Sinonasal Diseases in Children

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Abstract

Pediatric sinonasal diseases encompass a huge variety of pathologies. First of all is to be familiarized with the complex anatomy and its normal pattern of development from birth to adolescence. There are several imaging techniques for evaluating inflammatory disorders, which are the main common, congenital malformations, and neoplastic entities. Cross-sectional imaging, with both CT and MRI, has changed our approach and understanding of the anatomy and pathology of sinonasal disorders. In this chapter, we describe the various imaging techniques available, and provide an overview of the diverse pathologies affecting the paranasal sinuses in children.

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Imaging of the sinonasal region in children is frequently requested for the evaluation of congenital, inflammatory, or neoplastic conditions. Imaging modalities primarily include radiographs, computed tomography (CT), and magnetic resonance imaging (MRI). Imaging techniques such as CT scanning and MRI are currently recommended in consensus documents, while plain radiography is considered of poor diagnostic value as it lacks the anatomic resolution that is offered by CT and MRI. CT imaging is the modality of choice for detailed evaluation of the osseous structures, for instance, in evaluating children with congenital abnormalities, chronic sinusitis, orbital complications of acute sinusitis, as well as to provide a road map for the surgeon prior to functional endoscopic sinus surgery (FESS). MRI is ideal for attempting to distinguish between inflammatory and neoplastic conditions and for evaluating intracranial complications of acute sinusitis, as well as in the evaluation of intracranial extension of sinonasal lesions. MRI is also helpful in assessing brain anomalies in a child with significant congenital abnormalities involving the midface. MRI allows to investigate not only the morphology of structures but also their intrinsic biophysical and biochemical properties, such as water content, cellular density, lipid or blood product deposits, and fibrosis. MRI allows better soft tissue differentiation and provides high spatial resolution images depicting fine details. When indicated, MRI with contrast gadolinium-based agents may better characterize...
the local disease extension or its diffusion beyond paranasal and nasal cavities and has excellent contrast resolution. A combination of CT and MRI is useful in cases of diagnostic difficulties, especially in cases of intracranial complications.

Although there are individual variations, there is a predictable pattern of development and pneumatization of the paranasal sinuses. Embryologically, the paranasal sinuses begin as evaginations from the nasal fossae. The maxillary sinuses form during the third fetal month, from nasal sac invaginations into the maxillary bones. The maxillary sinuses gradually increase in size until late adolescence or early adulthood. As the maxillary sinuses increase in size, the floor descends from the level of the inferior turbinate neck in infancy to the mid portion of the inferior meatus by around age seven. By adolescence, the floor of the maxillary sinus has reached its adult level, the floor of the nasal cavity (Fig. 1). The ethmoid sinuses form during the fifth fetal month, from invaginations of the middle meatus into the ethmoid bones. The ethmoid air cells are small at birth but rapidly expand over the next several years with a second period of rapid growth in early adolescence. The sphenoid sinus is not significantly developed at birth. The sphenoid sinus develops as evaginations from the posterior nasal capsule into the sphenoid bone. These extensions appear in the fifth postnatal month but significant aeration does not begin until around age 3 years. Pneumatization expands most rapidly during the end of the first decade and may continue to increase in size until adulthood. The frontal sinuses do not appear until the fifth or sixth year of life, primarily from expansion of the ethmoid sinuses. The frontal sinuses gradually increase through adolescence into early adulthood (Maresh and Washbum 1940; Schoenwolf 2008).

Inflammatory Disease of the Paranasal Sinuses

Acute Sinusitis

Acute, bacterial sinusitis is an inflammation of the paranasal sinus mucus membrane caused by overgrowth of bacteria, frequently as a complication of viral upper respiratory tract infections. In the United States, children 2–5 years of age suffer from six to eight upper respiratory tract infections per year, up to 13% of these are complicated by acute bacterial sinusitis. Factors that increase the risk of upper respiratory infections and therefore sinusitis in children include smoke exposure and day care (American Academy of Pediatrics, Subcommittee on Management of Sinusitis and Committee on Quality Improvement 2001; Brook 2013; Kakish et al. 2000). Cystic fibrosis and ciliary dyskinesia also directly increase the risk of sinusitis. Controversy continues with regard to when, why, and how to image children with acute uncomplicated bacterial sinusitis. This is in part related to the lack of sensitivity and specificity of imaging findings. Incidental abnormalities of the paranasal sinuses are frequently found on conventional CT and MR scans in children without clinical evidence of sinusitis (Maresh and Washbum 1940; Hill et al. 2004; Lim et al. 2003; Von Kalle et al. 2012; Kristo et al. 2003; Wani et al. 2001). The presence of an upper respiratory tract infection (URTI) alone (without sinusitis) may
result in abnormal imaging findings on neuroimaging studies (Kristo et al. 2003; Wani et al. 2001; Triulzi and Zirpoli 2007; Wald et al. 2013). In addition, MRI changes in patients with symptoms of acute sinusitis may last longer than 2 months, well after symptoms have resolved (Leopold et al. 1994). Therefore the presence of imaging abnormalities cannot be equated with acute sinusitis.

In general, in the appropriate clinical setting, complete opacification of a paranasal sinus, the presence of an air-fluid level, or 4 mm or more mucosal thickening are the most reliable imaging findings of acute sinusitis (Fig. 2) (Triulzi and Zirpoli 2007; Mafee et al. 2006; Leo et al. 2012). However, these findings are not diagnostic and must be correlated with the clinical history. An air-fluid level in a sinus cavity indicates outflow obstruction, however is not diagnostic of superimposed bacterial infection. In fact the obstruction occurs first, followed by retained secretions that are a perfect medium for bacterial overgrowth. Mucosal thickening is a physiologic response that may be related to bacterial, viral, allergic, or fungal disease and may be acute or chronic. Therefore, routine radiographic studies are not indicated in the initial management of patients with suspected, uncomplicated acute bacterial sinusitis (Wald et al. 2013; McAlister et al. 2000; Esposito and Principi 2010). These children should be treated on the basis of clinical impression, without any imaging exam. Imaging in children with acute sinusitis should be reserved for those children in whom orbital or intracranial complications are suspected.

Orbital complications of sinusitis include periorbital and orbital cellulitis, subperiosteal abscess, and orbital abscess (Meara 2012). Imaging is not necessary in children who present simply with periorbital cellulitis. However, CT of the orbits is

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**Fig. 1** Paranasal sinuses in two different children. (a, b) Coronal T2-weighted images. (a) Two-year-old infant. Anterior ethmoid and maxillary sinuses are well seen with some mucosal thickening. The floor of the maxillary sinus is approximately at the level of the inferior turbinate neck. (b) Normal paranasal sinuses in 15-year-old kid. Note that the floor of the maxillary sinus now extends below the floor of the nasal cavity.
indicated in children with suspected subperiosteal or orbital abscess. Three millimeter axial and coronal images should be obtained through the orbits and paranasal sinuses after the administration of intravenous contrast. Findings reported to the clinician should include the extent of cellulitis (preseptal and/or post-septal) and the presence or absence of an abscess. Extraconal abscesses are usually subperiosteal in location and appear as crescentic or oblong-shaped fluid collections with or without enhancing walls. Occasionally an air-fluid level will be present in the subperiosteal collection (Fig. 3). Low-attenuation collections may also occur elsewhere in the orbits (orbital abscesses). Although uncommon, frank osteomyelitis secondary to frontal sinusitis (Pott’s puffy tumor) still occurs (Fig. 4) (Haider et al. 2012). In these children, axial imaging is imperative to assess the integrity of the posterior wall of the frontal sinus and rule out intracranial extension. Additional findings of proptosis, optic nerve compression, and sinus wall dehiscence should be reported.

Fig. 2 Acute sinusitis in two different children. (a, b, d) Axial T2-weighted images, (c) axial apparent diffusion coefficient (ADC). Twelve-year-old girl with diffuse mucosal thickening filling the ethmoid, sphenoidal, and maxillary sinuses (a, b) with low signal intensity in the right maxillary in the ADC map (c). Ten-year-old boy with air-fluid level and mucosal thickening in the sphenoid sinus (d)
Intracranial complications of acute sinusitis include meningitis, extra-axial fluid collections, focal cerebritis, venous sinus and cavernous sinus thrombosis, and parenchymal abscess. These complications occur in up to 11% of patients hospitalized for treatment of acute sinusitis (Mafee et al. 2006; Piatt 2011; Vázquez et al. 2004; Bayonne et al. 2009). Intracranial complications are most commonly secondary to thrombophlebitis and extension through valveless facial veins rather than from direct extension from sinus to the intracranial compartment. Occasionally, infection spreads via congenital, surgical, or traumatic defects. MRI is more sensitive than CT in visualizing intracranial complications. Extra-axial collections may be epidural or subdural in location and may be related to effusions or empyemas. Peripheral enhancement is suggestive of an empyema; however, the absence of peripheral enhancement does not exclude empyema. Diffusion-weighted imaging is the most sensitive technique differentiating serous from purulent collections, as the second shows low ADC values (Wong et al. 2004) (Fig. 5). Focal areas of cerebritis first appear as parenchymal hypoattenuating areas on CT, with hyperintense T2 signal on MRI (Fig. 6). If parenchymal lesions progress to abscess; there is subsequently a center of liquefaction and necrosis with diffusion restriction and formation of an enhancing peripheral capsule. Engorgement of the ophthalmic vein with enlargement of the cavernous sinus and bowing of the lateral dural margin are frequent findings in cavernous sinus thrombosis, a very rare complication (Fig. 7).

Surgical drainage of the affected paranasal sinuses and any intracranial abscess is emergently required. Antibiotics should be chosen to cover the most common organisms, and prolonged therapy is usually necessary. Neurosurgical consultation is strongly recommended, even in cases that are not immediately surgical. Despite modern diagnostic and surgical capabilities, the mortality rate associated with subdural empyema and brain abscesses remains over 25% (Vázquez et al. 2004).
Chronic Sinusitis

As opposed to treating noncomplicated acute sinusitis based on clinical impression without imaging, most authors agree that children with chronic sinusitis should be imaged. CT should be performed in any child who is a candidate for functional endoscopic sinus surgery. Helical CT with high-resolution 3 mm reconstructed

Fig. 4  Pott’s puffy Tumor. (a) Axial T2-weighted image, (b) contrast-enhanced left paramedian sagittal T1-weighted fat-saturated image. Sixteen-year-old boy with opacification of both frontal sinuses with cortical thinning of the anterior table of the left frontal sinus and associated forehead soft tissue edema and well-defined fluid collection (arrow) (a) with rim enhancement (b), consistent with sinusitis, osteomyelitis, and subsequent inflammatory involvement of the soft tissues of the forehead. Note associated left maxillary sinus mucosal thickening

Fig. 5  Empyema. (a) Postcontrast coronal T1-weighted image, (b) coronal diffusion-weighted image (DWI). Fifteen-year-old girl with opacification and mucosal enhancement of the left maxillary sinus (asterisks) and hypointense rim enhancing left frontal subdural fluid collections (arrows) with ipsilateral leptomeningeal enhancement (a), DWI high signal (b), and ADC low signal (not shown) reflecting restriction and purulent content is seen

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Coronal images should be obtained to provide an anatomic road map for the surgeon. This should ideally be performed after appropriate medical therapy (which often requires antibiotic treatment for up to 6 weeks) to allow identification of residual disease, resistant to medical therapy.

The most important area to evaluate is the ostiomeatal unit (OMU) that includes the maxillary sinus ostium, anterior ethmoid air cells, uncinate process, hiatus semilunaris, infundibulum, and middle turbinate. Location of residual disease should be noted, as well as anatomic variants that may contribute to chronic or recurrent disease. These variants are much more common in adults than in children. The most common variants in the pediatric population are Haller cells, concha bullosa, and large ethmoid bulla. Haller cells are infraorbital ethmoid air cells that may be large enough to cause narrowing of the infundibulum (Fig. 8). Concha bullosa describes aeration of the middle turbinate that may narrow the nasal passage at the middle meatus or deviate the uncinate process and result in narrowing of the infundibulum (Fig. 9) (Zeifer 2000; Anzai and Yueh 2003; Stallman et al. 2004; Beale et al. 2009). Other findings of importance include paradoxical middle turbinate, maxillary sinus hypoplasia, and nasal septal deviation or spurs, which may result in nasal passage obstruction. Maxillary sinus hypoplasia is frequently associated with an atelectatic infundibulum secondary to attenuation or hypoplasia of the uncinate process (Hourany et al. 2005). Bulging of the optic canal into the posterior ethmoid complex or sphenoid sinuses and congenital or posttraumatic dehiscence of the lamina papyracea or roof of the ethmoid labyrinth should also be reported to the surgeon, as these findings may increase the risk of FESS (Reddy and Dev 2012).

MRI lacks sensitivity in identification of the osseous structures that are necessary in the preoperative evaluation of chronic sinusitis and in the evaluation of complicated acute sinusitis. However, sinus findings are routinely noted on cranial MRI in
patients without symptoms of sinusitis; therefore, a review of these findings is warranted. Uncomplicated sinonasal secretions have a prolonged T1 and T2 relaxation time due to the high concentration of water and, therefore, will appear hypointense on T1-weighted images and hyperintense on T2-weighted images. As chronic inflammation persists, the secretions change in composition, with progressive desiccation and increase in protein content. With protein content greater than 25–35%, there is an associated change in MRI signal characteristics. The secretions become hypointense on T1- and T2-weighted sequences and may in fact appear as signal void when protein content exceeds 35–40% (Leo et al. 2012; Madani and Beale 2009; Eggesbø 2006; Som et al. 1990).

Fig. 7 Cavernous sinus thrombosis. (a) Contrast-enhanced axial CT scan, (b) axial diffusion-weighted image, (c) contrast-enhanced coronal T1-weighted fat-saturated image. Fourteen-year-old girl with sphenoid sinus opacification (asterisk), left cavernous sinus (arrow), and superior ophthalmic vein (open arrow) repletion defects (a). DWI shows diffusion restriction in the ethmoid and sphenoid sinuses (asterisk), cavernous sinus (arrow), and left temporal subdural empyema (b). Left ethmoid and maxillary acute sinusitis (asterisk) with left superior ophthalmic vein thrombosis (open arrow) (c)
Fungal Sinusitis

Fungal disease may be invasive or noninvasive. Fortunately, fungal sinusitis is uncommon in children and when it does occur is only rarely invasive. Invasive fungal sinusitis may be acute and fulminant or chronic and indolent. Acute fulminant invasive fungal sinusitis is most common in neutropenic or diabetic patients, characterized by vascular invasion and necrosis with or without intracranial or intraorbital extension. Chronic invasive fungal sinusitis follows an indolent course, usually in immunocompetent patients. Imaging demonstrates nonspecific mucosal inflammation with or without osseous destruction. Disease may invade adjacent structures such as the cavernous sinus. Aggressive treatment with surgery and antifungal agents should be started immediately in these cases (Chakrabarti et al. 2009).

Noninvasive fungal sinusitis may either be in the form of a fungus ball or allergic fungal sinusitis. Fungus ball is a chronic focal aggregate of fungal hyphae
(mycetoma) with minimal tissue reaction and no invasion. Allergic fungal sinusitis is defined by the presence of allergic mucin with necrotic cells, Charcot-Leyden crystals, and scattered fungal forms surrounded by significant mucosal reaction without invasion. These patients are immunocompetent and usually atopic, often-times asymptomatic. Fungus ball typically only involves one sinus cavity, while allergic fungal sinusitis usually involves multiple sinuses (Fatterpekar et al. 1999; Manning et al. 1997a; Mukherji et al. 1998; Gabelmann et al. 2007; Aribandi et al. 2007). Both forms of noninvasive fungal disease demonstrate high attenuation intrasinus contents, with or without peripheral low attenuation mucosal thickening or mucoid secretions on CT. MRI demonstrates central hypointense signal on T1- and T2-weighted sequences (Fig. 10). In this situation, MR images may be confusing in that the fungal disease has signal characteristics that simulate air.

Although the imaging characteristics may suggest fungal disease in the presence of hyperdense intrasinus secretions or bony erosion, in many cases fungal disease cannot be distinguished from bacterial infection on either CT or MRI. Early in the

**Fig. 10** Fungal sinusitis with osteolysis. (a) Axial T2-weighted image, (b) axial apparent diffusion coefficient (ADC), c coronal bone window CT image. Eight-year-old girl with bilateral maxillary sinuses opacification. Low T2WI signal with hypointense rim in the right maxillary sinus (a) and low ADC values (b) (asterisks). Right cribriform plate of the ethmoid bone osteolysis is depicted (open arrow) (c)
evolution of fungal infection or allergic response to a fungus, the sinus mucosa becomes edematous and thickened, identical to the findings of early bacterial infection, viral disease, or allergic inflammation (Manning et al. 1997b). When a mycetoma develops, the MRI appearance is similar to that of mucosal inflammation from a nonspecific etiology with a central region of desiccated secretions or air. The hypointense T1 and T2 signal within a mycetoma is secondary to the thick semisolid or solid consistency and the paramagnetic metals within the mycelia (Fatterpekar et al. 1999; Manning et al. 1997a; Mukherji et al. 1998; Gabelmann et al. 2007; Aribandi et al. 2007). Therefore, if MRI is used alone in patients with suspected fungal disease, the imaging characteristics may be confusing. If correlated with CT, the central hyperdensity present in desiccated secretions and fungal disease can be distinguished from central air. Mycotic aneurysms and cerebral infarctions may develop as severe complications of fungal sinusitis (Hurst et al. 2001).

**Polyps**

Although nasal polyps occur in less than 4% of the general adult population, they occur in as many as 17% of adult asthmatics and up to 23% of patients with chronic rhinitis. Fifty seven percent of patients with cystic fibrosis (CF) develop nasal polyposis (Chaaban et al. 2013). When polyps pass through the ostia of a sinus into the boundary between the nasal cavity and nasopharynx (the choanae), they are termed choanal polyps. These are most commonly antrochoanal in location, with sphenochoanal polyps being much less common. The antrochoanal polyp originates in the maxillary sinus antrum, usually partially or completely fills the antrum, and then protrudes into the nasal cavity via an enlarged maxillary sinus ostium or posterior nasal fontanel. As they enlarge, they extend into the nasal cavity, nasopharynx, and oropharynx (Fig. 11) (Chaaban et al. 2013; Frosini et al. 2009). The polyps are composed of highly edematous and hypocellular tissue; therefore, they are low attenuation on CT and hyperintense on T2-weighted MR images. CT or MRI will demonstrate the intrasinus and nasopharyngeal component; however, CT is best to evaluate the bony structures. On rare occasion, mucosal hypertrophy and maxillary ostium enlargement with protrusion of the mucosa into the middle meatus in children with acute sinusitis may mimic an antrochoanal polyp (Pruna et al. 2000). Sphenochoanal polyps are much less common, originate in the sphenoid sinus, and extend through the sphenoid sinus ostium and into the choanae (Weissman et al. 1991).

When the vascular supply of a polyp becomes compromised by vascular dilatation, intraluminal stasis of blood, edema, and infarction, the natural response is to produce neovascularity or an angiomatous polyp (De Vuysere et al. 2001; Wang et al. 2012; Zou et al. 2014). Some portions may be avascular and necrotic, while other portions may be hypervascular. The degree of vascularity determines the imaging findings. These lesions may be avascular or hypovascular on imaging without significant contrast enhancement, or may be contrast enhancing with multiple serpiginous intralesional flow voids on MRI, simulating a juvenile
nasopharyngeal angiofibroma (JNA) (Fig. 12). However, JNAs are almost always found in adolescent males, usually arise in or near the sphenopalatine foramen, and often show extension into the pterygopalatine fossa or sphenoid sinus (Mishra et al. 2013). By contrast, angiomatous polyps are usually choanal in origin and susceptible to vascular compromise secondary to their location and pattern of growth (De Vuysere et al. 2001; Wang et al. 2012; Zou et al. 2014).

Sinonasal polyposis is the term used when inflammation of the mucosal surface of the nasal cavity and paranasal sinus assumes a characteristic polypoid appearance. This has also been called chronic hypertrophic polypoid rhinosinusitis. The etiology is unknown; however, there appears to be an association with allergic and non-allergic atopic rhinitis, asthma, chronic infection, cystic fibrosis, and Kartagener’s syndrome. Patients may present with nasal stuffiness, rhinorrhea, facial pain, or headaches. Anosmia is usually a late sequela.

Imaging findings include polypoid soft tissue density masses in the nasal cavity and/or paranasal sinuses. This process is usually bilateral and associated with
Infundibular enlargement. Secondary post-obstructive inflammatory disease is common. The specific involvement of the individual paranasal sinuses by polyps versus post-obstructive inflammatory disease is difficult to determine with CT. MRI is better able to delineate the polyp from the post-obstructive sinus disease in that the latter is usually more hyperintense on T2-weighted series. Air-fluid levels are not uncommon in patients with sinonasal polyposis and may be present with or without superimposed acute bacterial sinusitis. When severe, there may be bony erosion of the sinus walls or nasal septum. Bulging of the lateral walls of the ethmoid sinuses can be seen in up to half of patients with sinonasal polyposis and may be severe, resulting in hypertelorism. Intrasinus polyps may be hyperdense relative to surrounding low attenuation secretions, simulating fungal disease (Fig. 13) (Mafee et al. 2006; Leo et al. 2012; Zeifer 2000; Chaaban et al. 2013).

Mucus retention cysts develop when a mucus gland in the sinus mucosa becomes obstructed, found incidentally in up to 10% of the population, most common in the inferior aspect of the maxillary sinus. They typically have CT and MRI characteristics similar to water, that is, hypodense on CT, hypointense on T1-weighted images, and hyperintense on T2-weighted images. These characteristics may be altered when the retention cysts contain more proteinaceous material. A recent report in adults showed a 12.4% incidence of mucus retention cysts on sinus CT, without evidence of persistent obstructive pathology. Therefore, the majority is most likely incidental and without clinical significance and should not be considered disease in terms of chronic rhinosinusitis (Bhattacharyya 2000).

Cystic Fibrosis

Children with cystic fibrosis (CF) have chronic rhinosinusitis and stasis of viscous sinonasal secretions, which results in retention of secretions and chronic sinus
inflammation with or without obstruction of the ostia and superimposed infection. The impaired mucociliary clearance in CF causes widespread inflammatory paranasal sinus disease, with inflammatory patterns more often requiring extensive surgery, with a higher risk of cerebrospinal fluid leak or bleeding, or involving areas that are more difficult to reach with the endoscope.

Chronic sinusitis is almost a universal problem and sinonasal polyposis is common. This association is so important that any child found to have sinonasal polyposis should be tested for CF. We have seen children as old as 18 years of age diagnosed with CF only after imaging findings suggested polyposis. Imaging findings in children with CF include pansinus opacification, uncinate process demineralization, and medial deviation of the lateral nasal walls and decreased maxillary and frontal sinus pneumatization (Robertson et al. 2008; Eggesbø et al. 2002). Occasionally, CF patients will have mucoceles, most commonly unilateral involving the ethmoid and maxillary sinuses (Fig. 14) (Eggesbø et al. 2002; Olze et al. 2006).

The main indication of CT scans in CF should be the preoperative planning regarding anatomy, extent of disease, and sites of nasal obstruction, as their use for disease evaluation does not seem to appreciably modify the treatment course and could be avoided (Cavel et al. 2013).

### Neoplasms and Tumor-Like Masses

Fortunately, most sinonasal masses in children are secondary to inflammatory or benign lesions, with malignancy much less common. Benign masses of the sinonasal cavity in children include juvenile nasoangiofibroma (JNA), neurogenic tumors, and papillomas, the latter two occurring only rarely. Esthesioneuroblastoma is also rare in children. Benign destructive lesions that may simulate neoplasm include
Langerhans cell histiocytosis, reparative granuloma, and lytic fibrous dysplasia. Foreign bodies should always been considered in the differential diagnosis of nasal masses, especially when malodorous secretion is present (Fig. 15).

Malignant neoplasms involving the sinonasal cavity in children include rhabdomyosarcoma, lymphoma, osteosarcoma, and metastatic neuroblastoma. Squamous cell carcinoma, although it is the most common neoplasm of the sinonasal cavity in adults, is extremely uncommon in children (Eggesbø 2012).

**Juvenile Nasopharyngeal Angiofibroma**

Juvenile nasopharyngeal angiofibroma (JNA) is a highly vascular, benign neoplasm that is typically locally invasive. It usually occurs in adolescent males. Most arise in or near the sphenopalatine foramen and extend into the pterygopalatine fossa. As they increase in size, they extend into the nasopharynx and present as a nasopharyngeal mass. Most patients present with nasal obstruction and spontaneous epistaxis. Typically, JNAs diffusely enhance on both CT and MRI. On MRI, intralesional flow voids are frequently present confirming the hypervascular nature of the mass. The majority widens the pterygopalatine fossa and deviates the posterior wall of the maxillary sinus anteriorly. Bony destruction of the floor of the sphenoid sinus and pterygoid plates is best visualized on CT; however, intracranial involvement and differentiation between neoplasm and post-obstructive sinus disease is best performed with MRI (Fig. 16). When surgical treatment is planned, preoperative angiography is recommended to define the feeding vessels and to perform preoperative embolization (Mishra et al. 2013; Blount et al. 2011; Lasjaunias et al. 1980).

![Fig. 14 Mucocele. (a) Axial bone window CT scan, (b) axial T2-weighted image. Ten-year-old girl with cystic fibrosis and a large expansive lesion arising within the right maxillary sinus homogeneously hypodense (a) and hyperintense (b) (asterisks), with erosion of the posterior and medial walls and discrete extension into the nasal cavity. The lesion showed peripheral but no central enhancement (not shown).](image-url)
Langerhans Cell Histiocytosis

Langerhans cell histiocytosis (LCH) is a rare proliferative disorder of the Langerhans cell that forms granulomas within any organ system. LCH is the preferred term for a spectrum of disorders that previously included eosinophilic granuloma of bone, Letterer-Siwe disease, and Hand-Schüller-Christian disease. Head and neck manifestations occur in up to 82% of children during the course of their disease (Nicollas et al. 2010). Skull and skin lesions are the most frequent site of head and neck involvement; however, additional areas include cervical lymph nodes, temporal bone, orbit, mandible, and occasionally the maxilla. There is typically a soft tissue osteolytic mass with T1 shortening due to lipid-laden histiocytes and slight T2 hyperintensity and enhancement (Fig. 17) (Prayer et al. 2004; Demaerel and Van Gool 2008).

Fig. 15  Foreign body in a 6-year-old boy with malodorous right nasal fossa secretions. (a) Coronal bone window CT scan, (b) coronal T2-weighted image, (c) axial T1-weighted image. Lineal irregular calcification (arrows) (better seen in a) and reactive granulomatous tissue (asterisks) markedly hypointense on T2WI (b) and T1WI (c) within the right nasal passage deviating the nasal septum to the left. Note opacification of the right maxillary and ethmoid sinuses, as well as mucosal thickening of the left

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There is no consensus about treatment, but authors highlight that all teams in charge of patients presenting with LCH agree to remain as conservative as possible. For solitary large lesions looking like a tumor which resection could result in functional or cosmetic morbidity, it would be important to get first a biopsy. For multisystemic LHC, therapeutic trials with chemotherapy agents still in process should increase the rate of success (Nicollas et al. 2010).

**Rosai-Dorfman Disease**

Rosai-Dorfman disease (RDD), also known as sinus histiocytosis with massive lymphadenopathy, is a rare non-Langerhans cell histiocytosis presenting in children.
or young adults, caused by homozygous or compound heterozygous mutation in the SLC29A3 gene on chromosome 10q22.

It is a benign pseudolymphomatous clinicopathological entity with enhancing painless bilateral cervical large lymph nodes. Extranodal presentation is seen in about 50% of patients in the sinonasal and orbital regions, as well as in the dura and skin, with nasal obstruction, epistaxis, hyposmia, proptosis, and headache.

CT demonstrates homogeneous enhancing nodes and extranodal infiltrates that may associate bone erosion. These lesions are typically relative hypointense in T2-weighted images, hypo-isointense in T1-weighted images, and enhance homogeneously after contrast media injection (Fig. 18) (La Barge et al. 2008).

**Erdheim-Chester Disease**

Erdheim-Chester disease (ECD) is a rare non-Langerhans cell histiocytosis of unknown etiology involving multiple organ systems and causing bilateral and symmetric osteosclerosis of diaphysis and metaphysis of long bones in 86% of patients, classically sparing epiphyses. Neurological manifestations include seizures, headaches, cognitive alterations, and cranial neuropathy. Cerebellar (41%), pyramidal (45%) syndromes, and diabetes insipidus (47%) are the most frequent manifestations.

MRI may show diffuse brain anomalies, especially in the infratentorial region in both cerebellar hemispheres and brainstem, as well as in the hypothalamus and orbits. Parenchymal enhancing nodules, meningeal thickening, and T2-hyperintense cerebellar lesions are the main features (Fig. 19) (Lachenal et al. 2006).

**Central Giant Cell (Reparative) Granuloma**

Giant cell reparative granuloma, also called central giant cell granuloma, is a rare nonneoplastic proliferative lesion that most commonly occurs in the mandible but
may also occur in the maxilla and may thus involve the maxillary sinus. It is most common in girls (Triantafillidou et al. 2011). Although the cause is uncertain, one theory suggests that it may be a reactive lesion related to an abnormal healing process in response to prior trauma or inflammation, rather than a true neoplasm. Hence, the used term is “reparative granuloma.” Lesions are typically expansile and uni- or multilocular (Fig. 20), do not cross midline, and cause tooth root displacement but no root resorption. Most giant cell granulomas reveal moderate to marked hypointensity on T1- and T2-weighted images, which is attributed to hemosiderin deposits and/or high collagen content, as well as enhancement of the soft tissue and septal component (Aralasmak et al. 2006; Bodner and Bar-Ziv 1996). Other giant cell lesions may be indistinguishable on imaging, such as Brown tumors, aneurysmal bone cyst, and cherubism. Treatment options include surgery, steroid injection, and calcitonin (Triantafillidou et al. 2011).
Aneurysmal Bone Cyst

Aneurysmal bone cyst (ABC) is an expansile benign nonneoplastic lytic bone tumor containing thin-walled, blood-filled cavities. The age at presentation is between 10 and 30 years with slight female predominance. They can emerge primary (66%) or secondary in preexisting benign (giant cell granuloma, fibrous dysplasia, chondroblastoma, osteoblastoma) or malignant (osteosarcoma, chondrosarcoma) lesion. Only 1% occurs in the skull.

Imaging characteristics include the fluid-fluid levels because of blood degradation products with differing signal intensities and even diffusion restriction and a peripheral T2-hypointense rim. After contrast administration, a honeycomb pattern may be seen when cyst walls and septations enhance (Fig. 21). Solid variant with diffuse enhancement is seen in less than 10% of all ABCs. The best treatment option is complete surgical excision with 20–30% of recurrence rate (Lui et al. 2011).

Nasal Glioma

Nasal glioma is a rare developmental mass of dysplastic neurogenic tissue sequestered and isolated from subarachnoid space, with no CSF connection to brain (i.e., an encephalocele without intracranial connection). The term “glioma” is a misnomer as this is nonneoplastic tissue.

There are three types, the extranasal accounting for 60% of cases, intranasal (30%), and mixed intra-extranasal forms (10%). Capillary telangiectasia may cover the nasal glioma, giving a blue or red color well-circumscribed, soft tissue mass off midline at nasal dorsum or within nasal cavity (Ajose-Popoola et al. 2011; Grzegorczyk et al. 2010).
The diagnosis should be considered prenatally by ultrasonography and fetal MRI and then should be confirmed by postnatal MRI. CT does not help in most cases. MRI depicts low signal in T1-weighted images and iso- to hyperintensity in T2-weighted images (Fig. 22). No enhancement is seen when gadolinium is injected, considering always the intrinsic risk of renal immaturity in neonates.

Surgical resection is the treatment of choice. Although CT and MRI images may in many cases suggest the diagnosis, histological examination or follow-up imaging should follow (Ajose-Popoola et al. 2011; Grzegorczyk et al. 2010).

**Frontoethmoidal Cephalocele**

Frontoethmoidal cephalocele, also known as sincipital cephalocele, is a congenital herniation of meninges, cerebrospinal fluid, and brain tissue through a mesodermal defect in the anterior skull or skull base. There are three types depending on the
location of the bone defect: frontonasal, nasoethmoidal, and nasoorbital, with extra-nasal, intranasal, and medial orbital mass presentation, respectively. The treatment consists of complete surgical excision.

Eighty percent of these cephaloceles associate intracranial abnormalities. CT depicts a well-defined round mass with mixed density extending through a bony defect. MRI demonstrates a soft tissue mass isointense to gray matter in T1-weighted images, and iso- to hyperintense on T2-weighted images due to associated gliosis. Fluid intensity surrounding the mass is better seen on T2-weighted images (Fig. 23). There is no mass enhancement after intravenous contrast media injection. Meninges may enhance in case of secondary inflammation or infection.

**Fig. 21** Aneurysmal bone cyst. (a) Axial soft tissue window CT scan, (b) axial T2-weighted image, (c) axial postcontrast T1-weighted image with fat suppression. Nine-year-old girl with expansive heterogeneous on CT (a), hyperintense with fluid-fluid levels on T2WI (b), and hypo-intense with rim enhancement on postcontrast T1WI (c) multiloculated lesion arising within the sphenoid sinus (arrows), destroying its walls extending to both cavernous sinuses, especially to the left one.
Fig. 22  Nasal glioma. (a) Photograph of the neonate, (b) paramedian sagittal T1-weighted image, (c) paramedian sagittal T2-weighted image. Left off-midline well-circumscribed extranasal bilobulated reddish mass (a), hypointense with hyperintense focal central area on T1WI (b), and hyperintense with isointense focal central area on T2WI (c) (arrows) with no intracranial connection.

Fig. 23  Frontonasal cephalocele. (a) Midline sagittal T1-weighted image, (b) midline sagittal T2-weighted image. Newborn with midline well-circumscribed frontonasal soft tissue mass, hypointense on T1WI (a), and hyperintense on T2WI (b) (asterisks) contiguous with intracranial parenchyma extending through bony defect, the patent fonticulus frontalis (open arrows).
Fibrous Dysplasia

Fibrous dysplasia is one of the fibroosseous lesions characterized by replacement of medullary bone with varying degrees of fibrous and osseous elements. Fibrous dysplasia may be monostotic, polyostotic, or disseminated. The majority is monostotic; extension by contiguity to another bone is still considered as a monostotic form. Up to 25% of patients will have head and neck involvement, the most common site being the maxilla. There may be rapid growth in late childhood and early adolescence, which subsides in adulthood (MacDonald-Jankowski 2009). The imaging appearance is variable, depending on the proportion of fibrous and osseous components. The classic “ground-glass” appearance may be seen on plain radiographs or CT and is usually not much of a diagnostic dilemma (Fig. 24). However, when the lesions are more radiolucent and expansile, there frequently present as enhancing soft tissue masses extending beyond the confines of the bone, which simulates a neoplastic process. In these cases, the differential diagnosis includes osteosarcoma. On MRI, fibrous dysplasia appears fairly well demarcated with variable T1 and T2 signal as well as heterogeneous contrast enhancement. When cystic, there may be intralesional fluid levels (Hanifi et al. 2013; Lisle et al. 2008; Cappabianca et al. 2008; Fusconi et al. 2013).

Malignant transformation of fibrous dysplasia is rare (<0.5% of cases). Currently, there is no therapy for preventing the disease from advancing or for malignant transformation (Cheng et al. 2013). Nondisabling surgery is utilized to prevent progressive loss of vision and severe cosmetic deformity. In less than 5% of cases, polyostotic fibrous dysplasia is associated with endocrinopathies and skin lesions referred to as McCune-Albright syndrome (DeKlotz et al. 2013).

Cherubism

Cherubism is a rare inherited autosomal dominant fibroosseous disorder that affects the jaws of children and adolescents and produces a characteristic facial appearance resembling a renaissance cherub. Histologically and radiologically, these lesions are indistinguishable from giant cell reparative granuloma. Cherubism usually appears in children between the age of 2 and 5 years, progresses until puberty, and then spontaneously regresses without treatment. The diagnosis is strongly suggested by bilateral, relatively symmetric jaw involvement that is limited to the maxilla and mandible. Imaging typically shows expansile remodeling of the involved bones, thinning of the cortices, and multilocular radiolucencies with a coarse trabecular pattern. MRI does not only accurately depict the anatomical extent of the lesions but also reveals signal intensity changes in those areas that are apparently normal on radiographs and CT (Carvalho Silva et al. 2007; Jain and Sharma 2006; Beaman et al. 2004).
Fig. 24 Fibrous dysplasia in two different patients. (a) 3D frontal view reformatted CT image, (b) 3D frontal view scintigraphy scan, (c) coronal T2-weighted image, (d) coronal postcontrast T1-weighted image with fat suppression. Sixteen-year-old girl with extensive fronto-orbital and ethmoid bone lesion with the classic “ground-glass” appearance on CT (not shown) and permeative pattern on 3D reconstruction (a). The nuclear medicine study rules out multicentricity and shows increased activity of the monostotic lesion (arrow, b). Fourteen-year-old teenager with markedly hypointense sphenoid lesion on T2WI (c), with heterogeneous enhancement (d) (asterisks), encroaching on both orbit passages.
Malignant Neoplasms

The most common sinonasal cavity malignancies in children include lymphoma, rhabdomyosarcoma, and metastatic neuroblastoma, with squamous cell carcinoma being identified only rarely.

Lymphoma

Most children with head and neck lymphoma present with cervical adenopathy. Primary extranodal lymphomas of the sinonasal region are rare and occur almost only as Non-Hodgkin lymphoma (NHL). The presenting symptoms of these patients included nasal obstruction, rhinorrhea, bloody discharge/epistaxis, postnasal drip, facial swelling, neck mass, orbital symptoms, fever, and body weight loss (Yen et al. 2012; Sandner et al. 2013; Zagolski et al. 2010; Lee et al. 2003).

The tumor shows a predilection for diffuse invasion of the nasal cavity, often involving both sides. Destruction of the midline structures (turbinates, nasal septum, and palate) occurs in half of patients, as well as inflammation and tumor necrosis. Regional nodal enlargement is rare. CT and MRI are nonspecific. Mildly enhancing masses with or without bone erosion or expansion is typically seen on CT (Fig. 25). Lymphomatous masses are intermediate in signal intensity on T1-weighted images and mildly hyperintense on T2-weighted images (Lee et al. 2003). In our experience, diffusion-weighted imaging may help as they are hypercellular tumors, and they may show diffusion restriction. Adequate amount of biopsy tissue is required for a definitive subtype histopathological diagnosis and exact therapeutic planning.

Most lymphomas that originate from the maxillary sinus are B-cell lymphomas with a good prognosis, whereas those originating from the nasal cavity or ethmoid sinus are peripheral T-cell lymphomas and NK/T-cell lymphoma with worse prognosis (Yen et al. 2012; Sandner et al. 2013; Zagolski et al. 2010; Lee et al. 2003).

Leukemia

The diverse spectrum of hematopoietic malignancies of stem cells can cause lytic, blastic, or mixed lesion with ill-defined margins affecting the sinonasal region, especially the maxilla, simulating periodontal disease or periapical osteitis, and the orbital region. The clinical presentation is with sudden onset of malaise, weakness, pain, fever, or even bleeding.

Acute lymphocytic leukemia is the most common childhood leukemia. Acute myelogenous leukemia constitutes the 15–20% of leukemia in children. Hispanic children younger than 19 years have the highest rates of leukemia.

Granulocytic sarcomas, formerly known as chloromas since 1853, are extramedullary masses of primitive precursors of the granulocytic cells, mainly occurring in children with myelogenous leukemia. At CT these masses are hyperdense, although may rapidly become hypodense if necrosis or liquefaction. MRI reflects
T1 hypointense signal, sometimes hyperintense signal if recent bleeding, and T2 hypo- or even hyperintensity. T1-weighted images after gadolinium with fat-saturation technique are essential for assessment demonstrates avid enhancement. Diffusion-weighted imaging may show restriction (Fig. 26). When skull base or paranasal leukemic infiltration, one should rule out brain, hypothalamic/infundibular, and dural extension (Vázquez et al. 2002; Noh et al. 2009).

Sometimes granulocytic sarcomas precede bone marrow infiltration. The prognosis is poor. The treatment consists in induction chemotherapy and bone marrow transplantation.

**Fig. 25** Nasopharyngeal lymphoma. (a) Axial postcontrast T1-weighted image with fat suppression, (b) axial T2-weighted image with fat suppression, (c) axial diffusion-weighted image. Huge homogeneous solid mass with peripheral enhancement (a), hyperintense on T2WI (b), and intense restriction on DWI (c), occupying the nasopharynx and both choanae (asterisks)
Rhabdomyosarcoma (RMS) is the commonest pediatric soft tissue Sarcoma constituting 3–5% of all malignancies in childhood. RMS has a predilection for the head and neck area (including nasopharynx, orbit, middle ear, and paranasal sinuses), and tumors in this location account for 40% of all childhood RMS cases. Imaging characteristics typically show an enhancing soft tissue mass, frequently with osseous destruction. CT is optimal for evaluating the bony destruction;
however, MRI is complementary to CT and more sensitive in the detection of intracranial extension which can be present in up to 55% of patients with middle ear, paranasal sinus (parameningeal sites), nasopharynx involvement, or intraspinal extension (Sanghvi et al. 2013; Thompson et al. 2013). On MRI, rhabdomyosarcoma is typically isointense to minimally hyperintense relative to muscle on T1-weighted images and hyperintense relative to muscle on T2-weighted images, with diffuse

**Fig. 27** Rhabdomyosarcoma. (a) Axial T1-weighted image, (b) axial T2-weighted image, (c) axial postcontrast T1-weighted image with fat suppression, (d) axial diffusion-weighted image. Well-defined isointense on T1 (a) and T2WI (b) with moderate and homogeneous enhancement (c) and diffusion restriction (d) lesion arising within the posterior region of the nasal fossa (*asterisks*) eroding the inner walls of both orbital cavities and nasal septum.
contrast enhancement (Fig. 27). Some tumors may appear relatively homogeneous, while others are frankly heterogeneous, probably correlating with cellularity, tumor matrix, and necrosis (Sanghvi et al. 2013; Thompson et al. 2013; Freling et al. 2010; Vazquez et al. 1995; Castillo and Pillsbury 1993; Lee et al. 1996). In our daily practice, diffusion-weighted imaging helps in their differential diagnosis as they present with low ADC values.

**Osteosarcoma**

Osteosarcoma of the head and neck remains a rare (5–9%) and highly malignant tumor arising from undifferentiated connective tissue of the bone. In children, most osteosarcomas are postradiation (the majority related with prior retinoblastoma), are osteolytic, and affect the sinonasal cavity, mandible, or maxilla.

CT provides excellent detection of tumor matrix calcification, cortical involvement, and, in most instances, soft tissue and intramedullary extension. MRI differentiates between densely ossified or calcified regions which show both T1- and T2 hypointensity and nonossified regions with higher signal intensity on T2-weighted images. In the paranasal sinuses, T2-weighted images will distinguish relatively hypointense tumor extent from the hyperintensity of retained mucous debris in the obstructed sinus (Fig. 28) (Lee et al. 1988; Maes et al. 1998; Patel et al. 1999).

**Nasopharyngeal Carcinoma**

Nasopharyngeal carcinoma is uncommon in childhood; however, an evaluation of the nasopharynx should be part of the initial physical examination in children. Earlier diagnosis may direct the patient to timely appropriate therapy.

The configuration of nasopharyngeal carcinoma is almost always asymmetric, in contrast to benign masses. At presentation, typically there are uni- or bilateral local lymph nodes simulating a lymphoproliferative disorder. Local spread of the tumor outside the confines of the nasopharynx is dictated in large measure by the local anatomy. The pharyngobasilar fascia acts as a barrier to local spread of the tumor and tends to direct the advancing tumor toward the central skull base. Invasion of the skull base is more easily recognized on MRI imaging than CT by changes in the marrow signal of the clivus (decreased signal on T1-weighted images, enhancement postcontrast administration, and generally increased signal on T2-weighted images). Widening of the petroclival fissure due to infiltration by tumor is best appreciated on CT bone windows. Later in the course of the disease, the tumor breaches the pharyngobasilar fascia and gains access to the parapharyngeal space. Tumor can also extend to the pterygopalatine fossa causing widening that is easy to detect on CT and MRI (Fig. 29). On rare occasions, the tumor can spread into the masticator space to involve the muscles of mastication. CNS involvement may also occur (Bass et al. 1985; Stambuk et al. 2005).
Fig. 28  Osteosarcoma. (a) Coronal T2-weighted image with fat suppression (b) coronal post-contrast T1-weighted image with fat suppression. Heterogeneous big mass with mixed signal intensity and very dark punctuate images (asterisk) on T2WI (a) showing huge peripheral enhancement (arrow, b) arising from the left nasal fossa protruding to the homolateral maxillary sinus and orbit, shifting the medial and inferior rectus muscles, as well as the nasal septum to the right. Note the intimate contact with the left olfactory bulb.

Fig. 29  Nasopharyngeal carcinoma. (a) Midline sagittal CT image, (b) paramedian sagittal T2-weighted image, (c) midline sagittal postcontrast T1-weighted image. Fifteen-year-old girl with large soft tissue mass in the nasopharynx (arrows) with odontoid process osteolysis (circle, a) and spinal anterior epidural involvement (asterisks). The mass is heterogeneous on T2WI (b) and has an avid enhancement (c)
Metastatic Neuroblastoma

It is known that neuroblastoma embryologically develops from the neural crest, an ectodermal tissue with pluripotential differentiating capability. It is postulated that tissues derived from the neural crest may provide the appropriate “soil” to support metastasizing tumors, such as neuroblastoma. This theory may explain the remarkable tendency for neuroblastoma to involve the facial bones and parts of the cranium, which are also derived from the neural crest.

Although neuroblastoma is a common childhood malignancy, which frequently metastasizes, involvement of the facial bones and paranasal sinuses are uncommon. Less than 5% of neuroblastomas involve the head and neck. Neuroblastoma is usually a secondary metastatic lesion rather than a primary lesion of the head and neck. Except in infants, in whom the liver is involved more frequently than the skeleton, bone is the most frequent site of metastases in patients with disseminated neuroblastoma. Secondary craniocerebral neuroblastoma is manifested most often as osseous metastases involving the calvarium, orbit, skull base, and cervical lymph nodes and rarely involves the sinonasal cavity and facial bones.

Lesions are typically heterogeneously enhancing soft tissue masses with bony destruction and aggressive periosteal reaction. Skeletal survey, bone scintigraphy, and MIBG nuclear scintigraphy are helpful to assess for additional lesions (Fig. 30) (Zimmerman and Bilaniuk 1980; D’Ambrosio et al. 2010).

Orofacial Clefting Disorders

Introduction

Patients with facial clefts may be classified according to their interorbital distance. Simple (common) clefts (mostly involving the lip and palate) have a normal interocular distance and comprise over 99% of all facial clefts (Castillo and Mukherji 1995). These patients require no imaging before treatment. Facial clefts with hypertelorism represent less than 1% of all clefts and are related to the midline cleft syndrome (Naidich et al. 1988). These patients require complex imaging of the face and brain. Facial clefts with hypotelorism are found in some patients with holoprosencephaly and are very rare.

Management of all patients with facial clefts is complex and requires a multidisciplinary team work. Prenatal diagnosis is done in most of the cases by US. Then, MRI should be done to confirm the diagnosis and to demonstrate additional findings as it provides more information compared with US (Wang et al. 2011). The initial diagnosis is generally followed by rehabilitation, surgery, and further rehabilitation. Although surgery may be performed early in life, most of these patients require follow-up until 18–20 years of age. Radiologists do not play a significant role in the management of patients with simple (common) clefts but assume an important role in the management of patients with other less common types of facial clefting.
Development of the Face

In the face, most of the skeleton and muscles derive from neural crest cells (Sulik 1996). These neural crest cells are regulated by many genes, among which are homeobox (Hox) and paired box (Pax). These genes express sequential protein products (morphogens) which regulate the expression of different cell populations. Neural crest cells located between the neural plate and the surface ectoderm give origin the mesenchyme of the face. Cells from the upper and lower mesencephalon contribute to the formation of the frontal prominence and the maxillary and mandibular regions, respectively (Fig. 31).

After the closure of the anterior neuropore, the frontal prominence develops (Som and Curtin 2011). Inferior and lateral to the frontal prominence are the olfactory placodes (thickened plates of skin) that will become the nasal pits. The nasal pits separate the nasal medial and nasal lateral processes. The nasal medial processes fused superiorly with the frontal prominence to form the frontonasal process. The lateral nasal processes fuse inferiorly and laterally with the maxillary processes. All of these structures are separated from the inferiorly located mandibular process by the primitive mouth. The nasal processes, frontal prominence, and maxillary segments are responsible for the formation of the nose (including alae), medial maxillary regions (from lateral orbital canthus to nose), the philtrum, and the upper lip (Hedlund 2006).

The hard palate is formed by the primary and secondary processes (Som and Curtin 2011). The primary process is somewhat triangular in shape and is located anteriorly in the midline. It arises from the intermaxillary segment. The secondary
processes are two lateral and posteriorly located shelves. They fuse in the midline to originate the posterior hard palate (Fig. 32). Their most posterior aspect does not fuse and gives origin the soft palate.

All patients with facial clefting demonstrate slower facial and skull growth than normal individuals (Kreiborg and Cohen 1996). The overall head size is reduced and their skeletal maturity is delayed. These abnormalities are multifactorial in nature, and feeding problems during early infancy and/or to recurrent upper respiratory infections are contributing factors. In addition, the adolescent growth spurt is slightly delayed (6 months on average) in all patients with facial clefting. Overall, patients with facial clefting are smaller than normal individuals.

In patients with facial clefts, the maxilla may show either increased or decreased width or grow normally (Kreiborg and Cohen 1996). The maxilla may be slightly retropulsed, and the mandible may be small. Despite these abnormalities, dental occlusion is generally satisfactory (KWL et al. 1996). In patients with cleft lip/palate, the sphen-occipital synchondrosis may be wider and its closure may be delayed. In patients with untreated facial clefts, the lower face (nasal bone, maxilla, and mandible) is characterized by retraction (Semb and Shaw 1996). The overall dimensions of the nasopharynx are reduced. The nose is displaced backward. The tongue tends to grow faster, and this may contribute to abnormalities in swallowing and breathing. The teeth are also small.

The size of the nasal airway and its function on the cleft side in adulthood are reduced compared with the non-cleft side. The size of the maxillary cleft in infancy does not seem to affect size and function of the nasal airway in adulthood (Reiser et al. 2011). Oropharyngeal airway volume is smaller in adolescents with cleft lip and palate, leading to mouth breathing. The mandible and the oropharyngeal airway are larger in the adolescent controls than in the juvenile controls without cleft lip and

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**Fig. 31** Diagram detailing the formation of the midface. The maxillary, the nasolateral, and the nasomedial processes influence the formation of the frontal prominence that in turn gives rise to several important structures in the midline of the face.

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FRONTAL PROMINENCE

- MAXILLARY PROCESS
- NASOLATERAL PROCESS
- NASOMEDIAL PROCESS

FRONTONASAL PROCESS

- NASAL BONES
- FRONTAL BONES
- CARTILAGINOUS NASAL CAPSULE
- ETMOIDS
- CEREBRAL INCISORS

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palate, but there are no significant differences between the adolescent and juvenile patients with cleft lip and palate (Yoshihara et al. 2012).

Alterations in facial growth may also be secondary to surgery. Patients with early repair of clefts isolated to the palate may show normal facial growth. Patients with clefts involving palate and lip show altered growth despite adequate surgery. Mandibular growth is not affected by surgery. The presence of surgical scar at the level of the palatal sutures may also affect the growth of the maxilla. Lip scars are not desirable. Lip surgery alone has a potential effect, and those patients will show a normal facial growth than non-operated ones. Overall, surgery is beneficial in the restoration of facial features and growth (Stella and Epker 1996).

The etiology of facial clefting may be syndromic or non-syndromic (Kreiborg and Cohen 1996). Delineation of syndromes provides information regarding phenotype, natural history, and inheritance and is helpful in counseling.

The Robin sequence with cytogenetic location at 17q24.3-q25.1 is associated with orofacial clefting, retrognathia, glossoptosis, and small mandible (Kreiborg and Cohen 1996; Benko et al. 2009). These abnormalities may be isolated or associated with well-defined syndromes. For example, the Robin sequence may be seen in the Stickler syndrome and in mandibulofacial dysostosis (5q31.3 to 5q33.3). More than half of patients with facial clefts harbor other anomalies. Non-syndromic defects may represent sporadic, and isolated genetic defects may be related to amniotic banding or secondary to teratogens (chemical, drugs, physical agents, and maternal disease during early pregnancy). Familial counseling is recommended for all patients with facial clefting.

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**Fig. 32** Formation of the hard palate. (a) In early life, the palatal shelves (P) do not reach the midline, and nasal septum (S) is short. The nasal cavity (N) communicates with the oral cavity (O) and the tongue (T). (b) Later, the palatal shelves fuse in the midline and superior with the nasal septum separating the nasal from the oral cavity. The turbinates (*) begin to form at this time.
Classification of Facial Clefts

Most craniofacial malformations are identified by their appearance. The majority of the classification systems are mainly clinical or anatomical, not related to the different levels of development of the malformation, and underlying pathology is usually not taken into consideration (Mazzola and Mazzola 2014).

Tessier System
In 1976, Tessier first emphasized the relationship between soft tissues and the underlying bone stating that “a fissure of the soft tissue corresponds, as a general rule, with a cleft of the bony structure” (Mazzola and Mazzola 2014). Clefting refers to an interruption in the skeleton and/or soft tissues connecting the hairline, eyebrows, eyelids, nostrils, lips, mouth commissures, and ears. The bones surrounding soft tissue clefts are almost always hypoplastic. Some clefts are common while others are extremely rare. Tessier was the first to classify facial clefts according to a system (Tessier 1976). The Tessier system is useful in classifying the clinical appearance of clefts but bears no significance as to the prognosis, associated anomalies, and management of these patients.

According to Tessier, facial clefts may be located in 14 different areas of the face, most related to the orbits (Fig. 33). This system provides a short, concise, and useful nomenclature for describing the topographical location of the clefts. The face is divided in clocklike fashion. Position zero begins in the midline nose and 14 ends in the midline forehead. The other positions are arranged in a counter clockwise rotation around the face. According to this system, most lip/palatal clefts are in positions 1–3, while most severe facial dysraphisms are in positions 0, 4, 5, and 14.

Sedano System
The Sedano system may be the best way to classify facial clefting and its relation to brain abnormalities. Naidich et al. found that certain types of Sedano facies have discreet intracranial abnormalities, thus mandating imaging of the brain in those patients (Naidich et al. 1988; Allam et al. 2011; Sedano et al. 1970). This classification is useful only in those patients with the so-called frontonasal dysplasia. The typical clinical features of this syndrome are hypertelorism, cranium bifidum occultum (generally frontal), a widow’s peak hairline, and midline nasal clefting which may extend in the upper lip, premaxilla, and palate (Fig. 34). Other abnormalities, present in varying degrees, include telecanthus, ocular colobomata, microphthalmia, and clefting of the nasal alae. The following describes the different Sedano facies:

Type A: Ocular hypertelorism, broad nasal root, groove in midline nose, absent tip of nose, no true bone clefting, anterior cranium bifidum, and preauricular tags. These patients have no intracranial anomalies and are of normal intelligence.

Type B: Ocular hypertelorism, broad nasal root, deep median facial groove, or true cleft affecting the nose or both the nose and the upper lip. The palate may also be cleft and anterior cranium bifidum may also be associated. It can be subdivided into (i) a “low group,” clefting the upper lip, the palate, and occasionally the nose
Fig. 33  Tessier clefting classification. The topographical distribution of facial clefts. The first is located in the midline below the lips, the second and third at the nose, and so on. This system has no relationship to the embryology and, other than providing a pictorial description of the location of a cleft, it has little utility.

Fig. 34  Photographs of two different patients. (a) Huge bilateral labial and palatine cleft with protrusion of the premaxilla (Image courtesy of Dr. R. Gander, Barcelona, Spain). (b) Central labial cleft and hypotelorysm.

(Fig. 35), and (ii) a “high group” involving the nose, nasal, and frontal bones. Both of these subgroups harbor intracranial anomalies (anomalies of the corpus callosum, lipomas, dermoids, and falcine calcifications) (Fig. 36) and orbital anomalies (optic
nerves dysplasia, anophthalmos, microphthalmos, and colobomata) (Albernaz et al. 1997).

Type C: Ocular hypertelorism, broad nasal root, anterior cranium bifidum, and unilateral or bilateral notching of the alae nasi. These patients may have dermal sinuses that communicate with dermoids/lipomas.

Type D: These patients represent a combination of the features found in facies B and C. They may harbor intracranial lipomas and falcine calcifications.

DeMyer System
In this system, midline facial clefts are divided into four groups that are formed by the major and minor defects of this syndrome (DeMyer 1967):

Group 1: Ocular hypertelorism, median cleft nose, absence/hypoplasia of upper lip/premaxilla/palate, and a cranium bifidum
Group 2: Ocular hypertelorism, complete nose cleft, normal upper lip/premaxilla/palate, and a cranium bifidum
Group 3: Ocular hypertelorism, cleft in nose and upper lip, normal palate, and no cranium bifidum
Group 4: Ocular hypertelorism and a medial nasal cleft

Simple Clefts

Simple (common) clefts comprise over 99% of all facial clefts. They involve only the upper lip and palate. In these patients the interocular distance is normal. They are isolated anomalies and imaging may not be indicated; the diagnosis is made based on the clinical findings. These clefts are eccentric in location, generally between the superior incisors and the canines. They represent a lack of fusion of one side of the primary palatal process with its adjacent secondary process. The cleft may continue posteriorly in the midline and be related to a lack of midline fusion of the secondary processes (shelves). These clefts may be accompanied by clefting of the upper lip. The cleft in the lip is probably an anomaly of fusion between the medial and lateral nasal processes. The cleft is located immediately laterally to the philtrum and continues superiorly to join one nostril. The complete cleft lip and palate is a significant malformation leading to abnormalities in mastication, hearing, speech, facial growth, feeding, and breathing (Mazzola and Mazzola 2014; Sailer and Gratz 1996). In addition, profound psychological problems occur in both the patient and the parents. There is an increased mortality rate in children with complete cleft lip/palate when compared to the normal population.

The simplest method of presurgical infant orthopedics is lip taping, which may be started soon after birth, trying to bring the alveolar segments into closer approximation. The most advanced method of presurgical infant orthopedics is a combination of a palatal appliance with nasal molding. The primary goals of cleft lip repair are to produce functional continuity of the orbicularis oris muscle, recreate symmetry, reconstitute the Cupid’s bow, produce a slight pout of the tubercle, balance the vermillion, and achieve nasal symmetry. Controversy still exists regarding the optimum timing and surgical technique for cleft lip and palate repair. Repair of the cleft lip is done as early as possible. Some surgeons prefer to wait until after 3 months to allow for some growth. A cleft palate is generally surgically closed by 1 year of age (Manna et al. 2009; Monson et al. 2013). This results in a minimal impairment of facial growth. Bone grafting of the defect is done in many patients with clefts (Sailer and Gratz 1996). The timing and specific techniques for bone grafting are controversial and beyond the scope of this review.

A more severe type of simple clefting is the bilateral complete clefts. These are similar to the unilateral ones but represent a lack of fusion of the primary process with the secondary processes. The primary process and the intermaxillary segment remain detached and present as a mass in the midline surrounded by clefts that extend into each nostril. This fleshy red mass may contain deformed teeth. The prolabium is located above this mass and is small. In order to avoid atrophy of the
maxilla, closure of one side at a time is suggested (Turvey et al. 1996). The opposite cleft is generally closed at 5 weeks after the initial surgery.

Most patients with facial clefts will have some degree of midfacial deficiency. Approximately 25% of these patients will experience significant malocclusion and other difficulties including abnormal breathing, nasal drainage, abnormal speech, hearing, and olfaction. In some of these patients, surgical advancement of the maxilla may be indicated (Turvey et al. 1996). This procedure is generally delayed until 6–8 years of age. End-stage reconstructions result in the best cosmetic appearance. End-stage procedures include lip revisions and rhinoplasty (Sailer and Gratz 1996).

A cleft palate may lead to velopharyngeal insufficiency (VPI) (Sloan et al. 1996). Because of the defect, air escapes into the nasal cavities resulting in an abnormal speech pattern. To compensate, misarticulations develop complicating the abnormal speech pattern even further. Noninvasive treatment includes the use of palatal prostheses and obturators. However, surgical treatment is still considered best. Patients with only a bifid uvula or a notch in the soft palate may have VPI and may not necessitate a specific treatment. Surgical procedures for treatment of VPI include the creation of a pharyngeal flap and a sphincter pharyngoplasty. Surgery should be done as soon as the diagnosis of VPI is confirmed. Best results are achieved when surgery is done between 3–8 years of age.

**Midline Facial Cleft Syndromes**

The midline facial clefting syndromes comprise less than 1% of all facial clefts. In these patients, hypertelorism is always present (Fig. 37). The clinical classification of these clefts has been previously discussed. Because of the increased incidence of intracranial anomalies, these patients will necessitate imaging of the face and brain. We image the face using spiral computed tomography (CT) with axial 3 mm thick sections from the mandibular symphysis to the skull vertex and then obtain three-dimensional reformations of these data. We prefer to image the brain with non-contrast MRI. There is an increased incidence of microphthalmia and anophthalmia in these patients. The abnormality tends to be unilateral but may be bilateral.

Most of the patients with midline facial dysraphism will have a *cranium bifidum occultum* (Albernaz et al. 1997). This refers to a bone defect occurring along the region of the metopic suture. The defect may extend from the bregma to the nasofrontal region and is covered by the skin. No anatomic structure (brain, lipoma, dermoid) traverses these defects.

As mentioned earlier, we prefer to use the Sedano system to classify these patients (Sedano et al. 1970). This system establishes a relationship between the facial morphology and the presence of intracranial anomalies (Naidich et al. 1988). Patients with facies types B, C, and D will necessitate brain MRI. These groups show intracranial lipomas and abnormalities of the corpus callosum. Falcine calcifications are better demonstrated by CT but have no clinical significance. The
percentage of patients with facies type B who have an abnormal corpus callosum is not known but it appears to be a frequent associated anomaly. These patients commonly exhibit moderate-to-severe developmental delay. Other less common abnormalities reported in patients with midline facial clefting include frontal, ethmoidal, and sphenoidal encephaloceles, clefts in the tongue, duplication of the pituitary gland, orofacial dermoids and teratomas, dysplastic brain, Klippel-Feil syndrome, Kallmann syndrome, renal agenesis, and polysyndactyly.

Hypertelorism is seen in all patients with midline facial clefts (Tessier 1972). It may be classified according to the Tessier scale that divides these patients into three groups according to the interorbital distance. Hypertelorism is almost always accompanied by a deformity of the nose (wide root, bifid nose, nose duplication, and complete or partial nasal hypoplasia). Correction of hypertelorism depends on the pneumatization of the maxillary sinuses and the development of the permanent dentition (Tessier 1972). Most surgeons believe that correction cannot be satisfactorily achieved before 4–10 years of age (Tessier 1972). Correction before eruption of the permanent dentition will result in an irreversible damage of the tooth buds. Subcranial procedures include medial orbital wall approximation, orbital medialization without orbital roof osteotomy, and a LeFort III osteotomy. The transcranial procedure which is probably the best is the Tessier hypertelorism operation. This procedure permits mobilization of the orbits in all directions, but is a complex procedure that is performed only by experienced surgeons (Marchac et al. 2012).

### Facial Clefts and Holoprosencephaly

A midline facial cleft in the presence of hypotelorism dictates the need for evaluation of the brain to exclude midline anomalies such as holoprosencephaly (HPE) and septo-optic dysplasia (SOD). DeMyer et al. noted in 1963 that there is a spectrum of
holoprosencephalic disorders representing impaired midline cleavage of the embryonic forebrain (DeMyer et al. 1963). Although not all HPE are associated to midline facial clefting, the following types exist:

(i) One with absent intermaxillary segment with central defect and hypotelorism: these patients have two eyes and hypoteloric orbits, an absent or flat nasal root, hypoplastic nasal alae, and a pseudomedian cleft of the upper lip (due to an absent intermaxillary segment)

(ii) One in which the patients have an intermaxillary rudiment with hypotelorism: these patients show bilateral cleft lip/palate, an absent or flat nasal root, and abnormal or incomplete nasal septum

All classic HPE, but particularly the severe grades, are also associated with a deficiency of the premaxillary segment of the face. HPE is the result of an abnormality that prevents the normal development of the forebrain and of the frontal prominence. This results in abnormal cleavage of the brain and deficiency of the upper central face. Most patients with severe grades of HPE are stillborn. We consider non-contrast MRI of brain essential in all patients with facies suspicious for holoprosencephaly (Hahn and Barnes 2010; Levey et al. 2010). The different types of HPE probably represent a continuous spectrum but traditionally they have been divided as follows:

(i) Alobar HPE: the most severe type, includes the absence of the falx cerebri, interhemispheric fissure, and the superior sagittal sinus. The thalami are fused and there is a single monoventricle. The septum pellucidum is absent. There may be a large dorsally located cyst filled with cerebrospinal fluid (CSF). Nearly 90% of these patients have severe facial anomalies. Approximately 10–17% of these patients have mild facial deformities or even a normal face.

(ii) Semilobar HPE: the intermediate form is the most commonly encountered type in clinical practice. There is partial development of falx cerebri, interhemispheric fissure, and the superior sagittal sinus. The monoventricle shows some posterior differentiation but the septum pellucidum is absent. There is a rudimentary third ventricle and thalami may be fused (Fig. 38). A dorsal CSF-filled cyst may be present. Nearly 30% of these patients have significant facial anomalies.

(iii) Lobar HPE: the least severe type. The midline structures are nearly completely formed. The ventricles are nearly normal in configuration but the septum pellucidum is absent. The posterior aspects of the brain are normal and the rostral brain may show subtle midline deficiencies. The face is usually normal in these patients. A single central upper incisor may be present. The piriform aperture may be narrowed. Some authors consider SOD as a variant of the least severe form of HPE.

(iv) Middle interhemispheric variant (MIH) (syntelencephaly): it is a milder subtype. Unlike classic HPE where the most severely nonseparated region is the basal forebrain, in MIH the posterior frontal and parietal lobes fail to separate.
The body of the corpus callosum is absent. The hypothalamus and lentiform nuclei are normal whereas the caudate nuclei and thalami are incompletely separated in many patients. The Sylvian fissures in most patients are oriented nearly vertically. Approximately two-thirds have either subcortical heterotopic gray matter or cortical dysplasia. Abnormally the thick cortex lining the anterior interhemispheric fissure was often present and was contiguous across the midline. Patients usually have normal or large intraocular distances (hypertelorism) (Simon et al. 2002).

There is an imperfect correlation between the type of facies and the intracranial anomalies. The severe types of HPE are commonly associated with severe facial deformities but the reverse is not always true. In one series of patients with no facial anomalies, 8% had alobar HPE, 20% had semilobar HPE, and 50% had lobar HPE.

Common medical problems related to HPE include hydrocephalus which occurs in about one-sixth of children; shunting with adjustable valve may be may needed. About one-half of children with HPE have at least one seizure, and epilepsy requiring treatment with antiepileptic medication occurs in about 40%. Abnormal muscle tone and impaired coordination are seen to some extent in virtually all children with HPE. Children with more severe motor impairment tend to have more severe impairment of swallowing function, so some swallowing problems are seen in almost all children with alobar and semilobar HPE. About two-thirds of these children have required placement of a gastrostomy tube because of risk of aspiration or inadequate oral intake. Besides oromotor dysfunction, facial anomalies

Fig. 38  Semilobar holoprosencephaly. (a, b) Axial T2-weighted images. Newborn with hypotelorism (a). The frontal lobes are hypoplastic and fused across the midline, with anterior falx defect and basal ganglia fusion giving a pancake-like appearance (asterisk) (b)
such as cleft lip and palate and congenital nasal piriform aperture stenosis contribute
to feeding problems as well. Children with HPE are at risk for aspiration and
development of recurrent respiratory problems and/or chronic lung disease and
upper airway obstruction due to facial anomalies. In general, the gastrointestinal
tract is normal; however, patients have functional gastrointestinal disorders including
poor gastric emptying, gastroesophageal reflux, and constipation, presumably
due to abnormal regulation by the nervous system. Hypothalamic dysfunction
(abnormal sleep-wake cycles, temperature instability, and impaired thirst mecha-
nisms) is common in children with HPE. Central diabetes insipidus occurred in
approximately 70% of patients with classic HPE. Anterior pituitary hormone defi-
ciencies such as hypothyroidism (11%), hypoadrenocorticism (7%), and growth
hormone deficiency (5%) are much less common (Levey et al. 2010).

**Rare Facial Clefts**

The percentage of these abnormalities is extremely small. Rare clefts include
transverse oral clefts (macrosomia), oblique clefts, isolated cleft of the median
upper lip, isolated clefts of the nose (rhinoschisis), and isolated clefts of the scalp
(Fogh-Anderson 1965).

- True medial upper lip clefts are easily repaired. Imaging of the brain is indicated,
as midline brain deficiencies may be present. These patients may have defects in
the hands and may belong to the *oral-facial-digital (OFD) syndrome*. There are
12 different OFD syndromes. Types I or Papillon-Leage and Psaume syndrome
(OMIM 311200) and VI or Váradi-Papp syndrome (OMIM 277170) are the most
studied (Bisschoff et al. 2013; Poretti et al. 2008; Darmency-Stamboul et al.
2013).
- Oblique clefts probably belong in the facial dysraphism syndromes. They repre-
sent an anomaly of fusion of the nasal lateral process and frontal prominence.
They extend from the mouth or nose into one orbit.
- Transverse facial clefts are due to anomalous fusion (or lack of) between the
maxillary and mandibular processes. This leads to a lateral extension of the
primitive mouth resulting in macrosomia. Associated abnormalities of the bran-
chial arch system are common in these patients.
- Irregular clefting of the palate may be accompanied by a small tongue, deformed
nasal cartilages, and finger deformities (OFD syndrome).
- Isolated clefts of the nose may involve one or both alae (coloboma of the nasal
alae) or result in a bifid nose. Most commonly, a bifid nose is accompanied by
hypertelorism and belongs to the midline facial cleft syndromes.
- Scalp clefts probably belong in the cranioschisis. The skin may be absent close to
the vertex and may be associated with clefts in the midface (Poretti et al. 2008;
Darmency-Stamboul et al. 2013).
Anomalies of the Nose with Respiratory Obstruction

Development of the Nose

The nasal processes are divided by the primitive nasal pits into medial and lateral components. The nasal pits are depressions of the epithelial thickenings called the nasal placodes. The naso-optic grooves extend bilaterally from the medial orbital canthi to the region between the frontal prominence and nasolateral processes (very close to the nasal pits). The development of the nasolacrimal apparatuses occurs in the region of the naso-optic grooves. The canaliculi and sacs form in the medial canthi and nasolacrimal ducts along the groove. The opening of the ducts is through the valves of Hasner, which are located lateral to the inferior turbinates in the medial nasal walls.

Internally, the future mouth is separated from the cephalic portion of the gut (which in itself is the future oropharynx) by the buccopharyngeal membrane (Tsai et al. 2003). Resorption of this membrane occurs, and its remnant is represented by the lymphatics in Waldeyer’s ring (lingual and palatine tonsils and adenoids). In a similar fashion, the nasal pits that will undergo progressive excavation are separated from the cephalic gut (stomodeum) by the bucconasal membrane. This membrane represents the junction between the nasal ectoderm and the stomodeal ectoderm (which lies at the level of the palate). Resorption of the bucconasal membrane establishes communication between the nasal cavities and the upper aerodigestive tract (oropharynx). The nostrils are the external nasal orifices and, together with the anteroinferior nasal passages, constitute the pyriform (anterior) aperture (Tsai et al. 2003; Halewyck et al. 2012; Sperber et al. 2010). The pyriform aperture is pear shaped, as its name implies. The posterior openings of the nasal cavities are termed posterior choanae. The primitive posterior choanae are formed by invagination of the nasal pits. Once established, they are filled with plugs of epithelium, which are resorbed later in life, resulting in the secondary or permanent posterior choanae. Lack of recanalization of these plugs is believed by some to be responsible for posterior choanal stenosis/ataresia. Inside the nasal cavities, the nasal septum migrates inferiorly to join the palatal shelves (secondary palate) in the midline and divides the nasal cavity into two fairly symmetric compartments (Sperber et al. 2010; Stool et al. 2003). Misdirection in the flow of these mesodermal elements also may be responsible for posterior choanal abnormalities such as stenoses and atresia. The hard palate is formed by the primary and secondary palates. Anteriorly, the triangle-shaped primary palate arises from the intermaxillary segment and fuses with the posterior palatal shelves to establish the hard palate (Som and Curtin 2011). In their most posterior aspects, the palatal shelves do not fuse and form a soft palate. By 8 weeks of life, the formation of the nasal cavities is complete (Castillo and Mukherji 1995). From this time to about 24 weeks of gestation, the nasal cavities are filled with epithelial plugs. Later these plugs are resorbed, and recanalization of the preformed nasal cavities occurs to establish definite patency, as previously mentioned.
The formation of the nasofrontal region is unique. The primitive nasal bones are separated from the lower aspect of the frontal bones by a small fontanelle called the fonticulus frontalis. The cartilaginous nasal capsule is separated from the nasal bones by the prenasal space (Sperber et al. 2010; Stool et al. 2003; Barkovich et al. 1991; Hedlund 2006). This space temporarily contains a dural diverticulum that communicates with the subarachnoid space of the anterior cranial fossa. As development progresses, the frontal and nasal bones fuse, obliterating the fonticulus frontalis. Its remnant is the frontonasal suture. The diverticulum contained within the prenasal space regresses into the skull and disappears, leaving behind a tiny, blind-ending depression anterior to the crista galli called the foramen cecum. The prenasal space closes, and the anterior aspect of the nasal capsule fuses with the nasal bones.

**Anomalies of the Nose**

From a practical standpoint, we prefer to divide nasal anomalies into those with and without respiratory obstruction. The former may require emergency treatment, whereas the latter are better treated before the child begins attending school (usually 5 years of age) or after the face has attained near-adult size (between 8 and 9 years of age). Anomalies associated with respiratory distress require securing an orotracheal airway, placement of nasogastric or percutaneous gastrostomy tubes, and in rare occasions, tracheostomy. Tracheostomies carry significant morbidity and mortality at this age and are therefore not commonly used. Polyrhinia (multiple noses) and hypoplasia of the nasal alae are seen with respiratory obstruction but are treated clinically; because these patients do not require imaging studies, they are not addressed here (Elluru and Vijayasekaran 2009). Clefting anomalies of the nose, such as the median cleft syndromes, holoprosencephaly, septo-optic dysplasia, and the proboscis lateralis, are not associated with respiratory obstruction.

**Posterior Choanal Obstructions**

Obstruction at the level of the posterior choanae is probably the most commonly encountered cause of nasal obstruction in the newborn. These obstructions may be the result of stenoses, atresias, and more commonly, a combination of both. They occur in 1:5000–8000 newborns and are more common in girls (Aslan et al. 2009; Gnagi and Schraff 2013; Adil et al. 2012). Of patients with posterior choanal obstructions, over 75% have systemic anomalies, which include acrocephalosyndactyly, amniotic band syndrome, intestinal malrotations, Antley-Bixter syndrome, CHARGE syndrome, Crouzon’s disease, de Lange’s syndrome, fetal alcohol syndrome, DiGeorge syndrome, and the Treacher Collins syndrome. Anomalies in chromosomes 18, 12, and X0 also may be detected (Som and Curtin 2011). Rarely, posterior choanal obstructions may be familial.

Clinically, these patients show early respiratory distress, which is aggravated during feeding and relieved by crying. A nasogastric tube cannot be introduced more than 2–3 cm into the nose. Unilateral choanal obstructions are twice as common as bilateral ones. Unilateral abnormalities may remain undetected until later in
childhood, when the principal symptoms are rhinorrhea, nasal stuffiness, and infection. In these older patients, the most important differential diagnosis is a retained foreign body within one nasal cavity.

Bony atresias and stenoses arise from an increase in thickness of the inferior and posterior vomer. They require surgery via a transpalatine approach with reconstruction of the openings and possibly stent placement. Membranous atresias may be related to incomplete resorption of the epithelial plugs (vide supra) that occupied the nasal passages in utero. Therefore membranous atresias may be thick and pluglike or thin and strand-like. Thin membranes may be amenable to endoscopic transnasal perforation with or without the use of laser. Thick membranes, in our experience, tend to occur with bony choanal stenoses and therefore require transpalatine surgery.

Computed tomography (CT) is the imaging method of choice. Before the study, the patient’s nasal passages are suctioned vigorously to evacuate secretions. Spiral acquisitions with 1-mm thick partitions are acquired and need to be processed by using the high-resolution (edge enhancement) bone algorithm because of the cartilaginous nature of the structures. By using CT computer calipers, the diameter of the posterior choanae (at maximum space) and the vomer (at its thickest point) are measured. In children younger than 8 years, the vomer should measure less than 0.23 cm and should not exceed 0.55 cm in width. The posterior choanae should measure more than 0.34 cm in diameter (Aslan et al. 2009; Gnagi and Schraft 2013; Adil et al. 2012). In bony atresia, the medial and posterior maxillae are also bowed inwardly and fused with the thick vomer. With stenoses, the posterior vomer also is thick, resulting in narrowed choanae. Membranous atresias appear as soft-tissue-density structures at the posterior choanae (Fig. 39). Membranous atresias may be thin or thick bands. Both bony and membranous abnormalities may be present in a patient.

**Nasolacrimal Duct Cysts**

Although these anomalies are rare, they are probably the second most common cause (after posterior choanal obstructions) of acute nasal obstruction in newborns. There is no gender predilection. These anomalies are the result of incomplete canalization of the distal nasolacrimal ducts or obstructions at the level of the valves of Hasner (Wong and Vander Veen 2008). It also is possible that in utero inflammation results in obstruction of the distal nasolacrimal ducts, as we had two newborn patients in whom histologic study of the cyst capsule showed chronic inflammatory changes.

Accumulation of secretions leads to dilatation of part or the entire duct. Proximal obstructions lead to masses in the medial orbital canthi, whereas distal obstructions lead to masses in the inferior nasal passages projecting under the inferior turbinates (Wong and Vander Veen 2008; Weber et al. 1996). These distal cysts may be unilateral or bilateral and may remodel the inferior turbinates by making them thin and displacing them superiorly. Treatment of these cysts is accomplished by endoscopic resection at their base or fenestration of their walls. It is possible that many of these cysts are perforated during the introduction of nasogastric tubes. In patients with distal nasolacrimal duct cysts, neuroimaging should be done.
CT shows smoothly marginated, homogeneous masses of soft tissue density in the inferoanterior nasal passages. MRI, especially when gadolinium is administered, differentiates fluid from solid masses within the sac and to define tumor extension from the sac into the duct and anatomic regions outside the sac and duct (Fig. 40). Both CT and MR imaging are required to adequately evaluate midface anomalies, thereby facilitating treatment planning. If bilateral, they tend to be asymmetric. If unilateral, the nasal septum may be slightly displaced toward the side opposite the lesion. The inferior turbinates may be thin and slightly displaced superiorly. These cysts may coexist with posterior choanal abnormalities. The nasolacrimal duct may be otherwise normal, or its caliber may be increased (Weber et al. 1996; Lowe et al. 2000; Castillo 1994). Although congenital dacryocystoceles may resolve with conservative measures, many become infected and require systemic antibiotic treatment, and most require surgical intervention. Referral in the early neonatal period can aid
in timely intervention before complications such as infection occur (Wong and Vander Veen 2008).

**Pyriform Aperture Stenosis**

The pyriform aperture is pear shaped and formed superiorly by nasal bones, laterally by the maxilla, and inferiorly by the horizontal portion of the maxilla. The incidence of pyriform aperture stenosis is unknown, but it is a very rare anomaly. Its incidence is, however, increased in patients with holoprosencephaly, particularly of the alobar and semilobar types. Clinically, symptoms are indistinguishable from those caused by posterior choanal abnormalities or nasolacrimal duct cysts. Mild cases may have apnea and problems at feeding, which improve with crying. Passage of a nasogastric tube or endoscope into the nose may be accomplished only with difficulty or not at all.

Patients may have associated facial hemangiomas, clinodactyly, endocrine dysfunction, and upper teeth anomalies (Lowe et al. 2000; Osovsky et al. 2007; Devambez et al. 2009; Bharti et al. 2011; Vanzieleghem et al. 2001; Lee et al. 2002). The latter are typically characterized by the presence of a central single incisor tooth, which results from congenital fusion of both upper central incisors (Fig. 41). This group of patients has an increased incidence of holoprosencephaly. Stenosis of the pyriform aperture without an upper central megaincisor is commonly an isolated anomaly (Johnson et al. 2008).

Treatment of pyriform aperture stenosis anomaly requires sublabial resection of the anteromedial maxilla and reconstruction of the anterior nasal passages. After surgery, 3.5 mm endotracheal tubes may be placed and left as stents for 3–4 weeks. Mild cases of pyriform aperture stenosis may be treated conservative with nasal decongestants and nasal humidification (Devambez et al. 2009; Bharti et al. 2011; Lee et al. 2002).

CT is the imaging method of choice in these children. Axial CT should be obtained by using at least 1 mm thick sections parallel to the hard palate and should include the lower maxilla. The overgrowth of the maxilla manifests as inward bowing of the medial surface of the premaxillary segment. Coronal images are particularly helpful in assessing the configuration of unerupted teeth. If the anomaly is isolated and there are no clinical manifestations other than respiratory distress, brain ultrasonography may be done, but if an intracranial anomaly is suspected, brain MRI must be performed. Normal pyriform aperture width is around 13.4–15.6 mm; when it is 4.8–7.0 mm or <11 mm in a term infant, stenosis should be diagnosed. Normal pyriform aperture area is about 0.7–1.1 cm², whereas 0.2–0.4 cm² is the area in stenotic patients (Lowe et al. 2000; Osovsky et al. 2007; Devambez et al. 2009; Bharti et al. 2011; Vanzieleghem et al. 2001; Lee et al. 2002).

**Nasopharyngeal Agenesis**

This is an extremely rare anomaly in which the nasopharynx fails to develop. It may be considered an extreme form of posterior choanal atresia (Smith et al. 1995). It is probably a result of lack of involution of the bucconasal membrane. These infants have severe respiratory distress at birth. A nasogastric tube or endoscope passes
through the pyriform aperture but rapidly encounters resistance. Patients need immediate establishment of an oral airway and tracheostomy thereafter. Surgery involves resection of the posterior hard palate and reconstruction of the posterior nasal cavities. Stenting after endoscopic repair of congenital bilateral posterior choanal atresia does not seem to decrease the incidence of reclosure and restenosis of the posterior choana. On the other hand, there are higher complication rate from using the stents like granulation tissue formation, excoriation or erosion of the nares, premature extrusion, dislodgement, stent blockage, and the unsightly aspect of having stents protrude from the nose. Surgery may be delayed until after 2 years of age to allow some growth of the structures involved (Saafan 2013).

Both CT and MRI are helpful in arriving at the correct diagnosis. CT shows fusion of the posterior hard palate and vomer with the ventral surface of the clivus (Fig. 42) (Smith et al. 1995). The posterior nasal cavities are hypoplastic and are filled with soft tissue. MR images (particularly sagittal) show the fusion of the hard palate with the clivus, the absence of the soft palate and uvula, and lack of air spaces in the nasopharynx.

Fig. 41  Solitary median maxillary central incisor with pyriform aperture stenosis. (a) Frontal view of 3D CT reformation, (b) axial bone window CT scan, (c) axial T2-weighted image. Small, triangle-shaped hard palate with congenital nasal pyriform aperture stenosis (asterisk, b), midnasal stenosis. Note the choanal atresia (arrowhead) preventing nasal tube to advance distally (a, b). Single maxillary central incisor in midline (open arrow, c) and oropharyngeal retained secretions
Agenesis of the Nose

This extremely rare anomaly is characterized by the complete absence of the nose and anterior nasal passages. Total nasal agenesis was first reported in 1967 by Palmer and Thompson (Palmer and Thomson 1967). At times, a rudimentary nose with blind-ending nostrils may be present. The embryologic characteristics of this anomaly are not certain, but probably it involves malformation of the nasal placode, frontonasal process, and maxillary and intermaxillary segments, as well as fusion between the latter process and the nasomedial and nasolateral processes. The abnormality is obvious at birth and, surprisingly, some children have little respiratory difficulty, whereas others have marked distress. Placement of a tracheostomy tube may be needed in patients with breathing difficulties. Reconstruction of the nose and its airway is delayed until 5 years of age or before the child is to begin attending school (Elluru and Vijayasekaran 2009; Brusati et al. 2009). Until that time, a prosthetic nose may be used.

The aims of radiological evaluation are to provide a basis for surgical planning and to map associated malformations. Imaging is better accomplished with CT. There is a thick atretic bony plate in the region of the nasal vestibule, the

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**Fig. 42** Nasopharyngeal atresia. (**a**) Axial and (**b**) midline sagittal bone window CT images. The soft palate is not formed, and the hard palate extends posteriorly to fuse with the anterior surface of the clivus, resulting in complete isolation of the nasal and oral cavities and the absence of a nasopharynx.
absence of the nasal bones, and the absence of the anterior nasal passages. The entire nasal cavity may be smaller even absent. Spiral CT three-dimensional imaging is helpful in depicting this anomaly (Fig. 43). The incidence of intracranial anomalies

**Fig. 43** Hemi-agenesis of the nose and ipsilateral orbitomaxillary hypoplasia. (a) Coronal soft tissue CT scan, (b) osseous frontal 3D CT reformation, (c) facial frontal 3D CT reformation. Fourteen-year-old girl with hypoplasia of the right maxillary sinus and orbit (a, b). Note in the facial 3D view the unilateral agenesis of the right fossa and nostril (c)
(and their types) is uncertain, and examination of the brain may be best done with MRI, especially to exclude frontal meningoencephalocele and to estimate the volume of the space between the floor of the anterior cranial fossa and the hard palate, which will be the location of a surgical nasal canalization (Olsen et al. 2001).

References

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