9 Sinonasal Radiology

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Introduction

Advances in sinonasal imaging have transformed our understanding of the highly variable sinonasal anatomy and have supported progress in endoscopic sinus surgery. Enhanced resolution, lowered radiation dosages and increasing use of image guidance have meant that radiological imaging is central to the planning of sinonasal surgery.

Imaging Techniques and Investigations

Unenhanced CT is the primary imaging investigation in the setting of inflammatory sinonasal disease. Sinonasal imaging focuses on the delineation of bony, soft tissue and air-filled structures, which have inherent high contrast on CT and are easily differentiated. This enables the identification of disease extent, delineation of variant sinonasal anatomy and provides a road-map for surgery. CT is also particularly helpful for the demonstration of calcific or ossific elements (e.g. mycetoma or osteoma) and sinonasal bony changes (e.g. inflammatory or neoplastic bony sclerosis, fungal or neoplastic bony destruction and bony remodelling with polyps or low-grade tumours).

Sinonasal multidetector CT is rapidly performed with a single axial volume acquired at sub-millimetric slice collimation, 180 mm field of view and a low dose (<50 mAS). This provides a volume of reconstructed isotropic data that may be reformatted in any plane (typically at 1 mm slice thickness) without any loss of spatial resolution. Sinonasal anatomy is initially best evaluated in the coronal plane (Fig. 9.1) and this well delineates the ostiomeatal complex (OMC) as well as simulating the sinonasal appearances at endoscopy. The sagittal plane is also useful for assessing the frontal sinus outflows, lamella and sphenoethmoidal recess anatomy (Fig. 9.2). Most modern imaging workstations incorporate multiplanar reformatting functionality, which is ideal for analysing the CT volume of data. The images should be routinely viewed with a bone algorithm and intermediate window widths (e.g. 2500:250 window width:level), however, a standard algorithm and soft tissue window width (e.g. 450:50), as well as a wider window width (e.g. 4000:400),

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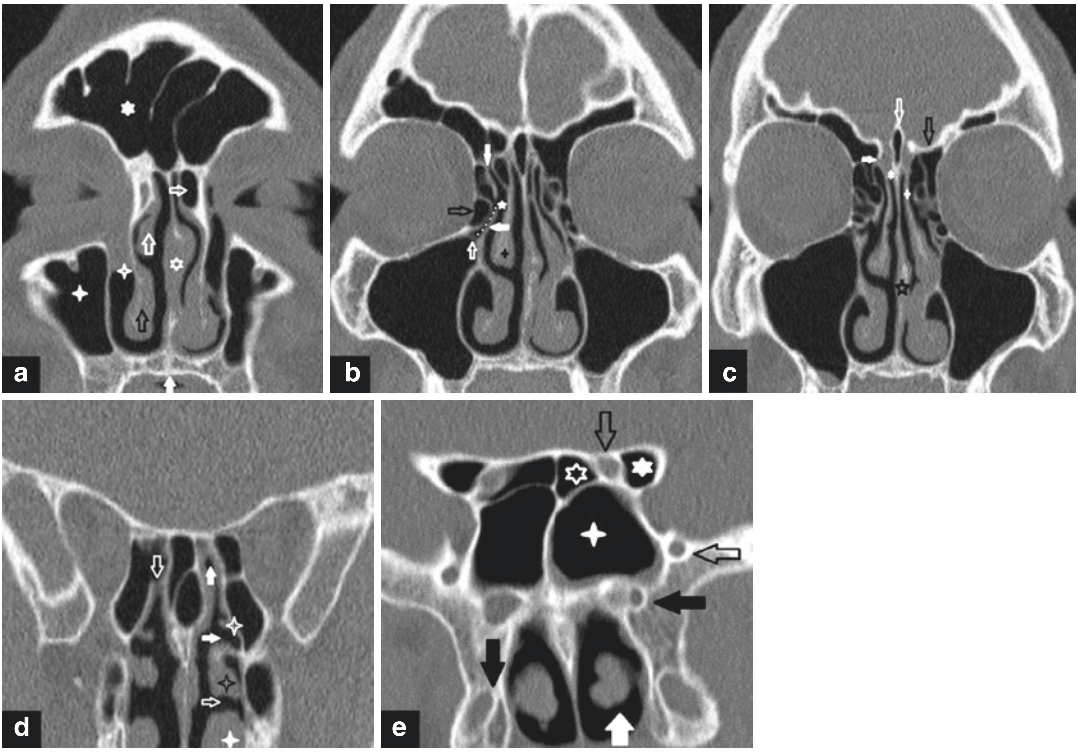

Fig. 9.1 Normal coronal cross-sectional CT anatomy from anterior to posterior. (**a**) Bone windowed coronal CT image of the nasal cavity. The inferior turbinate (black open vertical arrow) and the middle turbinate (white open vertical arrow) are seen to arise from the sidewall of the anterior nasal cavity. They delineate the inferior and middle meati. The nasolacrimal duct (open four pointed star) drains into the inferior meatus. The cartilaginous nasal septum is seen medially (open six pointed star) and is interposed between the major bones of the nasal septum (perpendicular plate of ethmoid superiorly and vomer inferiorly). The floor of the nasal cavity/hard palate is delineated inferiorly (solid white vertical arrow). The anterior maxillary sinus is demonstrated (solid four pointed star) and the infraorbital foramen is seen within its roof. The frontal sinus (solid six pointed star) is shown superiorly. An agger nasi cell, the most anterior ethmoid cell, may be found in 90% of adult specimens (horizontal open arrow) and is a remnant of the first ethmoturbinal and is located within the lacrimal bone. It may narrow the frontal recess, and removing its roof ('uncapping the egg') is key in frontal sinus approaches. (**b**) Bone windowed coronal CT image of the paranasal sinuses. An ostiomeatal complex is a functional unit consisting of the drainage pathway of the middle meatus and the ethmoid air cells, infundibulum and frontal recess. The principal components of the ostiomeatal complex are demonstrated. The maxillary sinus ostium (open vertical arrow) opens into the ethmoid infundibulum (dotted line). The infundibulum is bordered by the uncinate process medially (white horizontal arrow) and the ethmoid bulla laterally (black open arrow). There is subsequent drainage via the hiatus semilunaris (six pointed star) and the middle meatus. The middle meatus is delineated medially by the middle turbinate (black four pointed star). Frontal sinus drainage (white vertical arrow) into the middle meatus is also shown. (**c**) Bone windowed coronal CT image of the paranasal sinuses. The major anatomical structures of the median anterior skull base are shown at the naso-ethmoid roof. The vertical (pneumatised) crista galli (open vertical white arrow) and the horizontal cribriform plate (solid six pointed star) are derived from the ethmoid bone and form the roof of the nasal cavity. The fovea ethmoidalis (open black arrow) is derived from the frontal bone and forms the roof of the ethmoid labyrinth. The vertical lateral lamella (horizontal solid white arrow) connects the fovea ethmoidalis to the cribriform plate. This is also the point of attachment of the vertical lamella of the middle turbinate (solid four pointed star) and is a potential point of weakness following turbinectomy. The bony nasal septum at the junction of the vomer and the perpendicular plate of ethmoid (black open five pointed star) is often the site of a septal spur. (**d**) Bone windowed coronal CT image of the posterior nasal cavity. The posterior nasal cavity is the site of drainage of the posterior ethmoid air cells and sphenoid sinus. The sphenoid sinus drains through the sphenoid sinus ostium (open vertical white arrow) and sphenoethmoid recess (solid vertical white arrow). The inferior (solid white four pointed star), middle (open black four pointed star) and superior (open white four pointed star)

may also be useful to fully assess the soft tissue and bony structures.

In the context of complex infectious or neoplastic pathology (and if a concurrent MRI is not available) an increased mA (radiation dose) study with intravenous contrast and 3 mm thick reconstructions helps optimise the soft tissue appearances. If only bone detail is required, then CBCT is evolving as a low dose technique to evaluate the sinonasal bony structures. CT angiography (for demonstration of the arterial system) or CT cisternography (to evaluate CSF rhinorrhoea) are additional but rarely used CT-based techniques.

MRI is complementary to CT for characterising and demonstrating the extent of complex infectious or neoplastic processes within the sinonasal region, particularly when there is extra-sinus extension of pathology. The superior contrast resolution of MRI allows tumour to be distinguished from inflammatory processes, and hence the intra-sinus extent of tumours is better delineated. There is also a more accurate assessment of perineural, skull base, intracranial and orbital extension of disease. Occasionally MRI is used to assess the presence or extent of sinonasal inflammatory disease (e.g. when CT assessment of bony anatomy is already available or surgery is not anticipated). MRI also provides a combined evaluation of sinonasal and intracranial structures in the setting of olfactory dysfunction, developmental nasofrontal lesions and CSF rhinorrhoea or potential cephalocele.

MRI requires a combination of coronal and axial T1 weighted (T1W), T2 weighted (T2W) and gadolinium-enhanced T1W images, with sagittal sequences added for the assessment of midline pathology. Imaging is generally performed with 3–4 mm slice thickness and no interslice gap, with an optimal field of view of 16–18 cm. Supplementary volumetric sequences may be used for image-guided surgery, radiotherapy planning and (with 3D heavily T2W sequences) to demonstrate a CSF leak or cephalocele. Higher resolution (e.g. 512 × 512 matrix) sequences are also useful to evaluate the integrity of bone and periosteum at the anterior skull base or to assess for perineural spread. Fat suppressed sequences are often included for imaging the extra-sinus facial structures and the central skull base. In the setting of uncomplicated inflammatory disease or olfactory dysfunction, a simple MRI protocol is utilised without the need for gadolinium-enhanced imaging.

Sinonasal Anatomy

A full description of sinonasal anatomy is beyond the scope of this text, and readers are encouraged to read an anatomical text for the basic anatomy [1] and the European Position Paper on the Anatomical Terminology of the Nose and Paranasal Sinuses for an excellent description of current terminology and common anatomical variants [2]. Clinical anatomy teaching traditionally describes nasal anatomy in the parasagittal plane, describing the lateral nasal wall of the nose in terms of the space relating to the inferior, middle and superior turbinate, termed the inferior, middle and superior meatus, respectively. The middle meatus, the area of lateral wall covered medially by the middle turbinate is functionally the most

turbinates delineate the superior (solid horizontal white arrow) and middle (open horizontal white arrow) meati. The posterior ethmoid air cells and the sphenoid sinus (via the sphenoethmoid recess) drain into the superior meatus. (**e**) Bone windowed coronal CT image of the sphenoid sinuses. The sphenoid sinus (solid white four pointed star) and median central skull base are demonstrated. A horizontal septum within the sphenoid sinus separates a sphenoethmoidal (Onodi) cell (open white six pointed star). The Onodi cell represents an extension of the posterior ethmoid air cells superior to the sphenoid sinus and lies immediately adjacent to the optic nerve canal (vertical black open arrow) which is hence endangered during total ethmoidectomy. Further variant anatomy is seen with a pneumatised anterior clinoid (solid white six pointed star) lateral to the optic nerve canal. The superolateral foramen rotundum (open horizontal black arrow) and the inferomedial vidian canal (solid horizontal black arrow) are seen within the body of sphenoid and are just superior to the pterygoid base. The pterygoid plates are seen inferiorly (solid vertical black arrow). The dorsal nasal cavity (white solid vertical arrow) is seen at the level of the posterior choana with the inferior turbinates projecting within the lumen

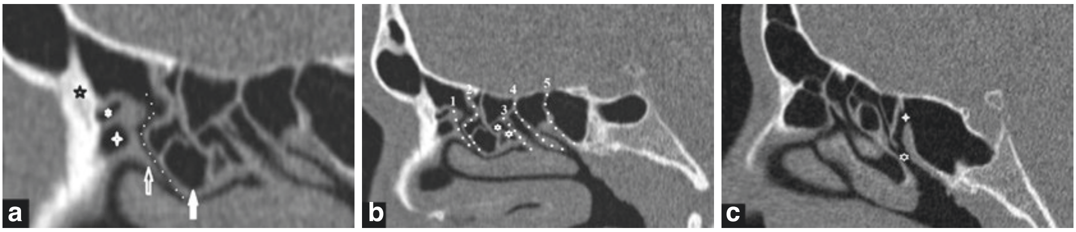

Fig. 9.2 Pertinent sagittal cross-sectional CT anatomy. (**a**) Bone windowed sagittal CT image of the paranasal sinuses. The sagittal plane is optimal for demonstration of the frontal sinus outflows. The nasofrontal beak is seen as an area of bony thickening (black open six pointed star) anterior to the frontal sinus ostium. More distally, the inferior frontal sinus outflow (dotted white line) is delineated by the agger nasi cell (white four pointed star) or the uncinate process (white open vertical arrow) anteriorly, and the ethmoid bulla (white solid vertical arrow) posteriorly. Note that a single anterior frontoethmoidal (Kuhn type 1) air cell is seen just superior to the agger nasi cell (black open five pointed star). (**b**) Bone windowed sagittal CT image of the paranasal sinuses. The lamellae of the nasal capsule are shown. These are 1: the uncinate plate, 2: the anterior aspect of the ethmoid bulla, 3: the basal lamella of the middle turbinate, 4: the lamella of the superior turbinate, 5: the face of the sphenoid sinus. The cleft between the posterior ethmoid bulla and the basal lamella of the middle turbinate is termed the lateral sinus of Grunwald (open white stars). These lamellae obliquely traverse the ethmoid labyrinth and extend from the lateral nasal wall to the skull base, forming important surgical landmarks as they segment the sinonasal cavity. Of note is that the basal lamella separates the anterior from the posterior ethmoid air cells. (**c**) Bone windowed sagittal CT image of the paranasal sinuses. The sphenoid sinus drainage pathway is well demonstrated on sagittal images, with delineation of the sphenoid sinus ostium (white four pointed star) draining into the sphenoethmoid recess and the superior meatus (white open six pointed star)

important, enclosing the drainage pathways of frontal, maxillary and anterior ethmoid sinuses.

In clinical practice and surgical approaches, the nose is viewed in the coronal plane, and it is cross-sectional imaging in this plane that is most useful for interpretation. We, therefore, describe a full coronal series below with relevant anatomical features (Fig. 9.3).

Clinical Applications of Sinonasal Radiology

Inflammatory Sinus Disease

Acute Rhinosinusitis and Its Complications

Radiological imaging is rarely required in uncomplicated acute sinusitis, and indeed may not be helpful in making the diagnosis, as diffuse mucosal opacification is also found in the common cold [3]. However, a contrast-enhanced CT should be performed expeditiously when orbital or intracranial complications are suspected.

Orbital Complications

Orbital complications are the most common infective complication of sinusitis.

Patients with preseptal signs only (lid swelling but no ophthalmoplegia or chemosis) may be treated with initial medical therapy and close observations. A CT scan should be organised without delay if there is no clinical resolution after 24 h or at the earliest indication of deteriorating orbital, visual and/or intracranial signs. The CT scan should be contrast enhanced—this must be specifically requested as it is not routinely part of a standard CT sinus series and is often missed as many such requests are made out of regular clinical hours. Contrast-enhanced CT effectively distinguishes between a pre and post-septal orbital infection and between inflammatory cellulitis/phlegmon versus abscess.

The presence, location and volume of periorbital, orbital and intracranial collections must be clearly defined to facilitate surgical drainage. Figure 9.4a demonstrates a medially placed and Fig. 9.4b demonstrates a superiorly placed subperiosteal abscess.

Fig. 9.3 Common anatomical variants of functional or surgical significance. (**a**) Bone windowed coronal CT image of the paranasal sinuses. The low lying and asymmetrical naso-ethmoid roof. The horizontal plane of the fovea ethmoidalis usually passes through the upper third of the corresponding orbit. Here we see the right fovea ethmoidalis attached to the mid-orbital plane (black open horizontal arrow). Asymmetry of the naso-ethmoid roof may also predispose to intracranial penetration; in this case, the cribriform plate is noted to be more inferiorly located on the right (vertical black open arrow on right; vertical white open arrow on left) with a sloping right lateral lamella. (**b**) Bone windowed coronal CT image of the paranasal sinuses. An air cell within the bullous portion of the middle turbinate is termed a concha bullosa (white open six pointed star). A large concha bullosa may obstruct the middle meatus and obstruct surgical access. There is an associated deviation of the bony nasal septum to the right (black open five pointed star) which may interfere with surgical exposure and result in symptoms of nasal obstruction. There is frequently a compensatory reduction in the size of contralateral nasal cavity structures such as the middle turbinate (black solid four pointed star). (**c**) Bone windowed coronal CT image of the paranasal sinuses. The anterior ethmoidal artery is a branch of the ophthalmic artery which exits the orbit (black open horizontal arrow) and passes to the anterior cranial fossa within the frontoethmoid suture. The canal is located in a similar coronal plane to the posterior globe. When the ethmoid labyrinth is well pneumatised, the canal may be dehiscent (white open vertical arrow) and the vessel lies just deep to the sinus mucosa. Thus there is potential for injury, retraction of the artery into the orbit and an orbital haematoma. A paradoxical middle turbinate (white open five pointed star) is characterised by a lateral rather than a medial convexity and it may interfere with surgical access to the ostiomeatal complex. Anatomical variations are common in the sinuses; an excellent description is presented in the European Position Paper on the Anatomical Terminology of the Internal Nose and Paranasal Sinuses [2]

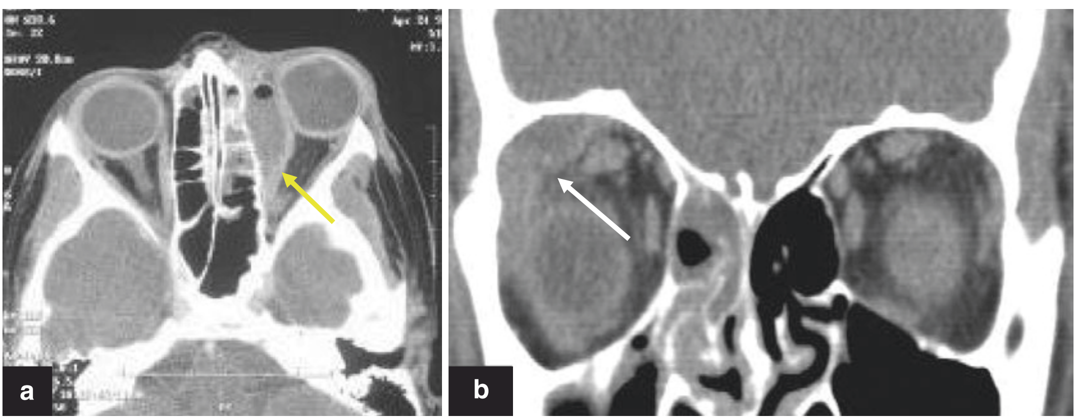

Fig. 9.4 Soft tissue windowed, post-contrast axial (**a**) and coronal (**b**) CT images of different patients. Image (**a**) demonstrates left ethmoidal opacification with a medially placed subperiosteal abscess (yellow arrow) and left-sided proptosis. Image (**b**) demonstrates a superolateral subperiosteal abscess (white arrow) secondary to right frontoethmoidal sinusitis

Cavernous Sinus Thrombosis

Cavernous sinus thrombosis (CST) is a rare complication of sinusitis with a high morbidity and mortality. Clinical features include bilateral proptosis, chemosis, ophthalmoplegia, high fever and retro-orbital pain. The condition advances rapidly due to the absence of valves in the orbital veins allowing blood to flow towards and away from the cavernous sinuses. Early and aggressive intravenous antibiotic administration is recommended. Although *S. aureus* is the cause in the majority of cases, broad-spectrum coverage for Gram-positive, Gram-negative and anaerobic organisms should be instituted pending cultures. Surgical intervention, provided the patient is fit for anaesthesia, may involve drainage of the sinuses and any associated orbital or intracranial abscess and optic nerve/orbital decompression if visual acuity is threatened. Debate surrounds the role of anticoagulation in the treatment of CST, but a recent Cochrane review of two small trials suggests a beneficial tendency [4] and should be considered to prevent further thrombosis. The cavernous sinuses may be imaged with contrast-enhanced CT or MRI, with characteristic features of CST including expansion, filling defects, narrowing of the cavernous carotid arteries and dilated superior ophthalmic veins.

Intracranial Complications

Intracranial extension occurs in approximately 4–5% of patients admitted with acute or acute-on-chronic sinusitis [5]. Intracranial complications are potentially life threatening and include meningitis, extradural or subdural abscesses, venous sinus thrombosis and intraparenchymal brain abscess, the latter of which are single in the majority of cases.

Infection can gain access to the intracranial compartment by several mechanisms:

- *Haematogenous spread* is thought to be the main mechanism for the development of an intracranial intraparenchymal brain abscess with the majority located in the frontal lobes.
- *Retrograde thrombophlebitis* in the valveless venous system, principally via the ophthalmic veins.
- *Direct extension* through a dehiscence in the wall of adjacent sinus cells.
- Brain abscesses may form secondary to venous obstruction causing ischaemia and necrosis.

The commonest responsible micro-organisms are anaerobic (isolated in over two-thirds of cases), aerobes (most commonly *S. Aureus* and *H. Influenzae*) and microaerophilic streptococci. Studies have shown a good correlation in the microbiological findings between the sinus and intracranial abscess [6]. Early and aggressive management with intravenous antibiotics can prevent conversion of cerebritis to abscess formation. Once an abscess forms, surgical drainage with prolonged antibiotic therapy is recommended. The role of steroid therapy is controversial, balancing the risk of immune suppression and progression with the need to reduce cerebral oedema. Contrast-enhanced CT may be appropriate in the emergency setting, however, the superior contrast resolution of a contrast-enhanced MRI helps define intracranial sepsis when an epidural abscess, subdural abscess, cerebritis, intracerebral abscess or venous sinus thrombosis may be demonstrated.

Pott's Puffy Tumour

Purulent frontal sinusitis which causes osteomyelitis of the anterior bony table and a subperiosteal abscess has previously been described as Pott's puffy tumour. Sequestration and necrosis of the underlying bone may occur, with fistula formation over the forehead and into the upper lid. Diagnosis is easily confirmed on CT scanning. Intravenous antibiotics, whilst essential, are often not sufficient to eradicate the severe infection and surgical drainage is usually required.

Chronic Rhinosinusitis

Diagnosis of Chronic Rhinosinusitis

The major symptoms of sinusitis (nasal obstruction, mucopurulent nasal discharge, facial pain, anosmia) are not specific, and only 40% of patients meeting a symptomatic definition of

Chronic Rhinosinusitis (CRS) have supporting evidence of disease on CT imaging [7]. The CT scan must be interpreted with caution as limited mucosal abnormalities are common in the healthy population, who have been shown to have a mean Lund-Mackay score of 4.3 [8]. Mucosal thickening, polyps, fluid levels and obstruction of the ostiomeatal complex would be supportive of a diagnosis of CRS.

For those with no abnormal endoscopic findings, 70% will also have a normal CT. CT imaging is usually reserved for patients with CRS who have failed a trial of appropriate medical therapy, but in those with negative endoscopy there is a role for upfront CT imaging to avoid unnecessary medical treatment and delays in the correct diagnosis (such as rhinitis or atypical facial pain) [9], and has been shown to be more cost-effective than empirical management in this setting.

Caution should be exercised before proceeding with surgery in a patient with a near normal scan, although there may be times when isolated sinus opacification or limited disease can be correlated with localised symptoms. Surgery in the presence of a normal CT scan is almost never justified, except perhaps in cases of recurrent acute rhinosinusitis with normal intervening episodes in which there might be no positive clinical or radiological signs, or in cases of sinus barotrauma.

Sinus Barotrauma

Case Study 1:

A 40-year-old male who was required to fly on a weekly basis for business presented with a clear history of sinus barotrauma on plane descent. CT imaging revealed large agger nasi cells and limited associated bilateral frontal sinus mucosal thickening (Fig. 9.5).

The patient was treated with balloon sinuplasty under local anaesthesia with excellent symptomatic improvement.

Learning Point This patient was essentially asymptomatic in-between episodes of barotrauma. With minimal disease on the CT scan, a minimally invasive surgical approach to deal with the large agger cells and frontal narrowing can strike the right balance between adequate disease management and risk reduction.

Mucous Retention Cysts

Case Study 2:

A 45-year-old male presenting with severe bilateral facial pain (5/5) but mild nasal obstruction (1/5) and nasal discharge (1/5) underwent endoscopic sinus surgery. He had very limited left ethmoid opacification, patent OMCs and a large right maxillary sinus cyst (Fig. 9.6), which was

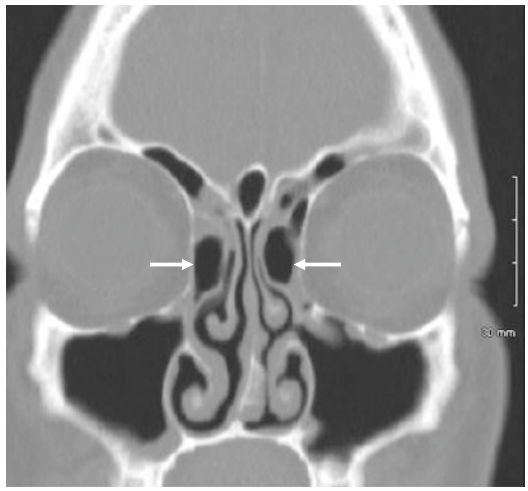

Fig. 9.5 Bone windowed coronal CT image of the paranasal sinuses of a 40-year-old patient with sinus barotrauma. Minimal disease was noted on CT, however, there were bilateral large agger cells (white arrows), narrowing the frontal sinus outflow. This was treated with balloon sinuplasty

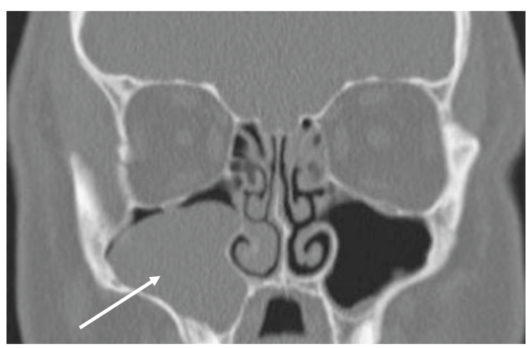

Fig. 9.6 Bone windowed coronal CT image of the paranasal sinuses. A patient with atypical facial pain was noted to co-incidentally have a right maxillary sinus inclusion cyst (white arrow)

thought to be the cause of his symptoms. There was no response to surgery but the patient improved significantly after a course of nortriptyline supporting the diagnosis of neuropathic pain.

Isolated mucosal retention cysts are prevalent in patients in the absence of sinus or dental disease and are usually asymptomatic. A study of 257 patients undergoing ophthalmological imaging found maxillary mucosal cysts in 35% [10]. Surgery is not normally indicated; indeed these can often be confusing in the setting of atypical facial pain or other sinonasal symptoms.

Learning Point Facial pain in the absence of nasal obstruction or mucopurulent rhinorrhoea is unlikely to be due to sinonasal disease. Treatment of the mucous retention cyst would not be predicted to improve symptoms and surgery should therefore be avoided.

Odontogenic Sinusitis

Case Study 3:

A 56-year-old male presented with heavy purulent discharge from the left nostril.

Signs of dental disease were identified on CT (Fig. 9.7) and appropriate treatment provided. Nasal purulence settled with conservative management and surgery was not required.

Fig. 9.7 Bone windowed coronal CT image of the paranasal sinuses demonstrating periapical odontogenic infection of an upper left maxillary tooth with associated left maxillary sinus mucosal thickening in keeping with odontogenic sinusitis

As this case demonstrates, imaging can detect alternative underlying causes. The dentition should be included within the imaging field and inspected for signs of disease—in particular, apical lucency is a common finding. Dental disease should be fully treated before embarking on sinus surgery, except in the case where complete obstruction of the sinus occurs and when an extraction is required, where a combined approach is advised.

Learning Point Primary treatment of associated dental disease should precede sinus surgery.

Allergic Fungal Sinusitis

Allergic fungal sinusitis is a type 1 and 3 mediated hypersensitivity reaction in immunocompetent patients. The diagnosis is often made on the basis of characteristic image findings in association with Chronic Rhinosinusitis with Nasal Polyps (CRSwNP), a positive skin prick test result to fungi and isolation of fungal hyphae within nasal mucin. The majority of affected sinuses show near complete opacification, although the disease can be unilateral. Non-contrast enhanced imaging typically demonstrates hyperdense central material with a peripheral rim of hypodense mucosa. There is expansion, remodelling and thinning of the sinus bony walls with focal dehiscence in some cases. MRI can have variable T1W signal appearances and often a low (dark signal void) T2W signal is characteristic (Fig. 9.8). This latter finding is thought to be due to high concentration of metals such as iron, magnesium and manganese (concentrated by fungi) as well as highly proteinaceous desiccated mucin. Surgery is usually required in these patients as the sinuses must be cleared of all secretions.

Preoperative Planning

A CT scan is mandatory prior to undertaking endoscopic sinus surgery for CRS, with the aims of reducing surgical complications through the identification of anatomical variations, and to plan the surgical approach required. Complications arising in the absence of pre-operative imaging would be difficult to defend medicolegally.

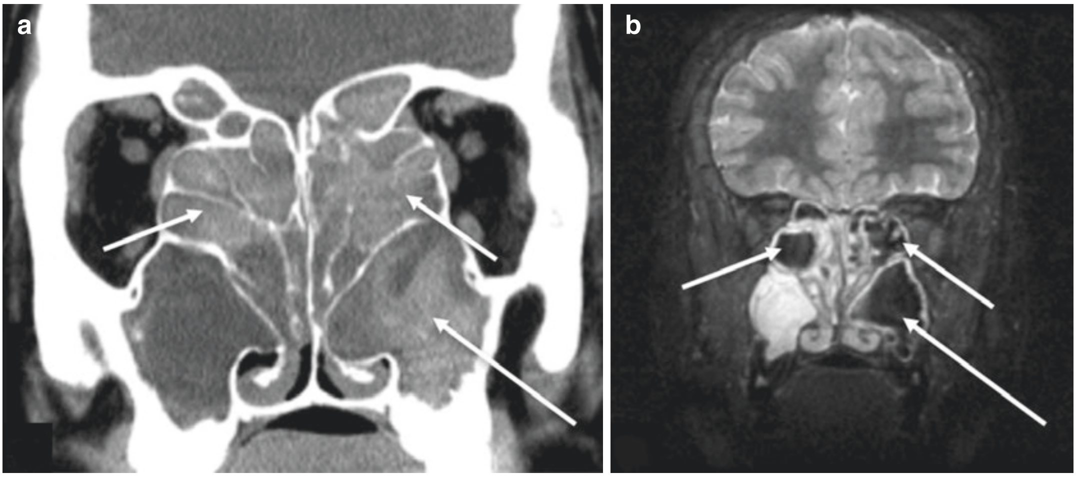

Fig. 9.8 Soft tissue windowed coronal CT image (**a**) and T2W fat saturated coronal MRI image (**b**) demonstrating allergic fungal rhinosinusitis. Image (**a**) shows hyperdense fungal material centrally with bony remodelling and sinus expansion. The hyperdense fungal material on CT corresponds with dark signal void on the T2W MRI image (white arrows)

Preoperative Checklist

The pneumonic CLOSED provides a framework with which to systematically review the pre-operative CT scan.

C	Cribriform	Depth, asymmetry
L	Lamina	Areas of dehiscence
O	Onodi	Presence of a sphenoethmoidal cell
S	Sphenoid/skull base	Septations, dehiscence of carotid or optic nerves
E	Ethmoid arteries	Position in relation to the skull base
D	Dentition may be overlooked	Reminder that odontogenic disease frequently causes maxillary sinusitis

C—Cribriform

Much is made of the Keros classification, which measures the depth of the cribriform niche (Type 1: 1–3 mm; Type 2: 4–8 mm, Type 3: >9 mm), but in reality, it has little clinical value. What is of more relevance is the presence of significant asymmetry in the height and slope of the niche (Fig. 9.9), with the lower side presenting a greater risk of penetration during surgery, particularly if the contralateral side has been addressed first.

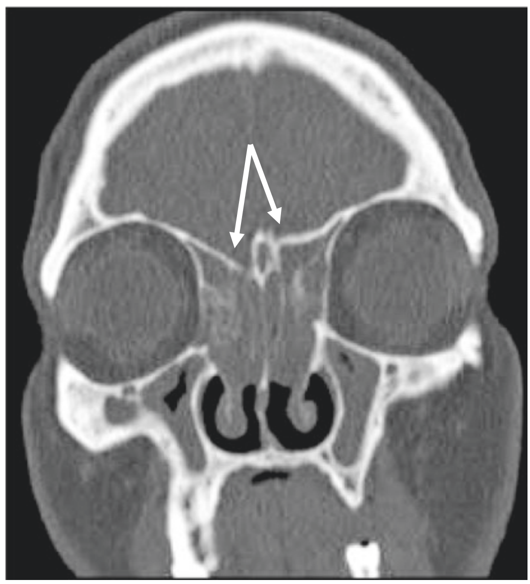

Fig. 9.9 Bone windowed coronal CT image demonstrating asymmetry of the skull base at the cribriform niche (white arrows)

L—Lamina papyracea

The lamina papyracea may be dehiscent congenitally or as a result of previous orbital trauma or

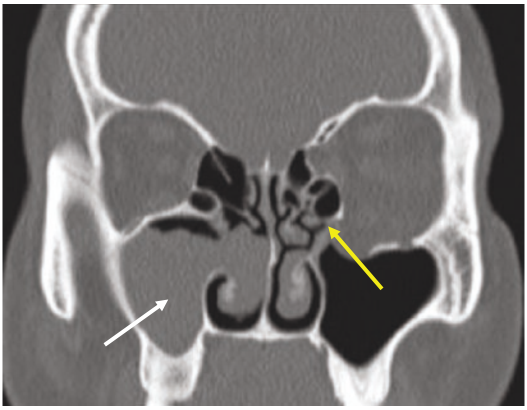

Fig. 9.10 Bone windowed coronal CT image demonstrating a right maxillary sinus inverting papilloma (white arrow) with dehiscence of the lamina papyracea on the contralateral side (yellow arrow)

mucoceles, allowing the orbital contents to be displaced into the surgical cavity (Fig. 9.10). It is also important to examine the relationship between the uncinate process and the lamina papyracea. Uncinectomy in the presence of a lateralised uncinate process, for example in cases of silent sinus syndrome, places the orbit at risk unless performed in a retrograde manner.

O—Onodi (Sphenoethmoidal) Cell

These are thought to arise from posterior ethmoid cells which have pneumatised above and lateral to the sphenoid sinus. They are of particular relevance if the sphenoid is approached through the posterior ethmoid cells, as failure to recognise their presence may risk damage to the optic nerve (Fig. 9.11). They appear as a horizontal bar dividing the sphenoid in the coronal plane (Fig. 9.12), but inspection in the parasagittal plane will reveal their true relation with the sphenoid sitting below.

S—Sphenoid Sinus and Skull Base

The sphenoid sinus is examined for dehiscence in the superolateral walls that may expose the optic nerve or carotid arteries (Figs. 9.13 and 9.14), for asymmetry in size and for the insertion of bony septae (as these commonly insert over the carotid arteries, and avulsion of which may therefore risk a severe bleed).

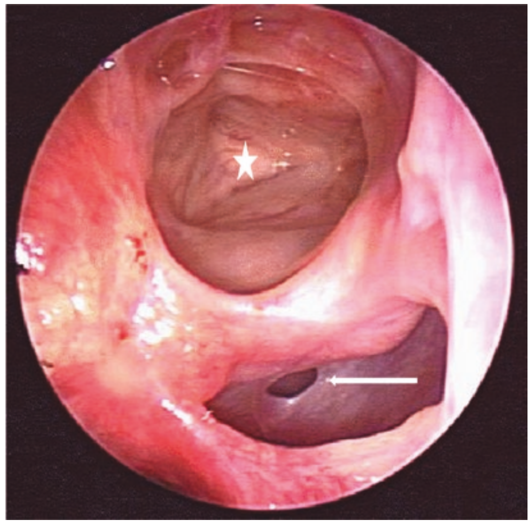

Fig. 9.11 Endoscopic image of a sphenoethmoidal cell with the optic nerve visible (white star) in the posterior wall, and sphenoid ostium visible inferiorly to the cell (white arrow)

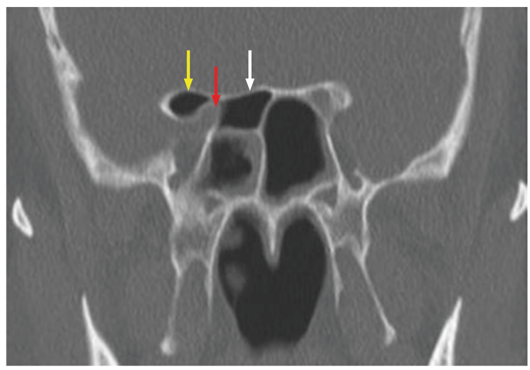

Fig. 9.12 Bone windowed coronal CT image demonstrating a sphenoethmoidal cell sitting above the right sphenoid sinus (white arrow), adjacent to the right optic nerve (red arrow). There is pneumatisation of the right anterior clinoid process (yellow arrow)

Depending upon the degree of pneumatisation, there may also be lateral sphenoid extensions separating the vidian and pterygopalatine canals.

The skull base should be examined generally for asymmetry or bony dehiscence, which can be found following previous surgery or in the setting of inflammatory or malignant disease (Fig. 9.15).

Fig. 9.13 Bone windowed coronal CT image demonstrating dehiscence of the planum sphenoidale (white arrow) and osteitis

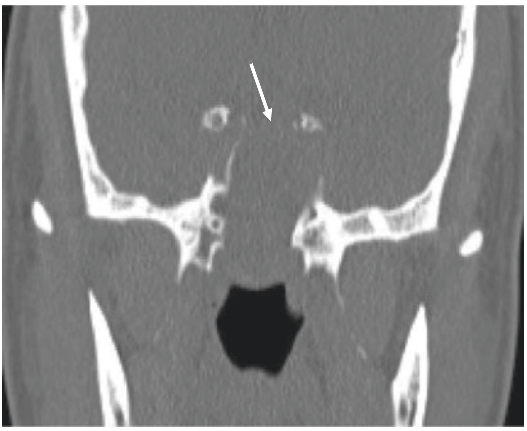

Fig. 9.14 Bone windowed coronal CT image demonstrating an expansile sphenoidal mass with destruction of the bony margins (white arrow)

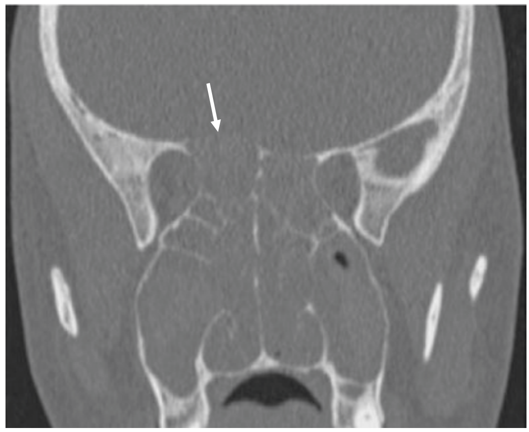

Fig. 9.15 Bone windowed coronal CT image demonstrating dehiscence of the skull base (white arrow) related to long-standing paranasal bilateral CRSwNP

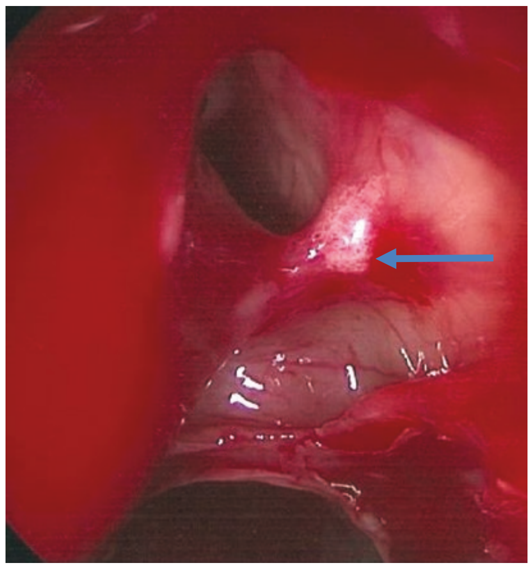

Fig. 9.16 Endoscopic image of the anterior ethmoid artery emerging from the orbit on the left side and traversing an ethmoidal cell (blue arrow)

E—Ethmoid Arteries

The ethmoid arteries are branches of the ophthalmic artery that traverse the roof of the ethmoid air cells before re-entering the anterior cranial fossa. The posterior ethmoid artery almost always crosses within the ethmoid roof, but the anterior ethmoid artery may cross as much as 5 mm below the roof in a mesentery, exposing it to risk of avulsion during surgery. Retraction of the arterial stump into the orbit may cause an orbital haematoma and irretrievable loss of vision. It is therefore essential to identify the artery on pre-operative CT and remain vigilant during surgery. The artery is frequently exposed within a supraorbital ethmoid cell (Fig. 9.16), where it can be found in its posterior margin. It may be identified on CT by finding 'Kennedy's nipple'; the only well-defined corticated break in the lamina papyracea where the artery emerges between the medial rectus and superior oblique muscles (Fig. 9.17).

Surgical Planning

Once the checklist has been performed, attention progresses to planning the surgical approach. Disease extent should be assessed, and usually matched by the extent of surgery. Most inflammatory disease is accessible endoscopically, but when disease progresses beyond the mid-pupillary line in the coronal plane in the frontal sinus access is increasingly difficult, and consideration should be given to external approaches in these cases. The need for specialised instrumentation (angled debriders, burrs, fluorescein for occult CSF fistulae) can normally be anticipated by careful preoperative review of the radiology.

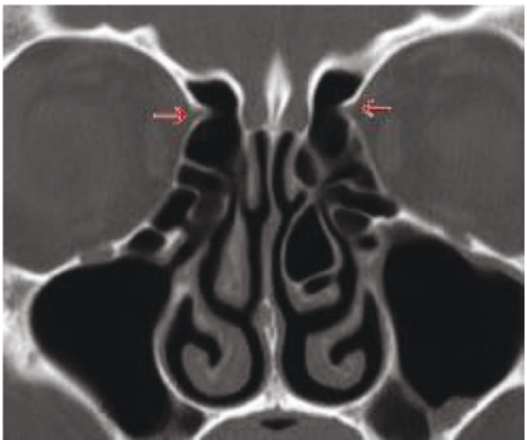

Fig. 9.17 Bone windowed coronal CT image with the anterior ethmoid artery emerging from the orbit below the skull base (red arrows)

The anatomy of the frontal sinus should be studied, paying close attention to the presence and anatomical relationships of frontoethmoidal cells located in or below the frontal recess. It may useful to try to map the relationship between the cells in the frontal and ethmoid region as a series of building blocks to help with surgical planning. Multiplanar software and augmented reality image guidance can facilitate orientation.

In the presence of complex anatomy (Fig. 9.18), or when previous surgery or disease has eroded natural landmarks, intra-operative image guidance may be used to aid real-time localisation of surgical tools. A tracking system (e.g. optical or electromagnetic) simultaneously references a sensor on a surgical instrument with the patient and a preoperative or intraoperative imaging data set (using volumetric CT or MRI). Whilst image guidance is no substitute for sound anatomical knowledge, it may confirm correct identification, and there is some evidence that this may reduce the risk of complications [11].

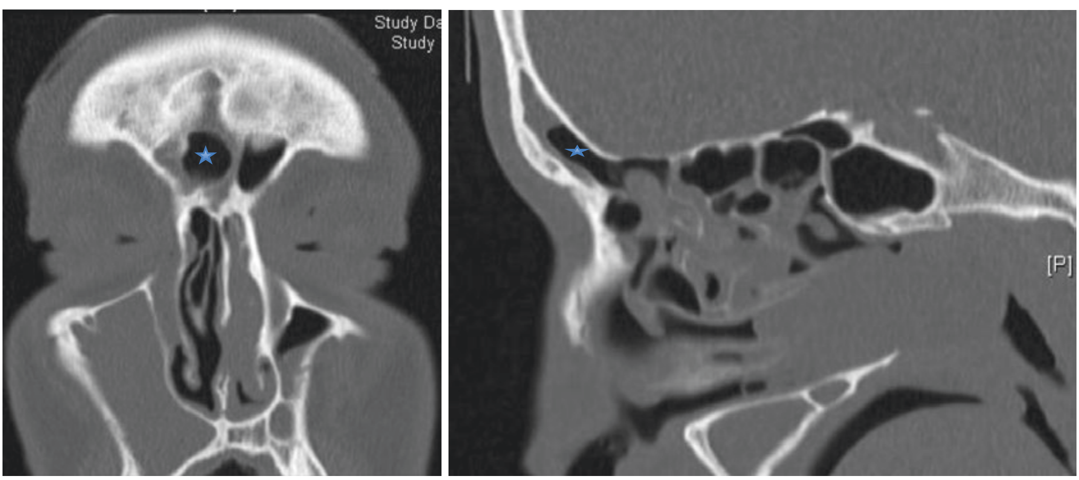

Fig. 9.18 Bone windowed coronal (left) and sagittal (right) CT images demonstrating the complex frontal sinus anatomy with a posterior frontoethmoidal cell (blue star)

Assessment of Recalcitrant FESS

When surgery has failed to improve inflammatory disease, and CT imaging has identified remedial technical failures, such as a retained uncinate (Fig. 9.19), restenosis, adhesions or incomplete dissection, image guidance can be of particular assistance, particularly in the vicinity of critical anatomical boundaries or structures.

Non-infective Complications of Sinusitis

Mucocele

A mucocele is a chronic cystic lesion arising from the paranasal sinuses. Owing to the presence of pseudostratified ciliated columnar epithelium containing goblet cells, mucus build up results in progressive expansion over the course of many years. Likely aetiologies include obstruction of the sinus ostium, often caused by previous surgical procedures (particularly in the case of the frontal sinus), or obstruction of a minor salivary gland (either secondary to trauma or infection/inflammation) which subsequently leads to accumulation of mucus. It is unusual for mucoceles to be accompanied by symptoms of acute or chronic sinusitis although pyoceles may develop secondarily.

Frontoethmoidal mucoceles are the most common type, likely due to the tight anatomical boundaries of the frontal recess which is more prone to obstruction following a minor traumatic or infective insult. Symptoms include frontal headache, proptosis and inferolateral displacement of the orbit, although the degree of diplopia that ensues correlates more closely with the rapidity with which the mucocele develops rather than its eventual size.

Sphenoid and sphenoethmoidal mucoceles are associated with headache and pain in the occipital, vertex and retro-orbital areas. Visual field disturbances are more likely than diplopia and globe displacement, although the latter do occur with larger lesions. Owing to expansion occurring in an anatomically restricted area and in proximity to the optic nerves, surgical removal with wide extirpation into the nasal cavity is usually recommended.

Synonymous with mucous retention cysts, mucoceles of the maxillary sinus are remarkably common yet rarely cause any notable symptoms. They are frequently detected as incidental findings on MRI scans performed for other reasons

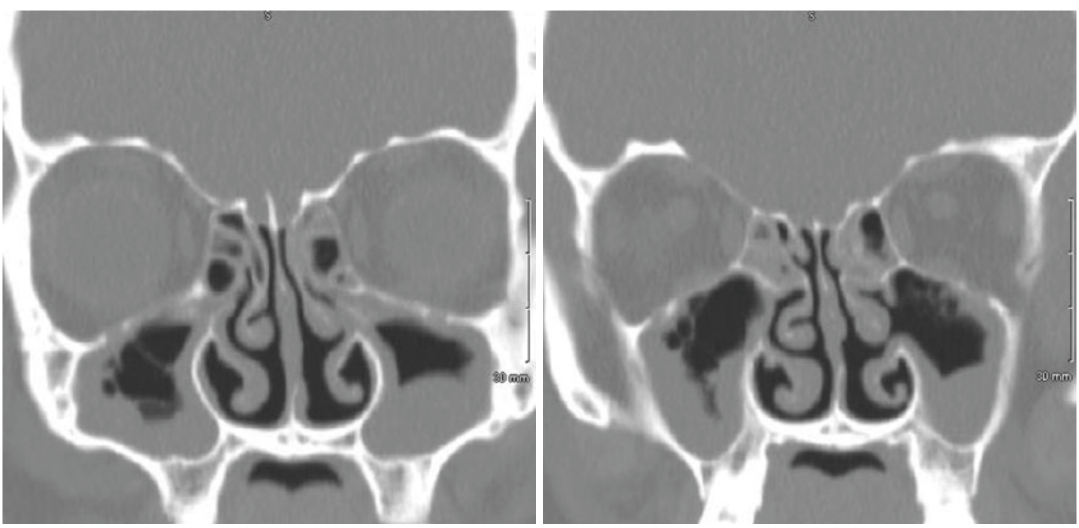

Fig. 9.19 Bone windowed coronal CT images demonstrating surgical failure due to incorrectly placed antrostomies with retained uncinate processes and recirculation of mucus

(e.g. MRI brain scans for headache). They rarely require surgical treatment unless of sufficient size to cause obstruction of the maxillary sinus ostium or where diagnostic doubt remains.

Radiological features of mucoceles include sinus opacification on CT scanning together with expansion and wall thinning. Sphenoid mucoceles may have a more aggressive pattern of bony erosion. MRI imaging is often requested when there is any bony dehiscence of the posterior table of the frontal sinus, skull base or orbital margin to define the extent (Fig. 9.20).

Unilateral Nasal Lesions

Careful assessment of unilateral nasal lesions is important to identify malignant disease, even though the majority of such lesions are likely to be benign. Discrimination between benign and potentially malignant lesions is on the basis of clinical and radiological parameters, with biopsy for histological confirmation (Table 9.1).

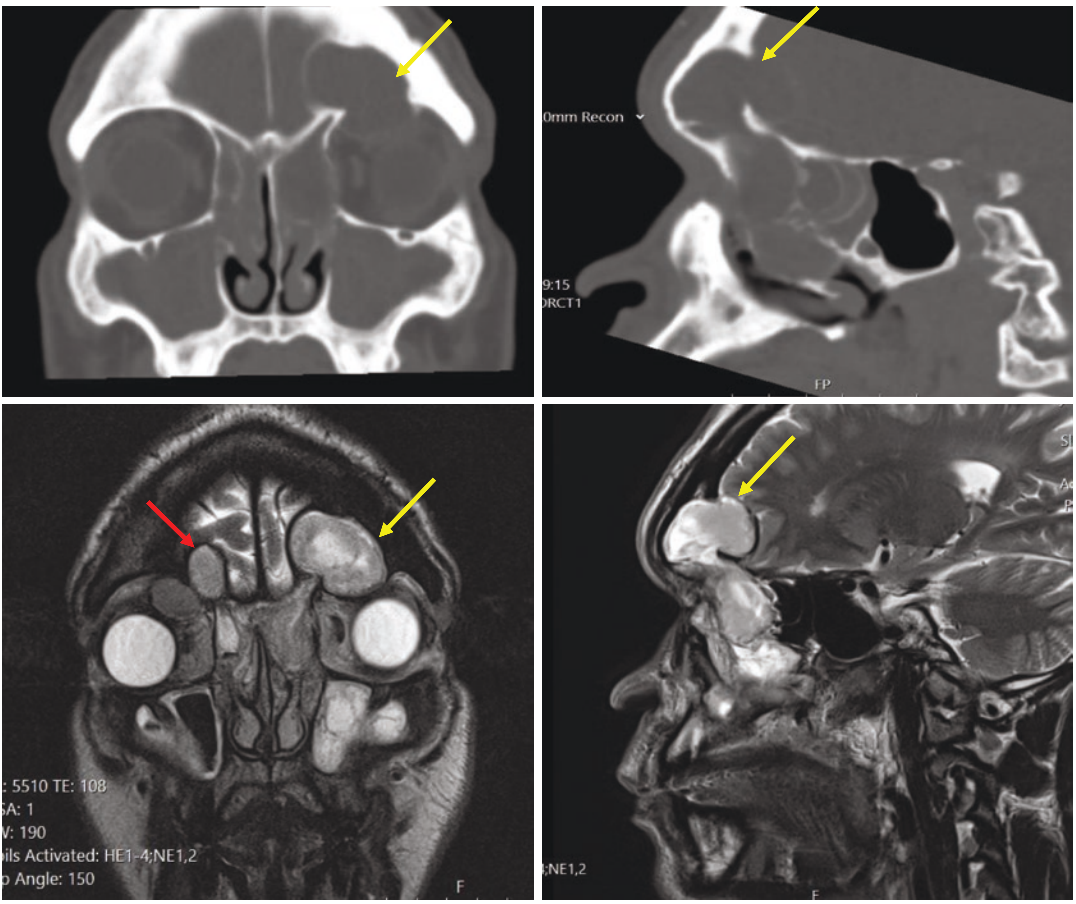

Fig. 9.20 Complementary bone windowed coronal (top left) and sagittal (top right) CT images and T2W coronal (bottom left) and sagittal (bottom right) MRI images showing bilateral mucoceles. MRI imaging determines the position and extent of the left frontoethmoidal mucocoele (yellow arrow). A small right frontal mucocoele is also seen (red arrow). CT provides superior bony detail

Table 9.1 Aetiology of unilateral nasal lesions

Non-neoplastic
Infective, e.g. TB, rhinoscleroma, rhinosporidiosis
Non-infective
Pyogenic granuloma
Nasal polyp/antrochoanal
Autoimmune, e.g. Granulomatosis with Polyangiitis (GPA), sarcoidosis
Intracranial—meningocele, encephalocele, meningoencephalocele
Neoplastic
Benign
Epithelial—Inverted papilloma, adenoma
Soft tissue—haemangioma
Bone and cartilage—chondroma, osteoma
Miscellaneous—teratoma, meningioma, odontogenic, minor salivary gland origin
Malignant
Epithelial—SCC, adenocarcinoma, undifferentiated carcinoma
Soft tissue—fibrosarcoma, rhabdomyosarcoma, malignant fibrous histiocytoma, juvenile angiofibroma
Bone and cartilage—chondrosarcoma, osteosarcoma
Lymphoid—lymphoma
Miscellaneous—Malignant melanoma, olfactory neuroblastoma, minor salivary gland carcinoma

Clinical Factors

- *Unilateral symptoms:* If a patient with a unilateral polyp or lesion has symptoms exclusively restricted to the ipsilateral nose, there should be a low index of suspicion for further investigation. A straightforward unilateral pyogenic granuloma should be easily identified and diagnosed clinically, and simple excision should suffice. A benign looking inflammatory unilateral polyp with ipsilateral epistaxis and nasal block where its origins and extent cannot be conclusively demonstrated clinically merits further investigation to exclude an underlying inverted papilloma or malignant pathology. Note that anosmia is not a specific clinical symptom as it may accompany a variety of different pathologies. Even in cases of olfactory neuroblastoma, anosmia may only occur in the presence of intracranial extension when the presentation is late [12].
- *Symptoms of malignant disease:* Extra-nasal symptoms may indicate a malignant process in the presence of a unilateral nasal mass. These include *ocular* symptoms (diplopia, displacement of the eye), *ear* symptoms (unilateral glue ear and hearing loss) and *dental* symptoms (teeth loosening or change in dental bite). Such clinical features merit urgent investigation.

Radiological Features

A patient with a unilateral nasal mass and a sufficient weight of corroborating clinical features will require further investigation, usually in the form of a CT scan although a MRI scan may also be required. High-resolution CT scanning of the nose and paranasal sinuses may demonstrate features of bony erosion in the presence of aggressive pathology and invasion of the mass into adjacent structures. A slower growing benign growth is more likely to demonstrate bony remodelling although there may be deficient bone due to pressure deossification. This requires an additional MRI to characterise the lesion and define extent within the sinonasal region. MRI is occasionally helpful in diagnosing lesions (e.g. 'cerebrose' appearance of an inverted papilloma) and in suggesting features such as hypervascularity, however, the MRI appearances are generally non-specific. MRI is, however, particularly useful to exclude a cephalocele as a presentation of a naso-ethmoid mass, since the associated anterior skull base defect may be subtle on CT. Most malignant masses are cellular and of T2W intermediate signal, and hence they are easy to separate from T2W high signal inflammatory changes in the paranasal sinuses. MRI is very useful in defining anterior skull base, orbital, infratemporal and perineural extension of tumour.

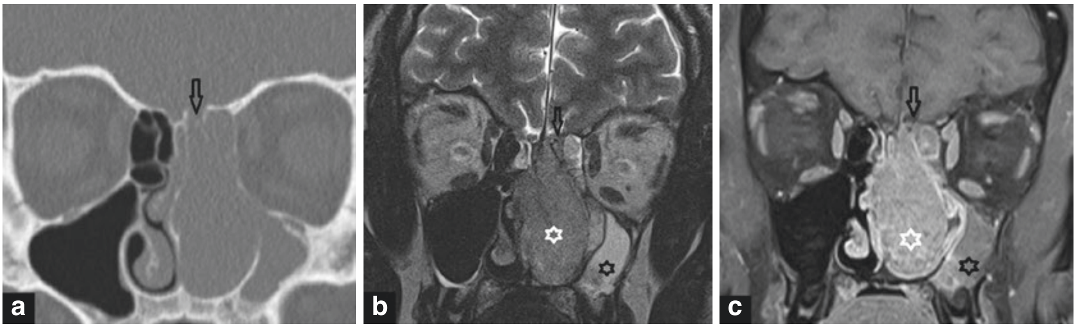

Fig. 9.21 Bone windowed coronal CT image (**a**), T2W coronal (**b**) and T1W fat saturated post-gadolinium coronal (**c**) MRI images demonstrate a left nasal olfactory neuroblastoma. CT is particularly adept at demonstrating the effects of the tumour on the sinonasal cortical bony structures. There is a pattern of bony moulding and expansion in places (e.g. inferior nasal cavity) with areas of focal bony destruction also seen (e.g. ethmoid air cells, bony nasal septum and medial orbital wall). Deficiency of the left cribriform plate is noted (vertical black solid arrow). The T2W and gadolinium-enhanced MRI sequences help distinguish the intermediate T2W signal (cellular) and enhancing nasal tumour (white open six pointed star in **b** and **c**) from adjacent high T2W signal and non-enhancing obstructed secretions (e.g. those in the left maxillary antrum: black open six pointed star in **b** and **c**). MRI also better demonstrates the intracranial extension of tumour, with interruption of the low T2W signal of cortical bone and periosteum at the cribriform plate, as well as loss of definition of the adjacent olfactory bulb (open vertical black arrow in **b**)

Sinonasal Tumours

CT and MRI have a complementary role in the evaluation and staging of sinonasal malignancy, which are demonstrated in the following images of an olfactory neuroblastoma (Fig. 9.21a–c).

Learning Points

- Sinonasal anatomy is complex and best evaluated in the coronal plane, synonymous to clinical assessment.
- Anatomical variants should be reported to guide intervention.
- Infective and non-infective complications of sinus disease should be evaluated on imaging.
- The CLOSED criteria should be reported to minimise surgical complications when treating CRS.
- Unilateral nasal masses should be addressed with suspicion and a tumour excluded.

References

1. S. Gray's Anatomy; the anatomical basis of clinical practice. Elsevier; 2015.
2. Lund VJ, Stammberger H, Fokkens WJ, et al. European position paper on the anatomical terminology of the internal nose and paranasal sinuses. Rhinol Suppl. 2014:1–34.
3. Gwaltney JM Jr, Phillips CD, Miller RD, Riker DK. Computed tomographic study of the common cold. N Engl J Med. 1994;330:25–30.
4. Coutinho J, de Bruijn SF, Deveber G, Stam J. Anticoagulation for cerebral venous sinus thrombosis. Cochrane Database Syst Rev. 2011:CD002005.
5. Clayman GL, Adams GL, Paugh DR, Koopmann CF Jr. Intracranial complications of paranasal sinusitis: a combined institutional review. Laryngoscope. 1991;101:234–9.
6. Brook I. Microbiology of intracranial abscesses associated with sinusitis of odontogenic origin. Ann Otol Rhinol Laryngol. 2006;115:917–20.
7. Bhattacharyya N, Lee LN. Evaluating the diagnosis of chronic rhinosinusitis based on clinical guidelines and endoscopy. Otolaryngol Head Neck Surg. 2010;143:147–51.
8. Ashraf N, Bhattacharyya N. Determination of the "incidental" Lund score for the staging of chronic rhinosinusitis. Otolaryngol Head Neck Surg. 2001;125:483–6.
9. Leung R, Kern R, Jordan N, et al. Upfront computed tomography scanning is more cost-beneficial than

empiric medical therapy in the initial management of chronic rhinosinusitis. Int Forum Allergy Rhinol. 2011;1:471–80.
10. Kanagalingam J, Bhatia K, Georgalas C, Fokkens W, Miszkiel K, Lund VJ. Maxillary mucosal cyst is not a manifestation of rhinosinusitis: results of a prospective three-dimensional CT study of ophthalmic patients. Laryngoscope. 2009;119:8–12.
11. Dalgorf DM, Sacks R, Wormald PJ, et al. Image-guided surgery influences perioperative morbidity from endoscopic sinus surgery: a systematic review and meta-analysis. Otolaryngol Head Neck Surg. 2013;149:17–29.
12. Connor SE, Umaria N, Chavda SV. Imaging of giant tumours involving the anterior skull base. Br J Radiol. 2001;74:662–7.