Current concepts in maxillofacial imaging

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Abstract

A review of state-of-the-art maxillofacial imaging is presented. Current imaging techniques include intra-oral radiographs, dental panoramic tomography, multidetector helical computed tomography, cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI). The commonest conditions encountered in clinical radiological practice are reviewed, including maxillofacial deformities, complicated dental impactions, maxillofacial trauma, jaw lesions (cysts, neoplasms, fibro-osseous lesions (FOLs) and infections), and temporomandibular joint pathology. Pre-operative assessment for dental implant placement is also briefly reviewed.

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1. Imaging techniques

Intra-oral radiographs, including periapical, bitewing and occlusal projections, are the basic and often the only imaging technique required for much dental pathology. Usually, these are performed and reviewed by the general dentist. The radiologist should be aware that intra-oral radiographs are performed without intensifying screens, and therefore have higher spatial resolution (of the order of 20 line pairs per millimetre (lp/mm)) than panoramic radiographs (about 5 lp/mm). This also implies a relatively high radiation dose for their small size. The higher spatial resolution allows detection of small carious lesions and periapical lucencies which may not always be detectable with dental panoramic tomography.

Dental panoramic tomography is a specialised tomographic technique used to produce a flat representation of the curved surfaces of the jaws. It is an excellent and widely performed technique for providing an overview of the dentition, generalised pathology such as periodontitis, and odontogenic and non-odontogenic lesions of the jaws. It also gives a basic assessment of the osseous status of the temporomandibular joints. However, it is subject to considerable and unpredictable geometric distortion, and has relatively low spatial resolution compared with intra-oral radiographs. Lateral and anteroposterior (AP) cephalograms (also known as cephalometric projections) are standard extra-oral radiographs performed in a cephalostat using film-screen or digital techniques. They are used for orthodontic assessment and are of value in assessing the dental and skeletal relationships of the jaws, as well as asymmetric deformity.

Multidetector row computed tomography (MDCT), using 16–64 detector rows, is the current state-of-the-art CT technique, with many applications throughout the body. The multiple detector rows and very thin slice profiles result in the volumetric acquisition of data, with isotropic voxels (i.e. as thin in the craniocaudal plane as they are in the transverse and anteroposterior planes), so that data can be presented at equal resolution in any plane, including curved (panoramic) planes. Three-dimensional reconstructions and thick, slab-like multiplanar reformats (MPRs) can also be derived from this volume data set. This is the imaging technique of choice in evaluation of most maxillofacial pathology, giving excellent bone detail. When a “soft-tissue” reconstruction algorithm is used, assessment of the maxillofacial soft tissues, including the articular disc of the temporomandibular joint, is also possible. CT may be impaired by beam-hardening artefact from dental amalgam, and it results in a relatively high radiation dose.

Cone-beam computed tomography (CBCT) uses a cone-shaped X-ray beam (unlike the fan-shaped X-ray beam used in conventional CT), to acquire projection data via a flat detector, during a single 360° rotation, from which a volumetric data set is reconstructed using algorithms similar to those used in conventional CT. It results in a lower radiation dose than conven-
tional CT (by one order of magnitude or more) [1], but therefore suffers from significant image noise, and is not suitable for soft-tissue assessment. CBCT is capable of higher spatial resolution (with isotropic voxels as small as 0.125 mm³) than conventional CT. Scanning time is comparable to that of state-of-the-art conventional CT (10–40 s). As with conventional CT, the volume data set can be used to create multiplanar and three-dimensional reconstructions. CBCT units are generally smaller and cheaper than conventional CT scanners, and the patient sits upright, similar to the positioning in a dental panoramic tomography unit. Thick multiplanar reconstructions can be used to produce lateral and frontal cephalometric images (without distortion or magnification) for orthodontic assessment. Some current CBCT units are also capable of acquiring panoramic tomograms and cephalometric projections directly.

Magnetic resonance imaging (MRI) is the technique of choice in the evaluation of temporomandibular joint pathology. Its excellent soft-tissue contrast resolution makes it ideal for the detection of internal derangement of the joint, and it can be used to show joint effusions, synovitis, erosions and associated bone marrow oedema. MRI also has a role in assessing the extent of soft-tissue invasion by maxillofacial tumours. It provides greater specificity than CT in distinguishing between odontogenic cysts (which are commoner) and tumours (which are more prone to recurrence).

2. Maxillofacial deformity

A full discussion of cranio-maxillofacial deformity is beyond the scope of this review. The subject is complex and associated with several syndromes with typical craniofacial deformities. This subject has been reviewed by Caruso et al. [2], who described the role of CT in the diagnosis and presurgical evaluation of craniofacial malformations.

Less complex maxillofacial malformations may be acquired or congenital. Acquired malformations are usually the result of trauma (Fig. 1) or the sequelae of surgical resection of tumours with no or inadequate primary reconstruction (Fig. 2). Congenital or developmental malformations may be symmetric or asymmetric in nature. The standard method of analysis of maxillofacial deformity employed by orthodontists or oral and maxillofacial surgeons, is lateral and postero-anterior cephalostat radiographs combined with clinical photographs and occlusal analysis. The inter-relationships of the maxilla and mandible to the fixed landmarks of the skull base as well as the overlying soft-tissue silhouette are measured and traced on the lateral cephalostat. This allows evaluation of the lateral dental and skeletal relationship of the teeth and bones of the maxilla and mandible respectively. Based on this analysis, an orthodontic treatment plan is formulated, occasionally supplemented by orthognathic surgery when there is significant skeletal discrepancy between the jaws. Cone-beam CT combined with state-of-the-art orthodontic software programmes allows more accurate and relatively low dose analysis of symmetric maxillofacial skeletal and dental discrepancy [3]. Scan data is provided on a CD disc with midline lateral maximum intensity projection (MIP) reconstructions supplemented by 3D volume rendered reconstructions of the maxillofacial region and conventional 2D axial, coronal and sagittal reformations. The orthodontist then analyses the data using proprietary software.

The lateral cephalostat is of limited value when the maxillofacial deformity is asymmetric as the abnormal side is superimposed on the normal side of the face. CT (either CBCT or MDCT) is advisable in these cases for optimal evaluation of the extent of deformity [4]. The commonest causes of asymmetric deformity are under or over-activity of one of the condylar growth centres in the growing skeleton resulting in hypoplasia.

Fig. 1. Acquired deformity, with neocondyle formation following a displaced condylar fracture of the right mandibular condyle. Coronal CT reconstruction (a) shows a “double condyle” appearance; the plane of the oblique fracture is still apparent (arrow). Volume-rendered three-dimensional CT reconstruction (b) shows a lateral view of the right mandibular ramus, with the deformed, flattened condyle responsible for facial asymmetry.
or hyperplasia of the affected condyle. This results in classical patterns of deformity including mandibular asymmetry and sometimes tilt of the occlusal plane and secondary deformity of the maxilla. When unilateral condylar hypoplasia is suspected, hemifacial microsomia requires exclusion and this is normally diagnosed clinically by concurrent developmental defects of other first branchial arch structures such as the pinna, external auditory canal or middle ear cleft.

Isotope bone scanning (Tc pertechnetate) is of value in determining:

i. whether condylar hypoplasia or hyperplasia is present and which side is affected;

ii. determining whether condylar growth has ceased and corrective orthognathic surgery can be undertaken without risk of relapse. Condylar metabolic activity is compared between right and left condyles as well as with a baseline, either the clivus or the L4 vertebral body producing a ratio for each side, which is then compared with the normal range.

3. Complicated dental impactions

The commonest dental impactions involve third molar teeth. Deeply impacted mandibular third molar teeth are often intimately related to the inferior alveolar canals, which may groove or perforate the roots, and be displaced and narrowed by them. This may be suspected on dental panoramic tomography, but is more accurately assessed with CT (Fig. 3). Damage to the inferior alveolar nerve during extraction of impacted third molars
results in permanent paraesthesia of the lower lip. Maxillary canines are also frequently impacted, as are supernumerary teeth, the commonest of which is the mesiodens, situated immediately adjacent to the midline nasopalatine canal, and frequently inverted (Fig. 4).

4. Maxillofacial trauma

Although plain radiographs are useful in the initial evaluation of suspected facial fractures, as is dental panoramic tomography for suspected mandibular fractures, CT is an excellent tool for detecting radiographically occult fractures, or fractures suspected on the basis of secondary signs, such as a sinus air–fluid level, and for defining the displacements of fractures (Fig. 5) prior to surgical reduction and fixation.

Fractures of the nasal bone are the commonest fractures in the maxillofacial region, and are generally adequately assessed clinically or by plain radiographs, taking care to recognise normal structures which can simulate fracture lines (Fig. 6). More extensive naso-orbito-ethmoidal fractures require CT for optimal evaluation, particularly of the attachment of the medial canthal ligament [5].

Central midfacial fractures include naso-orbito-ethmoidal fractures, isolated maxillary fractures and the Le Fort type fractures. The classic Le Fort fractures (type I, a “floating palate”; type II a pyramidal fracture; and type III, complete craniofacial dysjunction) are uncommonly seen in pure form. Le Fort type fractures are always bilateral, except when there is a paramedian fracture of the palate. However, they are frequently asymmetric, for example with a Le Fort I pattern on one side and a Le Fort II pattern on the other. The fracture lines extend through the pterygoid plates in all three types (Fig. 7).

Lateral midfacial fractures include the common zygomatic complex fractures (see Fig. 5) and orbital blow-out fractures, as well as the less common isolated zygomatic arch fractures, zygomaticomaxillary fractures and zygomaticomandibular fractures. Zygomatic complex fractures are the second commonest facial fractures (after nasal fractures), and are also known as triangular or tripod fractures, because there are three fracture lines, involving the three “legs” of the malar eminence. The first of
these involves the lateral orbital wall (usually diastasis of the zygomaticofrontal and zygomaticosphenoid sutures); the second involves the orbital floor and zygomaticomaxillary suture, close to the infra-orbital canal and foramen (accounting for the high frequency of infra-orbital nerve damage complicating these fractures); and the third is in the zygomatic arch, usually in the temporal bone, posterior to the zygomaticotemporal suture. Occasionally, the zygomatic arch is intact.

Orbital blow-out fractures result from a blunt blow to the orbit with an object (frequently a ball or a fist) which is larger than the orbital aperture: pressure is transmitted through the globe and other intra-orbital structures, to the weakest points in the orbital walls, which are the lamina papyracea (medial orbital wall) and the orbital floor in the region of the infra-orbital groove and canal. Important complications include damage to the infra-orbital nerve, with resultant loss of cheek sensation, enophthalmos (a late manifestation following resolution of oedema and haemorrhage) and entrapment or tethering of the extra-ocular muscles, resulting in diplopia (Fig. 8). Old, small blow-out fractures are frequent incidental findings on CT performed for paranasal sinus disease.

Frontal sinus fractures usually result from a direct blow, or are part of a larger calvarial fracture. The outer table is involved alone in about two thirds; in one third, the inner table is also involved (i.e. there is intracranial extension of the fracture line). The superomedial orbital rim is frequently involved.

Mandibular fractures are common. They may be subtle or inapparent on panoramic tomography, and full evaluation requires views at a right angle to the curved panoramic plane. This includes the mandibular condyle, which is not always clearly visualised, and CT may be necessary to demonstrate undisplaced fractures (Fig. 9). Condylar fractures are frequently bilateral or associated with a contralateral body fracture. Fractures of the condylar neck or head can result in a characteristic post-traumatic deformity, as the condyle is displaced anteromedially by the pull of the attached lateral pterygoid muscle (Fig. 10).

5. Cysts of the mandible and maxilla

Most cystic lesions occurring in the jaws are related to teeth (odontogenic); some are non-odontogenic, and others
are not true cysts, but are conveniently considered within this category because of cyst-like radiographic appearances. Some neoplasms, notably ameloblastoma, can appear cystic, and must be considered in the differential diagnosis of a cyst. The entity traditionally known as an odontogenic keratoctyst (OKC) has recently been reclassified as a neoplasm, the keratocystic odontogenic tumour (KCOT), to better reflect its potentially locally destructive behaviour and propensity for recurrence [6], but it will still be considered in this section.

5.1. Radicular (periapical or apical periodontal) cyst

Of the odontogenic cysts, the commonest is the radicular cyst (also known as a periapical cyst), which is a post-inflammatory lesion related to the apex of a non-vital tooth root, and the residual cyst, which is the same entity remaining in the jaw following loss or removal of the tooth (Fig. 11). The radicular cyst is characterised by its position adjacent to the apex of a carious or heavily restored non-vital tooth, often a maxillary incisor or canine. It can be difficult to distinguish from a periapical granu-
loma, but is generally larger (often greater than 20 mm), with a rounder contour, and a well-defined border. A residual cyst, the cyst remaining after extraction of the associated tooth, has a non-specific appearance, but its nature can usually be appreciated with the relevant history and prior radiographs.

5.2. Dentigerous (follicular) cyst

The second commonest odontogenic cyst is the dentigerous (follicular) cyst, characterised by its pericoronal position, around the crown of an unerupted tooth. The commonest teeth affected are the third molars (Fig. 12) and the maxillary canines, but dentigerous cysts may also be associated with the crown of an unerupted supernumerary tooth, most commonly a mesiodens. It can be difficult to distinguish a dentigerous cyst from a hyperplastic follicle; the follicular space should be less than 2–3 mm, and a hyperplastic follicle should not displace the tooth or cause cortical expansion. The pericoronal (dentigerous) position is not specific, and the keratocystic odontogenic tumour and other benign tumours may be pericoronal in position.

5.3. Keratocystic odontogenic tumour (KCOT, formerly OKC)

The keratocystic odontogenic tumour (formerly odontogenic keratocyst) arises from the dental lamina, and has a thin lining of keratinized epithelium, and can have thick cheesy contents due to desquamated keratinizing squamous cells. These contents can occasionally increase the radiographic attenuation of the lesion at CT (Fig. 13), but this is not appreciable on panoramic tomography. The KCOT has a wide age range but is commonest in the second and third decades. It most commonly occurs in the posterior mandible (90% posterior to the canines, 50% in the ramus). Like all odontogenic lesions, its epicentre is superior to the inferior alveolar canal. In 40% of cases it has a dentigerous relationship with an unerupted tooth, and should therefore always be considered in the differential diagnosis of a dentigerous cyst. It usually has a well-defined corticated margin, which may be scalloped. It causes relatively slight expansion, and is less likely to displace or resorb teeth than the dentigerous cyst. However, it may become large, and recurrence is relatively common following removal. Multiple KCOTs occur in the basal cell
nevus syndrome (Gorlin-Goltz syndrome), which is also characterised by vertebral and rib anomalies and heavy calcification of the falx cerebri (Fig. 14).

5.4. Uncommon odontogenic cysts

Lateral peridontal cysts are small, and occur lateral to the tooth root, often in the mandibular canine and premolar region. The buccal bifurcation cyst (also known as mandibular infected buccal cyst or paradental cyst) is centred buccal to the root bifurcation of the first or second mandibular molar, often presenting with delayed eruption. The buccal position may be inferred from tilting of the tooth, such that the occlusal surface of the tooth becomes visible, and is confirmed with occlusal films or CT (Fig. 15). The calcifying odontogenic cyst is uncommon, occurring anteriorly in either jaw (most commonly in the maxillary canine region), and internal calcification may be apparent.

5.5. Non-odontogenic cysts

Non-odontogenic cysts specific to the jaws include the nasopalatine duct cyst in the maxillary midline, which has a characteristic heart shape, and may have scalloped margins (Fig. 16). The simple bone cyst, which does not have an epithelial lining, and is therefore not considered a true cyst, can occur in the mandible, where it is sometimes known as a traumatic bone cyst (though no connection to trauma has been shown). As elsewhere in the skeleton, it occurs in the first two decades of life and is commoner in males. Its superior margin often scallops between the roots of the teeth, but it usually has no effect on the teeth themselves.

The so-called Stafne cyst, better termed a lingual mandibular bone depression, is a focal concavity in the lingual aspect of the mandible, classically in the submandibular fossa, close to the inferior margin of the mandible, and usually below the inferior alveolar canal. This is also described further mesially, in the premolar region, and rarely as far distal as the medial surface of the ramus. Although this may have the appearance of a cyst radiographically, the nature of this incidental finding is clear on CT, which also shows that the defect is not necessarily filled with salivary gland tissue (Fig. 17).

6. Odontogenic tumours

Odontogenic tumours comprise 9% of all tumours of the oral cavity. These arise from ectoderm, mesenchyme or a combination of these two tissues (ectomesenchyme) that are involved in the formation of the tooth germ. The recent revised histopathological classification of odontogenic tumours by the World Health Organization (WHO) [6] classified benign odontogenic tumours into four categories according to the tissue of origin.

Category 1: Tumours arising from odontogenic epithelium, e.g. ameloblastoma, keratocystic odontogenic tumour (previously known as an odontogenic keratocyst or OKC), calcifying epithelial odontogenic tumour and adenomatoid odontogenic tumour.
Category 2: *Tumours arising from odontogenic epithelium and mesenchyme with/without hard tissue formation*, e.g. ameloblastoma variants (such as an ameloblastic fibroma), odontoma, calcifying cystic odontogenic tumour (previously known as a calcifying odontogenic cyst).

Category 3: *Tumours arising from mesenchyme and/or ectomesenchyme with/without odontogenic epithelium*, e.g. odontogenic fibroma, odontogenic myxoma and cementoblastoma.

Category 4: *Bone-related lesions*, e.g. ossifying fibroma, fibrous dysplasia (FD), osseous dysplasia, central giant cell lesion, cherubism, aneurysmal bone cyst and simple bone cyst.

*Malignant* tumours are generally considered as the malignant counterpart of these benign categories and are very uncommon. Neoplastic lesions and cysts that arise embryologically from epithelium (ectoderm) appear as *pericoronal* lesions being closely related to the crown of an unerupted tooth (Category 1). In contrast, Category 3 tumours arising from ectomesenchyme are related to the tooth root apex (*periapical* lesions).

6.1. Imaging of odontogenic tumours

Most odontogenic tumours are cysts which are discovered on intra-oral radiographs or dental panoramic tomography. Intra-oral radiographs have extremely high spatial resolution, optimally demonstrating the relationship of a lesion to the tooth crown or apex but due to their small size can only show small lesions less than 20 mm in size. Dental panoramic tomography given a very good overview of medium to large-sized lesions and multiple lesions and bone-related lesions can also be demonstrated.

Multidetector or cone-beam CT has excellent spatial and high contrast resolution. Application of ‘Dentascan’ software allows the production of panoramic, radial and axial 2D reconstructions. Additional software allows the production of maximum intensity projections and 3D volume rendered images. MDCT has the advantage over CBCT of demonstrating soft-tissue detail and allowing accurate measurement of attenuation. Soft-tissue visualisation allows detection of dense keratin debris in kerato-cystic odontogenic tumours (see Fig. 13) and allows distinction between cysts and solid tumours. The extent of a lesion’s relationship to teeth, root resorption, internal structure, cortical expansion and erosion, the boundary of a lesion and the presence of multiple lesions can all be evaluated. Lesions are commonly classified according to the type of matrix into: radiolucent, radiopaque or mixed radiolucent–radio-opaque.

MRI can add specificity in diagnosis allowing accurate distinction of solid and cystic lesions on the basis of signal characteristics and enhancement patterns. Application of specific criteria for diagnosis allows accurate distinction between the keratocystic odontogenic tumour and other odontogenic lesions [7]. The keratin-rich debris in a KCOT shows characteristic central drop in signal on T2-weighted images.

6.2. Radiolucent lesions

Well-defined radiolucent lesions are the commonest radiographic appearance of benign odontogenic cysts and tumours. They are sub-classified as unilocular, lobulated or multilocular depending on their margin and peripheral internal structure. Usually well defined with a corticated margin, this may be lost if secondary infection occurs.

6.3. Ameloblastoma

Ameloblastomas account for 11% of all tumours in the maxillofacial region and are the most common and clinically significant odontogenic tumours. They arise from odontogenic epithelium, cyst formation is common and there are several histological patterns which cannot be differentiated radiologically.
Ameloblastomas predominate in the molar region and ascending ramus of the mandible. They may be unilocular (Fig. 18), multilobular or multilocular (Fig. 19). Unilocular lesions in young people have the best prognosis but solid lesions show high recurrence rates (50–90%). Differentiation from a KCOT and other odontogenic lesions is very difficult by plain radiography and CT, and usually a differential diagnosis is given. The ameloblastoma usually replaces a tooth (especially when multilocular) and produces more marked buccolingual expansion and root resorption than a KCOT.

MRI features of ameloblastomas provide a more specific diagnosis: multilocularity, mixed solid and cystic components, mural and septal enhancement, irregular thickened walls and papillary projections [7] (see Fig. 18).

6.4. Radio-opaque lesions

There is a wide differential diagnosis of sclerotic lesions in the maxilla and mandible. A representative radio-opaque odontogenic tumour is the odontome.

6.5. Odontome (compound and complex)

The odontome is characterised by the proliferation of hard dental tissues and can be classified into two types:

a. Compound—coalescent mass of multiple, deformed tooth-like structures (denticles) and is most common in the anterior maxilla.

b. Complex—is found in older individuals and is most common in the mandibular molar and premolar region. It appears radiographically as a conglomerate mass of densely calcified and ossified tissues.

6.6. Mixed radiolucent and radio-opaque

Lesions of this category include fibro-osseous lesions (FOLs), inflammatory processes (e.g. osteomyelitis, osteonecrosis) and less commonly, odontogenic tumours. Typical tumours in this category include the adenomatoid odontogenic tumour and the calcifying epithelial odontogenic tumour. They will not be discussed further.

7. Non-odontogenic neoplasms of the jaws

A wide variety of non-odontogenic neoplasms can involve the jaws and maxillofacial region. Invasion by squamous cell carcinoma is common (Fig. 20). Lymphoma is relatively common in the head and neck region (Fig. 21). Discussion of the various non-odontogenic tumours is beyond the scope of this review.

8. Maxillofacial infection

Caries (decay of the tooth crown), periodontitis (infection of the supporting structures of the tooth root) or pericoronitis (infection of the gum flap or operculum around a partially erupted tooth) are common problems in the maxillofacial region. They can lead to pain, swelling, and infection. Prevention and proper treatment are crucial to maintain oral health.

Fig. 18. Maxillary ameloblastoma. Initial imaging for a cheek lump was performed with ultrasound (a), which showed a complex mass (arrows) breaching the antral cortex. Coronal bone-algorithm CT reconstruction (b) shows a well-defined opacity in the inferior aspect of the left antrum. This could be mistaken for a retention cyst, but thinning and focal defects (arrowheads) in the antral wall are evident. Coronal gadolinium-enhanced T1W fat-saturated MRI (c) shows a complex lesion with nodular mural enhancement (arrow).
erupted tooth, most commonly a third molar) are the common causes of pyogenic infection in the oral cavity. Depending on the bacterial load and host immunity, this may lead to the formation of pus and acute maxillofacial infection.

8.1. Acute infection

The infection and pus may remain localised and drain intra-orally or extra-orally (i.e. drainage occurring either spontaneously or surgically). Infection may also spread either haematogenously, via the lymphatics or directly, via the deep fascial spaces.

i. Haematogenous: There is an extensive interconnecting vascular network in the maxillofacial region with communication between the extra- and intra-cranial vessels. Veins act as valveless, low velocity conduits which may lead to cavernous sinus thrombophlebitis, orbital cellulitis or a cerebral abscess.
Lymphatic: There is a complex and rich lymphatic system in the maxillofacial region and infection may cause either lymphadenitis or a lymph node abscess.

iii. Direct extension: This is the most common cause. Spread is by pre-determined routes dependent on local anatomy and fascial attachments. The deep fascial spaces of the maxillofacial region communicate freely. A single space or multiple spaces are involved with the same frequency. The buccal space is the most commonly infected space when a single site is involved and the submandibular space, when multiple sites are infected. The predilection for these spaces is because of the proximity of the mandibular molars, the teeth most commonly affected by periapical or pericoronal sepsis.

Most acute maxillofacial infections are minor, localised and respond rapidly to correct medical and surgical management. However, if treatment is delayed and there is significant bacterial load or virulence, then infection may spread along fascial planes to become severe and life-threatening [8], especially when host resistance is impaired. Significant morbidity includes airway obstruction, retrophyangeal abscess, orbital cellulitis, necrotising fasciitis, carotid sheath suppuration, mediastinitis and pulmonary, pleural or pericardial sepsis.

Acute maxillofacial infection is odontogenic in origin in 75% of cases and non-odontogenic in 25%. Odontogenic infections are polymicrobial in nature with anaerobes more common than aerobes (reflecting the oral flora) and streptococci are pre-eminent. In children, infection of the palatine (faucial) tonsil is the most common cause of maxillofacial infection [9]. Streptococci are the most common causative organisms and the major complication is peritonsillar abscesses (quinsy). Infection may spread to the lateral pharyngeal or parapharyngeal spaces and subsequently to the retropharyngeal space.

8.2. Imaging of acute maxillofacial infection

Intra-oral or dental panoramic tomograms provide excellent evaluation of the dentition, periodontium and supporting alveolar bone and should exclude an odontogenic cause for infection in most cases. However, this does depend on radiographic quality and correct evaluation, supplemented by adequate clinical details (Fig. 22).

Cross-sectional imaging (optimally post-contrast MDCT) is required for optimal evaluation of suspected serious or complicated maxillofacial infection. Information is provided concerning:

(a) Source of infection: CT supplements standard radiographic examination. Application of applied anatomy may determine the likely source of sepsis when this is not apparent clinically or radiographically. Sublingual sepsis (above mylohyoid) is caused by sepsis related to tooth roots/apices that lie above the mylohyoid line, i.e. incisors, canines, premolars and first molars.

The apices of third (and usually second) molars lie below the mylohyoid line. Periapical infection therefore passes directly to the submandibular space. The submandibular and sublingual spaces communicate via the posterior, unattached margin of mylohyoid.

(b) Extent of disease: Understanding of fascial boundaries and common patterns of spread of maxillofacial infection are necessary to correctly interpret cross-sectional imaging. From the commonly affected sublingual, submandibular and buccal spaces infection may spread posterio-superiorly to the masticator space and from there to other critical, deep fascial spaces.

(c) Presence of an abscess: If pus is present it should be surgically drained unless spontaneous drainage occurs. Cross-sectional imaging demonstrates a defined fluid collection with an enhancing margin. This must be distinguished from a phlegmon (Fig. 23), which is managed medically.

(d) Complications: Ludwig’s angina is a diffuse infection of the submandibular spaces and the midline submental space without large pockets of pus. Seventy percent of cases result from odontogenic infection. Cellulitis results in rapid airway compromise and is a medical and surgical emergency. Vascular complications and osteomyelitis significantly affect management.

8.3. Osteomyelitis

In the maxillofacial region this is defined as an inflammatory process that involves the marrow and cortex of the maxilla and mandible. Osteomyelitis affects the mandible much more commonly than the maxilla.

Acute osteomyelitis lasts up to 1 month. Subacute osteomyelitis refers to a transitional stage of osteomyelitis including the third and fourth weeks within the initial one month of acute infection. This may heal with appropriate treatment or progress to chronic osteomyelitis, defined as osteomyelitis persisting
Fig. 22. Periapical sepsis presenting with a fistula. Cropped panoramic tomogram (a) shows irregular periapical lucency (arrowheads) associated with the heavily restored lower right first molar tooth, and very subtle periosseous new bone formation (arrow). Panoramic reconstruction from a CT Dentascan (b) shows similar findings. Radial reconstructions from a CT Dentascan (c) show a defect in the buccal cortex (arrow) and extensive periosteous new bone formation. Coronal soft-tissue algorithm CT reconstruction (d) demonstrates the fistula (arrows) extending from the buccal mandibular defect to the skin.

Beyond one month. If preceded by an acute episode it is known as secondary chronic osteomyelitis. Primary chronic osteomyelitis is an insidious disease not preceded by an acute phase. It is usually confined to a hemimandible and includes entities such as diffuse sclerosing osteomyelitis, chronic osteomyelitis with proliferative periostitis (Garre’s osteomyelitis) and non-suppurative osteomyelitis. Rarely, primary chronic osteomyelitis may be a manifestation of systemic disease including chronic recurrent multifocal osteomyelitis (CRMO) and synovitis, acne, pustulosis, hyperostosis and osteitis (SAPHO).

Acute osteomyelitis of the jaws usually results from periapical infection at the apex of a tooth rendered non-vital by carious involvement of the pulp, most commonly a mandibular molar. Non-odontogenic causes are uncommon; haematogenous osteomyelitis most commonly affects the maxilla in children. Secondary chronic osteomyelitis results from persistence of
bacteria in necrotic bone or within tooth fragments despite treatment.

8.4. Imaging of acute osteomyelitis

The acute inflammatory infiltrate of osteomyelitis results in lysis of cancellous bone by osteoclasts. Bone density has to be reduced by 30–50% to be visible on plain radiography and this usually takes 2–3 weeks. Computed tomography (either MDCT or CBCT) depicts the osteopaenia and better demonstrates cortical lysis (including the inferior alveolar canal and mental foramen), sequestra and periosteal new bone formation. This periosteal reaction most commonly affects the buccal plate of the mandibular angle or body. Both CT and MRI show adjacent soft-tissue inflammation especially within the masticator and submandibular spaces. MRI shows soft-tissue involvement in 12% of cases, most commonly in masseter. Multiple studies have demonstrated the high sensitivity of MRI in detecting cancellous marrow abnormality in acute osteomyelitis. This results in reduced T1 signal, increased T2 signal and contrast enhancement of bone and the adjacent inflamed soft tissues. In contrast, abnormalities of cortical bone (e.g. sequestra) are more clearly
shown by CT. Scintigraphy is highly sensitive (up to 100%) in the detection of acute osteomyelitis but requires anatomic correlation. Technetium-labelled compounds depict bone turnover and labelled white cell scans confirm this is due to infection.

8.5. Imaging of chronic osteomyelitis

Plain radiographs, and more accurately CT, demonstrate medullary sclerosis, periosteal reaction and sequestration formation. In secondary chronic osteomyelitis, sequestra occur in approximately 90% of cases (as depicted by CT) and most commonly on the buccal aspect. Periosteal new bone apposition results in cortical thickening and mandibular enlargement, this is more marked in young patients. Swelling of the adja-

Fig. 24. Osteoradionecrosis: bone-algorithm (a) and soft-tissue algorithm (b) axial CT images of the mandible in a patient with a history of prior segmental resection and radiotherapy for squamous cell carcinoma which involved the mandible. Bone sclerosis (arrowheads), a large lucency and a small sequestrum (long arrow) are demonstrated, as is significant soft-tissue swelling in the sub-mandibular space (short arrows). A miniplate and surgical clips are also visible.

Fig. 25. Fibrous dysplasia: cropped orthopantomogram shows a poorly defined lesion centred in the posterior body and angle of the right side of the mandible. Note the superior displacement of the inferior alveolar canal (arrows).

Fig. 26. Fibrous dysplasia: axial CT of the skull base showing ground-glass opacification and expansion in the left sphenoid bone (between arrowheads), surrounding and mildly narrowing the left Vidian canal (white arrows). A second small focus of fibrous dysplasia was also present in the right mandibular condyle (black arrow) and extending into the condylar neck, and this was therefore polyostotic disease.
cent masseter and medial pterygoid muscles is common. Post Gadolinium-enhanced T1-weighted MRI distinguishes sequestra from normal cortical bone and demonstrates periosteal inflammation, important in planning decortication surgery.

In secondary chronic osteomyelitis, sclerosis is commonly mixed with lysis and foci of mixed density giving a heterogeneous appearance. Primary chronic osteomyelitis is characterised by more extensive and diffuse sclerosis sometimes accompanied by expansion. Scintigraphy can be used to monitor disease activity.

8.6. Osteonecrosis

Osteoradionecrosis (ORN) is an uncommon complication of radiation therapy of head and neck tumours, the reported incidence varies from 0 to 37.5%. If radiation induced mucositis persists after a few weeks following treatment, soft-tissue ulceration, bone exposure and eventually bone necrosis occur secondary to impaired vascular and lymphatic flow because of endothelial damage and fibrosis. Because irradiated tissue has a reduced capacity for repair, local trauma is associated with the development of ORN with an initial peak at 3 months following completion of radiotherapy and a second, delayed peak from 2 to 5 years. The mandible and particularly the buccal cortex of the body, are vulnerable to ORN because radiation-induced fibrosis occludes the inferior alveolar artery. Vitality of bone then depends on transcortical vascularisation by the periosteum and muscular insertions.

Typical imaging appearances of established ORN on plain radiography and CT are mixed sclerosis and lysis, sequestra, bone fragmentation, pathological fracture, gas bubbles and soft-tissue swelling [10] (Fig. 24). CT shows radiological changes to be more advanced and extensive than is visible on radiographs. In addition to cortical fragmentation and adjacent soft-tissue swelling, MRI shows diffuse marrow signal alteration with intense enhancement following contrast.

Fig. 27. Cemento-ossifying fibroma. Cropped panoramic tomogram showing a well-defined ovoid mixed radiolucent and radio-opaque lesion (arrows) related to the roots of the lower right first and second molar teeth. Note the apical resorption of the distal root of the 47 tooth (arrowhead).

Fig. 28. Compound odontome. Cropped panoramic tomogram (a) shows a well-defined sclerotic lesion preventing the eruption of the upper right third molar tooth (18), the crown of which is directed distally. There is a thin radiolucent margin around this lesion (arrows), and there is very dense material within it, consistent with enamel. Axial CT (b) confirms the presence of denticles (tooth-like structures) (arrows), pathognomonic of compound odontome.
Increasing therapeutic use of bisphosphonates to decrease bone turnover by inhibiting osteoclast activity is associated with osteonecrosis of the jaws. These drugs have a role in the treatment of osteoporosis, Paget’s disease, pain from osseous metastases and malignancy-related hypercalcaemia. Patients with this condition present with non-healing extraction sockets and painful bone exposure. The most common findings on dental panoramic tomography and CT scans are osseous sclerosis commonly affecting the alveolar margin, thickening of the lamina dura and poor-healing or non-healing extraction sockets [11].

9. Fibro-osseous lesions of the jaws

The term “fibro-osseous lesion” is applied to bone dysplasias and benign bone neoplasms characterised by replacement
of normal bone by a fibrous stroma within which varying amounts of woven bone and cementum-like material are found [12]. This term encompasses three main entities: (1) fibrous dysplasia (which affects extra-gnathic sites as well as the jaws, and is therefore familiar to general radiologists), (2) cemento-osseous dysplasias (COD) (which includes periapical cemental dysplasia (PCD), florid COD and focal COD); and (3) cemento-ossifying fibroma (COF), a benign bone neoplasm which encompasses the previously separate entities of ossifying fibroma and cementifying fibroma, now considered to be parts of the spectrum of a single disease.

Fig. 30. CT of reducing anterior disc displacement with hypermobility. (a) Sagittal oblique soft-tissue reconstruction shows marked anterior displacement of the disc (between arrowheads). (b) With mouth opening, the disc is recaptured (arrowheads) and there is evidence of hypermobility, with excessive anterior translation of the condyle, which lies anterior to the summit of the articular eminence.

Fibrous dysplasia (FD) may be monostotic (about 70%) or polyostotic. Rarely, almost exclusively in girls, the polyostotic form may be accompanied by multiple smoothly-marginated café-au-lait spots and endocrine hyperfunction (classically causing precocious puberty), when it is known as the McCune-Albright syndrome. FD of the maxillofacial region is usually unifocal (i.e. monostotic), although frequently affecting more than one adjacent bone within the facial skeleton, extending in a flowing manner across sutures, but not usually crossing the midline. Radiographically, lesions vary from radiolucent to radio-opaque, frequently with a ground-glass texture, depending on the degree of mineralisation. The margins of the lesion are frequently ill defined in the jaws (although usually well defined

Fig. 31. CT of internal disc derangement and associated arthropathy of the temporomandibular joint. Sagittal oblique soft-tissue algorithm reconstruction (a) shows marked anterior displacement of the disc (between arrowheads), a large superior compartment effusion (large arrow) and evidence of inferior compartment synovitis (small arrow). Sagittal oblique bone-algorithm reconstruction in a different patient (b) shows a small superior condylar cortical erosion (arrow).
elsewhere in the skeleton), and this feature is helpful in distinguishing FD from other radio-opaque lesions. Expansion occurs, usually fusiform in the mandible, and more complex in the maxilla, reflecting the more complex anatomy of the latter; in both cases the underlying morphology of the bone is largely preserved, and this is useful to distinguish FD from a neoplasm such as COF. Because FD has no dental relationship, it is not confined to the alveolar processes; and may superiorly displace the inferior alveolar canal [13] (Fig. 25). CT is useful to assess the precise extent of the lesion in the complex facial skeleton, especially when there is orbital involvement, or involvement of the neurovascular foramina of the skull base (Fig. 26).

Periapical cemental dysplasia is the commonest subtype of cemento-osseous dysplasia. Well-defined lesions typically occur in a periapical relationship to several anterior mandibular teeth, usually in women (90%), especially Asian and black women, over the age of 30. The lesions are asymptomatic, being discovered incidentally on radiographs, and the related teeth are vital. In the early stages, the lesions are radiolucent. With abnormal bone and cementum formation within the fibrous tissue, central radio-opacity appears, and mature lesions are almost completely radio-opaque, although a thin radiolucent margin is usually visible: the latter is helpful in distinguishing the lesion from an enostosis (also known in the jaws as idiopathic osteosclerosis (IOS)). PCD usually affects two or more anterior mandibular teeth. When a single site is involved, the lesion is sometimes known as focal COD. Florid COD is probably the widespread form of PCD, occurring in the same demographic population, but usually affecting three or more quadrants in both jaws. Bone expansion may occur, and the lesions may present with pain, although frequently asymptomatic. Bone cysts may develop, and there is a propensity for osteomyelitis to develop in the poorly vascularised lesions.

Although cemento-ossifying fibroma is classified as a benign neoplasm, it has the same pathology as the other fibro-osseous lesions. It is focal, round or oval, and often causes resorption of tooth roots, as well as displacement (Fig. 27). Although the internal structure can be similar to that of FD, it has well-defined margins and a thin radiolucent line, separating the lesion from surrounding bone. The concentric growth pattern also distinguishes it from FD, the latter tending to expand bone while largely preserving its morphology. A subtype of COF in young patients (under 20), known as juvenile ossifying fibroma (JOF), is a more aggressive, rapidly growing lesion.

Other radio-opaque lesions of the jaws may need to be considered in the differential diagnosis of fibro-osseous lesions. Idiopathic osteosclerosis (i.e. enostosis) and periapical condensing osteitis (CO) lack a radiolucent margin; CO is related to the apex of a carious or heavily restored tooth, while IOS may have a periapical relationship to a vital tooth, or may be unrelated to teeth. Benign cementoblastoma is usually fused to a root, typically that of a mandibular premolar or first molar tooth, and may cause pain which responds to non-steroidal anti-inflammatory drugs. It is well defined and has a radiolucent margin. Hypercementosis is smooth, less nodular, and has a thin radiolucent margin which is continuous with the periodontal ligament space. Compound odontomes are usually easily diagnosed because of the presence of tooth-like structures (denticles) (Fig. 28), but a complex odontome may be harder to distinguish from COD, although the latter tends to have a less well-defined and more irregular radiolucent margin. A flow-chart may be helpful in the diagnosis of radio-opacities within the jaws [12].

10. Temporomandibular joint pathology

Internal disc derangement (IDD) is common, and may be seen in asymptomatic temporomandibular joints. The disc is usually displaced anteriorly or anterolaterally, and less frequently

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**Fig. 32. TMJ osteoarthritis.** CT sagittal oblique bone-algorithm reconstruction (a) shows marked condylar flattening, irregularity and sclerosis and anterior condylar osteophyte (arrow). CT coronal oblique bone-algorithm reconstruction (b): joint space narrowing is typically most severe superolaterally (arrow).
anteromedially. Pure medial and pure lateral displacement are uncommon, and posterior disc displacement is rare [14]. With mouth opening, the disc may be reduced (recaptured) or remain displaced. There may be an associated arthropathy. Joint effusions, synovitis, erosions (usually condylar), and subchondral marrow edema are all well demonstrated with MRI, performed with dedicated surface coils in the closed- and open-mouth positions (Fig. 29). Multidetector CT, also performed in the closed- and open-mouth positions, with sagittal oblique and coronal oblique reconstructions using both bone and soft-tissue reconstruction algorithms, and with careful attention to optimal windowing, can also show disc displacement (Fig. 30) as well as synovitis, effusions and erosions (Fig. 31). Long-standing IDD and the associated arthropathy may progress to osteoarthritis (OA), which is usually apparent on panoramic tomography and MRI, but is optimally visualised with CT (Fig. 32). Fibrous and bony ankylosis are also well seen with CT (Fig. 33). Tumours and tumour-like conditions in the region of the TMJ include osteochondromas (Fig. 34) and synovial chondromatosis (Fig. 35). Ultrasound has been described in imaging the TMJ, but its role is doubtful. Fluoroscopy is useful in guiding joint injections of corticosteroids and local anaesthetic for symptomatic relief; these injections are usually made into the

Fig. 33. TMJ ankylosis. CT coronal oblique bone-algorithm reconstruction of the right temporomandibular joint (a) shows marked joint space narrowing, and relatively congruent irregularity of the condylar and temporal articular surfaces, consistent with fibrous ankylosis. Axial CT of the left temporomandibular joint in a different patient (b) shows early bony ankylosis, with bridging of bone (arrow) in the anterolateral aspect of the joint.

Fig. 34. Osteochondroma. Axial CT (a) and T1W MRI (b) show a large cartilage-capped exostosis (osteochondoma, arrows) projecting anterolaterally from the left mandibular coronoid process (arrowhead), and forming a pseudoarthrosis with the remodelled anterior aspect of the left zygomatic arch. The patient was referred for MRI evaluation of the temporomandibular joints because of severe trismus.
inferior compartment, where the synovitis usually appears more severe.

11. Pre-operative assessment for dental implant placement

Osseo-integrated, root-form implants are the treatment of choice for edentulism, but these require sufficient residual alveolar bone for placement of the titanium implant fixture. Alveolar bone is resorbed in edentulous segments, sometimes quite dramatically, and imaging is required to assess residual bone height, width and quality. Dental panoramic tomography is sometimes used in the initial assessment, but suffers from unpredictable magnification, and does not render an assessment of alveolar bone width in the buccolingual plane. Conventional tomograms may overcome the latter shortcoming and are sometimes useful if a short edentulous segment is being assessed. However, the imaging technique of choice is CT (either multidetector CT or cone-beam CT), with curved (panoramic) and radial reconstructions [15]. Bone height, width and quality are easily assessed on the radial reconstructions. Unerupted teeth and retained root fragments within proposed implant sites are also important findings (Fig. 36).

Within the mandible, the critical structure is the inferior alveolar canal: if this is breached at implant placement, permanent paraesthesia of the lower lip may result. The inferior alveolar canal is usually visible, or its position can be inferred from a

![Fig. 35. Synovial chondromatosis. T2W sagittal oblique MRI (a) demonstrates a large superior compartment effusion (arrows) containing small bodies of approximately uniform size. A reformatted sagittal oblique CT image in the same patient (b) shows the effusion (arrow) and the bodies, some of which are faintly calcified.](image)

![Fig. 36. Retained root fragment on a CT maxilla performed for pre-implant assessment. Axial (a) and sagittal (b) reconstructions show a non-healing extraction socket (arrowhead) in the proposed 12 implant site, with a filled root fragment (arrow) protruding through the buccal cortex.](image)
niche in the lingual cortex. The depth of the submandibular fossa can be assessed. If insufficient bone remains in the mandible, anterior implants can be placed mesial to the mental foramina, and these can be used to support an overdenture. The canal for the incisive artery, mesial to the mental foramina, must not be mistaken for the inferior alveolar canal (Fig. 37).

Fig. 37. Pre-implant assessment in edentulous mandible. Radial (a) and panoramic (b) reconstructions from a CT Dentascan of the mandible. The radial reconstructions show the right mental foramen (MF). Distal to this, there is insufficient bone height for implant placement: the superior margin of the inferior alveolar canal (horizontal white line) is close to the crest of the partially resorbed alveolar ridge. However, implants can be placed in the anterior mandible, mesial to the mental foramina, where the thin canal for the incisive artery (arrow) should not be mistaken for the inferior alveolar canal. Panoramic reconstructions show the inferior alveolar canals (arrowheads). The numbers at the bottom of each image show the site of the corresponding radial reconstructions.

Fig. 38. Buccal bone augmentation graft. Axial image (a) and radial reconstructions (b) from a CT Dentascan of the maxilla show an onlay bone graft, fixed with a screw, in the anterior left maxilla at the site of planned implant placement. Graft union is not complete.

Within the anterior maxilla, the degree of proclination of the alveolar ridge can be assessed, and the size of the nasopalatine canal and its relationship to the proposed implant site noted. Mesio-distal width is frequently narrow: this is best assessed in the axial plane. If the labiopalatal width is narrow, a buccal bone graft may be placed prior to the first stage of implant placement (Fig. 38). Within the posterior maxilla, alveolar bone width is usually adequate, but bone height is often markedly reduced. A maxillary sinus lift procedure, with placement of bone graft in a subperiostial position in the sinus floor, may be used to supplement bone height prior to implant placement. Therefore, antral disease and inferior antral septations should always be noted. Interactive software allows simulated placement of implants of varying size with appropriate angulation avoiding the inferior alveolar canal, nasopalatine canal and maxillary antrum. These reconstructions can be used to make a stent which is worn at the time of surgery and acts as a drill guide for complication-free implant placement, avoiding critical neurovascular structures.
12. Conclusion

We have presented a short review of the commonest problems encountered in maxillofacial imaging, a discipline which straddles the areas of expertise of the head and neck radiologist and the dental radiologist.

References