolated MT in the antral floors may be secondary to alveolar bone loss from periodontitis, but care should be taken not to overdiagnose this as OS.

Recognition of a dental aetiology as the predominant cause of unilateral opacification of the maxillary sinus on imaging has been well recognized in the otolaryngological literature for the last 12 years.[3,38,39] In addition, the prevalence of OS is higher than previously reported and it forms a significant percentage of unilateral opacification of the anterior paranasal sinuses with predominant involvement of the maxillary sinus.

We recommend that CT radiographers always scan the maxillary dentition with the scan plane being parallel to the plane of occlusion as determined on the lateral planning digital radiograph. Streak artefact from restorations on low-dose multidetector CT may impair visualization of tooth crowns, but the majority of the roots and especially the apices, alveolar bone and sinus floor should be clearly visualized if scanning is performed in this plane. CBCT produces less streak artefact than multidetector CT.[24] CBCT provides very high spatial resolution[24] with a small field of view (up to 50 mm supero-inferior coverage); however, CBCT for CRS or suspected OS should always include the OMU and optimally the ethmoid and maxillary sinuses. This necessitates a lower resolution scan (similar voxel size to CT) to provide adequate scan volume in a reasonable time; CBCT scan times are longer than those of multidetector CT. In addition, the absence of soft-tissue information on CBCT is a major disadvantage.

Reporting guidelines for sinonasal CT should include routine assessment of the maxillary dentition focussing on the apices of the maxillary premolar and molar teeth and the overlying floor of the maxillary sinus. Establishing the true aetiology of maxillary sinusitis has an important impact on clinical management, as the pathophysiology, microbiology, and treatment of OS are different from those of rhinogenic sinusitis.

Conflict of interest

The authors declare no conflict of interest.

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