Endoscopic Management of Developmental Anomalies of the Skull Base

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Abstract

Keywords

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- glioma
- teratoma

Developmental anomalies of the skull base may present in childhood or as an adult. The most common pathologies include dermoid, encephalocele, and glioma. Encephaloceles may present as part of a syndrome. Other entities include infantile hemangiomas and teratoma. Endoscopic techniques provide a less invasive and morbid option for treatment. Proper evaluation and treatment is necessary to prevent complications such as meningitis.

Introduction

Endoscopic endonasal surgery (EES) is a safe and effective alternative to traditional skull base approaches for skull base lesions in pediatric patients. The principles and practice of EES as developed in adults can be applied to the pediatric population but there are numerous anatomic, developmental, and technical considerations that are unique to pediatric skull base surgery. The objective of this article is to review these considerations and describe EES for developmental anomalies of the pediatric skull base.

When considering EES in children, one of the first considerations is to recognize the difference between children and adults. Children have smaller blood volume and, thus, are less tolerant of intraoperative blood loss. Neonates are obligate nasal breathers. Therefore, lesions leading to nasal airway obstruction can quickly become life threatening in this special population. The sinonasal and skull base anatomy of children is not just smaller, it is different. Furthermore, growing skeletons have to be considered. Disruption of facial growth centers can lead to lifelong developmental impact. Knowledge of these anatomic areas and differences is important; morphologic analysis utilizing imaging studies have provided insight.^{1,2}

Historically, these lesions were treated with an open approach, often with craniotomy. EES has been increasingly used in children, eliminating facial incisions and cerebral retraction while speeding recovery and decreasing hospital

stays and costs.³ Many studies have examined the effectiveness and safety of EES in children.^{4–10} All have shown this to be an effective technique with acceptable morbidity, even in very young children.^{11,12}

Developmental anomalies at the skull base primarily form what is referred to as congenital nasal masses. These anomalies have been reported to occur in 1:20,000 to 1:40,000 live births. It is estimated that ~60% of these anomalies are nasal dermoids, with encephaloceles followed by gliomas comprising most of the other 40%. Much of the published literature on skull base surgery in pediatric patients assesses tumors, mostly in older children, as this is more common. Chivukula et al⁷ reviewed 112 pediatric skull base cases, noting 9 to be dermoid/epidermoid lesions, 12 Rathke's cleft cyst, 16 craniopharyngiomas, 10 chondroma/chondrosarcomas, 24 angiofibromas, and the remaining 30 making up other pathologies. Many of the congenital anomalies develop due to errors at fusion planes, resulting in a bony dehiscence, or failure of fetal foramina to close within the normal developmental window.

Skull Base Embryology and Growth during Childhood

Understanding skull base embryology is important for recognition and management of developmental skull base defects. It has been described in detail and will be summarized here.^{13,14}

The nasal capsule is formed in the fourth week of gestation by ectoderm from the frontonasal process. As the lateral walls enlarge, nasal grooves form, enlarging the nasal capsule. Ethmoturbinals can be seen by 9 to 10 weeks of gestation and go on to develop into the turbinates, uncinate, ethmoid bulla, and ethmoid infundibulum.

The maxillary sinus is also developing around the 9- to 10-week mark, developing as a lateral outgrowth from the ethmoid infundibulum. The ethmoid sinuses began to develop right after the maxillary sinuses, with the anterior cells evaginating from the middle meatus nasal wall and the posterior evaginating from the superior meatus lateral wall. The frontal sinus does begin developing in utero as an upward extension from the frontal recess but is not notable at birth. The sphenoid sinus actually begins developing early, around the fourth week of gestation. It begins as paired evaginations from the sphenothmoidal recess.

The sinuses continue to pneumatize and expand throughout childhood. The maxillary sinus grows from 0 to 3 years and then again between 6 and 12 years of life, reaching adult size around age 18. The ethmoids continue to pneumatize until approximately age 12. Frontal sinuses expand into the frontal bone, becoming radiographically evident around 5 years and continue to pneumatize into late adolescence or early adulthood. The sphenoid sinus pneumatizes anteriorly and to the planum around age 6 to 7 but pneumatization into the clivus does not start until ~10 years of age.

The skull develops from three components, the membranous neurocranium forming flat bones of the skull, cartilaginous neurocranium forming the majority of the skull base, and the viscerocranium forming the facial skeleton. There are ~110 ossification centers in the embryonic skull that fuse and ultimately form the 22 skull bones. The skull base develops around the fourth month of development, with the anterior and posterior skull base developing from distinct tissues. The anterior skull base develops from neural crest cells, the posterior developing from mesoderm. The anterior skull base grows at a faster rate than the posterior skull base and serves as a scaffold for facial growth. Understanding the foramen cecum is important in congenital skull base lesions. This is formed by the articulation of the ethmoid bone and frontal crest of the frontal bone. It often closes before birth but may remain open, elevating the risk of transmission of neural contents.

After studying this timeline, it is clear that careful planning based on radiographic imaging is necessary to individualize surgical decision making in each child. Surgical corridors will develop at different rates, and congenital lesions or defects may affect this development as well. Lack of pneumatization in young patients hides the usual landmarks and increases dependence on image-based navigation.

In addition to the size of the sinuses and nasal aperture, the developing neurovascular anatomy must be considered. Most importantly, intercarotid distance in the cavernous sinuses is narrower in children. Detailed morphometric studies assessing skull base development through imaging studies are available for further details.^{1,2}

Skull base growth center locations are important information to understand. The spheno-occipital synchondrosis is one of the primary skull base growth centers, closing around age 12 to 16 when skull base ossification is complete. By many accounts, after age 16, the skull base can be considered to be at its final development stage.^{1,2,15} Long-term analysis of facial and cranial growth after pediatric EES of the skull base has not been reported. There are, however, several studies looking at facial growth after sinus surgery,^{16,17} and these have not found alterations. It is still best to use caution and preserve these centers when possible.

Preoperative Evaluation

The presentation of developmental skull base anomalies can range from a visible mass, to nasal congestion or rhinorrhea, to headaches. Some lesions are present at birth, while others develop over time and can present years later, even in adulthood.

Complete history and examination is necessary. A multidisciplinary team consisting of at least an otolaryngologist, neurosurgeon, and pediatrician should be a part of the evaluation in any skull base lesion in a child. Physical examination should include a diligent head and neck exam with attention to neurologic function. Nasal endoscopy may be limited in small children but is usually well tolerated. If a lesion involves the temporal bone, audiologic evaluation is an important component of the evaluation. If the lesion involves any orbital bone or the sphenoid bone, referral for complete ophthalmologic evaluation is essential. Maxillary or mandibular involvement should prompt including a dentist in the treatment planning team. With developmental anomalies, a genetics evaluation should be prompted if there is any concern for additional anomalies or syndrome. Syndromes associated with encephaloceles are usually of the occipital type, but may involve anterior skull base defects as well. Syndromes associated with encephaloceles are listed in ►Table 1.

Imaging is essential in evaluation of skull base lesions; usually, both a computed tomography (CT) and magnetic resonance imaging (MRI) are obtained in a complementary fashion. Careful review of imaging should then ensue to define the extent of the lesion(s) and assess degree of skull base and sinonasal development.

Table 1 Syndromes associated with encephaloceles

• Amniotic band syndrome
• Meckel syndrome
• Chemke syndrome (a/k/a Walker–Warburg syndrome)
• Cryptophthalmos syndrome
• Dyssegmental dwarfism
• Frontonasal dysplasia
• Knobloch syndrome
• Von Voss–Cherstvoy syndrome
• Roberts syndrome

It is important to note that any child (or adult) with more than one episode of meningitis needs thorough imaging evaluation of the skull base to evaluate for a defect. Repetitive episodes often indicate a connection of the cerebrospinal fluid (CSF) containing space to the respiratory mucosa, leading to bacterial contamination and meningitis. These defects can be small and overlooked on simple head CT or brain MRI.

With any identified lesion, consideration must be made as to whether or not biopsy is indicated. In developmental anomalies, imaging and examination findings are pathognomonic and biopsy is rarely necessary. For lesions that are a solid mass, one must consider risks and benefits of biopsy. If there is an intracranial connection, biopsy can lead to CSF leak and intracranial infection. If the lesion is vascular, biopsy may lead to high volume blood loss. One should not biopsy any sinonasal or skull base mass without careful review of imaging beforehand.

Indications and Contraindications for Endoscopic Management

With an experienced pediatric skull base surgical team, the majority of these lesions can be treated with EES. There are no absolute contraindications to management of congenital anomalies by EES. However, the skull base team must assess the best management approach, deciding whether an open or combined approach is necessary for both excision of lesion and reconstruction. If lesions are large, skull base, sinonasal and facial development may be affected, and this must be considered as well.

In very young children, if no evidence of open CSF connection or CSF rhinorrhea exists, the team may consider observation until growth allows for a more facile and complete surgery. Especially in neonates and infants (with small blood volume), delays of weeks to months greatly improve the medical stability of these patients. On the other hand, patency of the nasal airway is essential in neonates, who are obligate nasal breathers for approximately the first 6 weeks of life. Without adequate nasal airway, there is increased work of breathing which can lead to failure to thrive or even respiratory failure. Consultation with the neonatology and pediatrics teams is of great value in assessing these patients and weighing the risks and benefits of surgical treatment. Additionally, if surgery is delayed, careful education regarding early signs of meningitis must be provided to the caregivers.

Developmental Skull Base Lesions

Dermoid

Congenital midline nasal masses occur anywhere from the tip of the nose to the glabellar region. Most are dermoids, ~60%, with others being gliomas or encephaloceles. Dermoids, by definition, contain both ectodermal and mesodermal (adnexal structures) components. The etiology of these lesions is a failure of separation of the dural diverticulum (neuroectoderm) through the foramen cecum to the over-

lying skin. The mean age at presentation varies from 1 to 3 years.^{18,19}

A pit in the midline nasal skin, especially with adnexal features such as hairs, is pathognomonic for a nasal dermoid. Sometimes there is no pit, but a subcutaneous mass; some present initially with infection (locally or as meningitis). An intracranial (extradural) component is identified in 5 to 45% of dermoids.²⁰⁻²² Both CT and MRI are recommended. If CT scan shows a bifid crista galli, intracranial extension is highly likely and MRI is necessary. If left untreated, these lesions will continue to grow and can lead to infection, nasal deformity, or intracranial mass effect.

Surgical excision is the only treatment option. Approach will depend on location of the cyst. If there is a skin component, this must be excised using an incision on the nasal dorsum or an external rhinoplasty approach. The intranasal (intraseptal) and intracranial components can be excised using EES. The bone of the skull base circumferential to foramen cecum is drilled to the underlying dura; a CSF leak can be avoided in most cases. Multiple case series have shown EES to be safe and effective.^{18,20,23-25} In planning, one must consider that though these lesions may appear extradural, some are adherent to the dura and will therefore require dural resection and reconstruction.

Example

A 32-year-old male presented with two nasal pits near the tip of the nose. He was otherwise asymptomatic without a history of inflammation or drainage. Physical examination including nasal endoscopy was otherwise unremarkable. Findings on CT scan were consistent with a nasal dermoid (►Fig. 1). At surgery, the nasal pits and tract were excised to the nasal bones using an external incision. Intranasally, a superior septal defect was created deep to the nasal bones. The dermoid cyst was opened and the contents were evacuated. Surrounding bone was drilled anterior to the crista galli and the walls of the cyst were dissected from exposed dura without creating a CSF leak. Complete removal of the dermoid cyst was achieved and the patient had an uneventful postoperative course.

Encephalocele

Congenital encephaloceles are herniation of intracranial contents through congenital skull base defects. These can be described as a meningocele (meninges and CSF) or a meningoencephalocele (meninges, CSF, and brain tissue). Anterior fossa encephaloceles are estimated to occur in 1:35,000 live births in North America.²⁶ Further classification divides these into sincipital encephaloceles (resulting from a defect at the foramen cecum), and basal encephaloceles (resulting from a defect at the cribriform plate or planum sphenoidale). Presentation of these lesions may be nasal congestion/obstruction, rhinorrhea, or meningitis. In these cases, a full neurologic examination is warranted, and in cases of large lesions, endocrine workup is prudent to detect pituitary dysfunction.

Surgical treatment is highly recommended to prevent meningitis and facial deformity but can be delayed in young

Fig. 1 Coronal (A) and sagittal (B) computed tomography (CT) demonstrate an expansive fat-density lesion (asterisk) extending to the skull base at foramen cecum (arrow) anterior to the crista galli.

asymptomatic patients without evidence of CSF leak. Pre-operative imaging (CT angiography or MRI) is important to assess the contents of the meningoencephalocele, especially in regards to vascular structures. EES avoids the additional morbidity of open approaches and is effective in long-term follow-up.^{13,27} The goals of surgery are to resect the encephalocele, minimize any injury to normal brain tissue and vessels, and provide a watertight seal to divide the sinonasal and intracranial contents.

Example

At 6 months of age, a male was evaluated for poor sleeping habits. An intranasal mass was detected but imaging was deferred until age 2 years. At that time, MRI demonstrated a meningoencephalocele involving the right cribriform plate (→ Fig. 2). The parents noted clear rhinorrhea but no episodes of meningitis. Following endoscopic reduction of the herniated brain tissue, a defect of the skull base anterior to the cribriform plate was exposed. The meningoencephalocele was repaired endoscopically using a free mucosal graft. The postoperative course was uncomplicated and there has been no recurrence of the meningoencephalocele.

Glioma

Nasal glioma (glial nasal heterotopia) is a congenital midline malformation consisting of neuroglial tissue in the nose or nasopharynx without an intradural (CSF) connection.¹² These lesions often have an intracranial connection by way of a fibrous stalk. It is suspected to be derived from an encephalocele which has lost its intracranial connection or

entrapped neuroectodermal tissue after closure of the skull base.

Gliomas may be extranasal (~60%), intranasal (30%), or combined.^{12,22,28} They are present at birth but, depending on the size, may not be recognized until later. On the other hand, some may be large enough to cause complete nasal airway obstruction, requiring emergent airway intervention at birth through an ex utero intrapartum treatment procedure (EXIT procedure).²⁸ The most common presenting signs are airway distress and nasal obstruction.^{12,28}

MRI is necessary in these cases to evaluate any intracranial connection. On T1-weighted images, gliomas are hypointense or isointense to gray matter. On T2-weighted images, hyperintensity is often observed within the mass. Diffusion-weighted imaging helps differentiate glioma from epidermoid cysts, the latter with increased signal. CT imaging is complementary in these cases to assess skull base anomalies, sinonasal development, and plan for surgical resection. It is important to recognize that in neonates/infants, the skull base will not be completely ossified, appearing on CT imaging as a defect. MRI and CT used together provide a greater understanding.

These lesions require resection. As with other congenital skull base pathology described in this article, EES is effective for resection of these lesions and skull base reconstruction.^{12,21,29}

Example

A 2-week-old female presented with left nasal obstruction. At birth, a suction catheter could not be passed through the

Fig. 2 Coronal (A) and sagittal (B) magnetic resonance imaging (MRI) demonstrate a large meningoencephalocele involving the right gyrus rectus and orbital gyrus (asterisk) and extending through a defect of the right cribriform plate (arrow) and filling the nasal cavity. There is deviation of the nasal septum from the large mass.

left nostril. She had no problems with feeding. Physical examination was consistent with a nasolacrimal duct cyst. Intraoperative biopsy of a friable tumor mass medial to the inferior turbinate was performed and pathology confirmed glioneuronal tissue consistent with glioneuronal heterotopia (nasal glioma) or encephalocele. Imaging demonstrated a left nasal mass that extended to the skull base (►Fig. 3). At the time of surgery, the glioma extended to the skull base at foramen cecum but there was no intracranial connection. Her postoperative course was complicated by a scar contraction of the left nostril that required reconstructive surgery.

Infantile Hemangiomas

Infantile hemangiomas are proliferative lesions often not present at birth followed by rapid growth in the neonatal period. While most common in the skin and subcutaneous tissues, it is possible for these lesions to develop along the respiratory tract. There is medical treatment for hemangiomas; propranolol can slow growth and reduce the size of the lesions significantly.^{30–32} If intranasal hemangioma is suspected, MRI with and without IV contrast should be obtained to rule out other pathologies. If diagnosed, evaluation by a vascular malformation team is important for prompt initiation of treatment. Surgery is reserved for lesions that threaten an organ such as the eye and those that do not respond to medical therapy.

Teratomas

Teratomas are malignant neoplasms that often show aggressive growth and involve large skull base defects (►Fig. 4).³³ These often lead to nasal airway obstruction and neonatal airway distress. If the tumor also involves the oral or oropharyngeal airway, as it commonly does, an EXIT procedure

must be planned to manage the airway at birth.^{34,35} These lesions are all very different, necessitating an individualized surgical approach. Though EES can be effective, a combined or open approach is often necessary to remove all tumor depending on extent of facial skeleton involvement.^{33,36} Complete surgical resection is essential and a pediatric medical oncologist should evaluate adjuvant treatment needs.

Operative Preparation

Image navigation systems should be used to assist with confirmation of anatomic landmarks and tumor boundaries. It is important to ensure that scans are compatible with the system to be used. Studies have verified the accuracy of intraoperative navigation in pediatric patients.^{12,37–39}

As discussed earlier, the blood volume in children is much lower than adults. Therefore, blood products should be available if needed. If a tumor is highly vascular on imaging, consideration should be made for preoperative embolization; planned staging of surgery may be necessary.

One must ensure instrumentation suitable for pediatric patients is available prior to the day of surgery. Both standard 4-mm as well as 2.7-mm pediatric telescopes should be available. Narrow instruments have been developed for use in pediatric cases, and these should be available as well. Endoscopic bipolar and monopolar cautery as well as hemostatic topical agents should be available to minimize blood loss throughout the procedure.

Reconstructive considerations should be discussed prior to the start of the case. Review of the imaging can help identify whether options such as a nasoseptal flap will have enough length in smaller children. Often, free mucosal grafts

Fig. 3 Axial computed tomography (CT) (A) demonstrates a left nasal mass (asterisk). Sagittal magnetic resonance imaging (MRI) (B) demonstrates an intranasal mass that extends to the skull base but there is no evidence of intracranial extension (arrow).

and/or fat will need to be used if the nasoseptal flap is of insufficient length. Further information regarding reconstruction is presented in the following section.

Surgical Technique

After induction of general anesthesia and intubation, ensure padding of all pressure points is adequate, as children are more sensitive to pressure related injury than adults. If the head is fixated in a clamp, a pediatric head clamp should be used to avoid excessive pressure on the cranium. Intraoperative navigation is used routinely due to decreased pneumatization of the sinuses and lack of usual bony landmarks. Neurophysiologic monitoring, consisting of somatosensory evoked potentials, electromyography, and brainstem evoked responses varies depending on the risks and region of

surgery. Indications and use of neurophysiologic monitoring have been described.⁴⁰

The surgical technique will vary based on the location of the pathology and degree of sinonasal and skull base development. The nares and pyriform aperture can be limiting in small children. While the soft tissue of the ala can be manipulated, the maxilla is limiting and damage could potentially alter facial growth. In smaller children, it is best to start with a pediatric, 2.7 mm telescope and pediatric instruments to open up the intended corridors. Once additional space is created inside the sinonasal cavity and during times of fine dissection, the surgeons can change to the 4-mm telescope for improved optics.

Reconstruction of dural defects is important to prevent CSF leak and meningitis. Options for repair include synthetic materials (Duragen, Integra, New Jersey, United States),

Fig. 4 Example of a large teratoma involving the midface and anterior skull base (A). Three-dimensional (3D) reconstruction (different patient) demonstrates tumor protruding from the oral cavity (B). These tumors were resected using a transpalatal endoscopic endonasal approach.

allogeneic materials (Alloderm, Allergan, Dublin, Ireland), or autologous tissue including free fat, free mucosal, or fascia graft or a vascularized flap from a nasal turbinate or the septum. In the adult literature, there is good evidence to support reduction of postoperative CSF leak rates with vascularized pedicled flaps. A study by Stapleton et al reviewed 55 pediatric patients who underwent ESS for tumor pathology and had intraoperative CSF leak. They found postoperative CSF leak rate of 23%, higher than what is commonly reported in adults. Furthermore, in this study, CSF diversion and use of vascularized flaps did not reduce the rate of this complication. Additional study in the future will be necessary to optimize intraoperative repair of CSF leaks in children. CSF diversion through lumbar drain or extraventricular drain is recommended for patients with large dural defects of the anterior and posterior cranial fossa, and those with elevated intracranial pressure.

Postoperative Management and Surveillance

The importance of a multidisciplinary team to care for these patients cannot be overstated. Monitoring by the surgical team has an important role, but in the postoperative state, medical care by an experienced neonatal or pediatric intensivist team is essential. Complications may present differently in children than adults and early recognition is key to successful remedy; these are described in the next section.

If nasal packing is left in place, one should plan on taking young children back to the operating room for removal under sedation or general anesthesia. It is important to discuss this with the patient and parents preoperatively so as not to raise concerns when it is discussed postoperatively.

Imaging studies are a necessary part of follow-up and may require sedation in young patients. Often, MRI can be utilized for surveillance imaging, thus avoiding the harm of repetitive exposure to ionizing radiation of CT imaging. Study type (MRI vs. CT) is dictated based on quality of preoperative images. If MRI shows the lesion preoperatively, this will be both an effective surveillance tool and avoid ionizing radiation. Timing of first study and frequency depends on lesion type and growth rate preoperatively. At ~3 months, it is prudent to obtain new imaging to both assess for tumor and to also serve as a new baseline. However, in cases of juvenile ossifying fibroma close to important structures, such as the optic nerve, earlier imaging may be warranted due to rapid regrowth.

Complications

A postoperative CSF leak places the patient at risk for numerous complications including meningitis, pneumocephalus, and mental status changes. Children are at higher risk of developing postoperative CSF leak.³ CSF leaks can be difficult to detect in pediatric patients due to inaccessibility of the nasal cavity to examination and lack of reporting of symptoms by young patients. Congenital skull base anomalies are particularly challenging because of often-large defects with little available

tissue options. Studies have assessed nasoseptal flap length by CT scans correlated to intraoperative findings. Shah et al¹⁵ conclude that at age 6 to 7 years, nasoseptal flap length is adequate to reach a sellar defect and by age 9 to 10 years, the flap can reach the anterior skull base. By age 14, nasoseptal flap becomes a reliable option.

Blood loss can quickly become significant in very small children. Blood should be available intraoperatively. In the postoperative setting, monitoring hemodynamic status alongside the medical intensivist team will determine if blood transfusion is necessary. Infection, particularly intracranial infection, can become a serious complication if not treated quickly. Preincision antibiotics as well as antibiotics while any packing or drains are in place is recommended.

Long-term monitoring is necessary in all of these cases, as complications can develop months to years or even decades following surgery. Incomplete resection can lead to recurrence of the lesions. Close monitoring will allow early identification. Sinus complications can develop such as sinusitis or mucocele formation due to scar tissue formation and sequestration of mucosa. Chronic sinusitis symptoms or chronic headaches should be investigated with clinical examination and radiographic imaging. Finally, facial growth can be affected by disruption of any growth centers. While much of this does not require treatment, coordination with facial reconstructive surgeons, orthodontists, or oral surgeons may offer options in affected patients.

Summary

Developmental anomalies of the skull base are rare, but place the child at high risk of devastating complications including meningitis. Surgical treatment is necessary for these lesions, with the exception of many hemangiomas. In most cases, EES is safe and effective for treatment. A multidisciplinary team including otolaryngology and neurosurgery skull base surgeons as well as neonatal or pediatric physicians is essential for thorough evaluation and treatment of these patients.

Conflict of Interest

None.

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