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Open anterior skull base surgery in the pediatric population: anatomy, approaches, and considerations

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Skull Base;
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The objectives of this paper are to synthesize the existing literature on open approaches to the anterior skull base in children. First, we review the developmental anatomy of the anterior skull base. Next, we describe the most commonly used open approaches to the anterior skull base and other adjunctive procedures. Lastly, we review the reconstructive options and comment important pediatric-specific considerations. Our review reports the variety of open approaches to access the anterior skull base in children. Detailed preoperative planning, taking age-related considerations into account, is necessary in order to plan to type and extent of access and reconstruction.
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Introduction

Advances in our knowledge of techniques to access the skull base have rapidly progressed over the years. However, most of the published literature reports methods and approaches that are specific to the adult population. Since the incidence of skull base pathologies in children is much lower than in adults,[1] techniques and strategies in managing skull base pathologies in children is not as well described.

In the published literature, most of the skull base lesions in children are located in the anterior skull base (ASB), at about more than 50%.[1-3] There are several other key considerations in pediatric skull base disorders. Firstly, the variety of lesions in children is largely composed of benign or congenital disorders, such as craniopharyngiomas or encephaloceles.[1,3,4] Malignant lesions, such as sarcomas, have also been reported.[1,3] Secondly, due to the immature craniofacial complex and skull base, surgeons need to be aware of the differences in the anatomy and anatomical landmarks in children. Third, surgical planning needs to take into consideration the immature craniofacial structure, in order to prevent unwanted sequelae. For example, surgeons should take extra care in reconstructing the developing nasomaxillary complex as well as preserving the maxillary dentition process if possible.

This paper seeks to synthesize the existing literature on open approaches to the ASB in children. First, we review the developmental anatomy of the ASB and frontal sinus. Next, we describe the most commonly used open approaches to the ASB and other adjunctive procedures. Lastly, we review the reconstructive options and comment important pediatric-specific considerations.

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Developmental anatomy of ACF and associated structures

The complex processes of skull base and sinonasal embryology have been described in detail by other authors.[4] Very briefly, the human skull develops from three distinct parts. The membranous neurocranium gives rise to the flat bones of the skull. The viscerocranium forms the facial bones. Lastly, the chondrocranium forms the skull base. Embryologically, the anterior and posterior skull base develops from different origins. The ASB is formed through neural crest cells, whereas the posterior skull base (PSB) is derived from paraxial mesoderm.[4] The ASB serves as a platform for the developing facial skeleton. During the first 6 years of age, the ASB is enlarged primarily by frontal lobe growth,[4] that result in the ASB expanding at an accelerated rate compared to the PSB. As the ASB enlarges, the nasomaxillary complex is brought forward anteriorly, enlarging the dimensions of the facial skeleton. After the age of 6, the growth of the ASB slows, and the nasomaxillary complex is instead brought further anterior by middle fossa expansion.[5]

In the neonatal period, the ASB is composed primarily of cartilage.[4] But by 4 months of age, the ASB would have undergone significant ossification. By the age of 3, the ASB would have developed most adult structural characteristics.[6] From the age of 4 onwards, the sutures in the ASB (sphenoethmoidal, frontosphenoidal) begin to fuse, and would be fully fused by early adolescence.[7]

Detailed description of paranasal sinus development is described by Brockmeyer and Gruber.[4] Of particular relevance to open ASB approaches is the finding that frontal sinuses are not radiologically visible until the age of 6.[8] After the age of 6, expansion of the frontal sinus is driven largely by anterior expansion of the nasomaxillary complex. Therefore, surgeons should be aware of this developmental process when performing frontal/subcranial osteotomies in children younger than 6 years of age. This is described further below.

Open approaches to the ASB in children

There are several open approaches to the ASB in children depending on site of lesion and anatomy of the child. The most common approaches are the subfrontal, subcranial, and transfacial/transmaxillary approach (Figure 1). Combination of approaches is also possible if needed. Other less reported approaches might also be utilized, such as the midfacial degloving approach, combined subcranial-Le Fort Type 1, or combined subcranial-transorbital.

Subfrontal approach

The subfrontal approach is one of the more common of open approaches to the ASB in children.[3] The indication for this approach is to access lesions that have originated in the ASB which have intracranial involvement. The advantage of this approach is that access to the ASB is possible with minimal brain retraction.

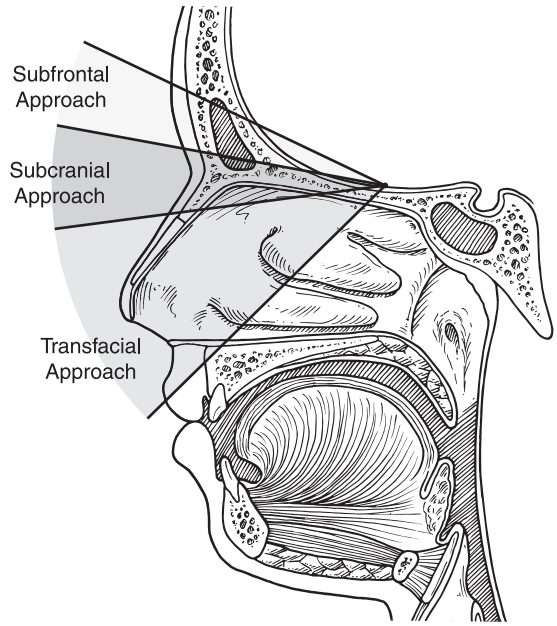

Figure 1 Main open approaches to the anterior skull base in children. The primary open approaches to the anterior skull base in children are represented: (1) the subfrontal approach, (2) subcranial approach, and (3) transfacial approach.

Regarding the soft tissue incisions, the coronal or bitemporal approach is used to reduce visible scarring. This technique described in detailed elsewhere.[9] Very briefly, a bow-shaped incision is made from the level of the auricular helix to the vertex, slightly behind the coronal suture, to the contralateral level of the auricular helix. The plane of dissection depends on whether the use of pericranial flap is anticipated. If the obliteration or cranialization of the frontal sinus is planned with a pericranial flap, then the soft tissue dissection is carried out in the plane superior to the periosteum. Dissection of the pericranium from the subgaleal tissues is extremely difficult once the flap has been raised. Once the flaps have been raised anteriorly, the craniotomy is performed, involving both anterior and posterior tables of the frontal sinus. If the lesion extends further inferiorly, nasal osteotomies may be performed, which are carried out along the nasolacrimal suture line.

Classic subcranial approach

The subcranial approach is another commonly used open approach to the ASB in children.[3,10] The indication for the subcranial approach is tumors that involve the cribiform plate, frontal sinus, or extension into the nasal cavity, paranasal sinuses, orbits. Access to the sphenoethmoidal region and clivus is also possible.[11] Soft tissue incision and dissection is carried out as above, except that the flap is further extended inferior to the glabella and supraorbital ridges. Thus, dissection of the supraorbital neurovas-

cular bundle from the supraortbial notch is also required. In adults, the supraorbital neurovascular bundle exits through a bony foramen or notch at the upper circumference of the orbital cavity. However, in children less than 8 years old, there is an absence of the landmark of the supraorbital notch/foramen.[4] Therefore, in younger children, the suprarorbital bundle may be simply reflected together with the periorbital dissection from the bone. When identified, the anterior ethmoidal arteries may be clipped or ligated. Next, exposure of the walls and roof of the orbits are obtained, together with dissection of the periosteum over the nasal bones. After the soft tissue dissection is completed the flap is fully reflected anteriorly. The osteotomies are carried out next, comprising the anterior and posterior walls of the frontal sinus, the medial orbital walls, upper segment of the nasal bone, and superioposterior segment of nasal septum. Fixation of titanium miniplates to the frontal bones is recommended, in order to ensure accurate reconfiguration during the reconstruction process. A type A or type B osteotomy may be performed on the frontal bones. A type A osteomy is where the frontal bone with anterior wall of frontal sinus plus nasal bone are removed en bloc. The posterior wall of the frontal sinus is removed as a next step. The type B osteotomy is where both the anterior and posterior walls of the frontal sinus are removed in a one-step procedure. As mentioned previously, the frontal sinus is not a radiologically distinct structure until after the age of 6. Therefore, frontal cranial osteotomies need to be planned around this consideration in younger children.

Transfacial-transmaxillary approach/combined subcranial-transfacial approach

The transfacial-transmaxillary approach is another common open approach to the ASB. In a large retrospective case series analyzing skull base approaches in children, the most frequently used approach was the transfacial-transmaxillary approach.[3]

The indication for this approach is tumor involvement of the anterior, lateral, posterior maxillary walls, the pterygomaxillary fossa, or alveolar bones. This approach may also be combined with the subcranial approach in order to have good access to maxillary and skull base components of the lesion.[3,4] The soft tissue incision for this approach starts with the Weber-Fergusson incision followed by maxillectomy. The reconstruction portion of this approach is divided into the subcranial and transfacial components. The subcranial reconstruction is performed as described above. Reconstruction of the transfacial component may be performed with free flaps or obturators. In children, special consideration needs to be given to the growing facial skeleton when deciding on reconstructive options. For large 3-dimensional defects, reconstruction with soft tissue is recommended.[3,4] Bony free flaps should only be performed in adolescents who have completed development of facial skeleton maturity.

Midfacial degloving/subcranial-midfacial degloving approach

The midfacial degloving approach or combined subcranial-midfacial degloving is also available. The midfacial degloving approach is indicated in small tumors of the ASB which extend to the inferior or lateral midface.[12,13] Similar to the above techniques, this approach results in minimal aesthetic scarring. A "circumvestibular release" is needed, in order to expose the bony nasal dorsum from the external nose. This is performed by a transfixion incision, bilateral intercartilaginous incisions, continued around the piriform margin. Next, a sublabial incision is performed across the midline to approximately above the third molar. Tissue dissection is continued in the subperiosteal plane, elevating the soft tissue structures over the nasal dorsum. Subperiosteal dissection is followed to the piriform margin. The remaining soft tissue attachments are released from the columella and anterior maxillary spine. The soft tissues of the midface are then retracted superiorly. The combined subcranial-midfacial degloving approach may be needed if the tumor extends to the superior craniofacial skeleton. The subcranial portion is performed first, followed by the midfacial degloving approach as described above.[12,13]

Subcranial-Le Fort I approach

The combined subcranial-Le Fort I Approach is needed when tumors of the ASB extend inferioposteriorly to involve the lower part of the clivus. This approach allows good surgical exposure from the cribiform plate to the lower part of the clivus. The subcranial approach is performed as above, with the Le Fort I procedure performed next. A sublabial incision is made and extended from third molar to contralateral third molar. Next, the location of the maxillary bone cuts are identified, which are above the dental roots. The cuts will extend from pyriform aperture to the pterygoid plates. Soft tissue septal and lateral nasal wall cuts are then performed. The pterygomaxillary bone union is then fractured. Finally, down fracture of the maxilla with the palate is performed. It is important to take into consideration the location of the dental roots and undescended maxillary teeth, especially in younger children. It is important to attempt to preserve the dentition process in the maxillary complex, particularly in children younger than the age of 10.[4] In such cases, an alternative approach may be warranted to extirpate the tumor.

Subcranial-transorbital approach

The subcranial-transorbital approach is needed for ASB tumors that involve the bony orbit or orbital contents. First, the subcranial approach is performed as described above. Next, orbital exenteration may be performed, or exposure of the orbital contents with removal of sections of orbital wall. The medial orbital wall or superior orbital roof may be removed in 1 or 2 pieces with the frontal osteotomy,

which also includes the proximal nasal bone and frontal bone.

Reconstruction

In most cases of ASB surgery, some form of reconstruction is required. This is necessary to preserve the compartmentalization of the cranial contents and the nasal/paranasal contents. Reconstruction options are planned according the approach required, the age of the child, the size of surgical defect planned, radiological, and intraoperative calculations.[10,12,14] If the dura is violated, then primary closure is performed. If the primary closure of dura is not possible, then locoregional flaps may be utilized. If the size of the defect is small, temporalis fascia may be utilized for reconstruction. A larger defect may benefit from double-layer fascia lata reconstruction. If the tumor invades nasal bone or fronto-orbital segments, a split calvarial bone graft may be utilized. A split bone graft may be used to repair the medial orbital walls as well. Bone fillers with osteogenic properties such as materials containing hydroxyapatite (HA) may be used to fill the resulting calvarial defect used for grafting. In cases of more extensive defects, soft tissue free flaps or free tissue bone flaps may be used. The use of composite rectus abdominis free flaps has been previously described.[3] Also, other methods such as laparoscopically harvested omentum free flap reconstruction of the ASB are possible in children.[15] Free or local flaps can also be performed if there is planned adjuvant radiation therapy. This is used to attempt to mitigate the chances of osteoradionecrosis. The age and stage of development of the child should also be taken into consideration when planning reconstructive methods. Bone free flaps should be avoided wherever possible in children who still have yet to fully achieve full facial skeleton maturity. Follow-up X-ray or lateral cephalograms may be taken postoperatively at regular intervals to track proper facial growth and development, but is not necessary. In a cohort study of children treated with the open subcranial approach to the ASB, there was no adverse craniofacial or skeletal growth, with a mean follow-up time of 3.2 years.

Considerations in the pediatric population

In general, many of the concepts and approaches in the adult population also apply to the pediatric population. However, certain pediatric-specific considerations are worth mentioning. The developing craniofacial structure means that certain landmarks are different in children than in adults. For example, the frontal sinus is not fully formed until the age of 6, and the supraorbital notch may not be present in younger children as well. Another major concept is that of permanent dentition within the maxillary complex. In children below the age of 10, the dentition process is still underway, thus in younger children there is a need to preserve the maxillary complex. Avoiding the use of procedures which disrupt the maxillary process unless absolutely necessary, such as the Le Fort I procedure, are prudent. To preserve tooth eruption, Gil et al recommended the midfacial degloving and transmaxillary approach, in cases of tumor involvement of the nasal cavity/paranasal sinuses.[3] In children whose permanent teeth have erupted, the Le Fort I is a viable option. Panoramic dental X-rays or CT scans may assist in determining the candidacy for the Le Fort I procedure.

As mentioned above, the adverse growth of the craniofacial skeleton is a valid concern. Cephalometric studies by Gil et al in 11 children with open ACF surgeries through the subcranial approach indicated that no significant deformities were experienced in their patients.[3] The age range of their patients was 2 and up. In this paper, they measured craniofacial reference growth planes in the children over time in the SNA (sella tucica, nasion, deepest point of maxillary alveolar ridge), SNB (angle between sella turcica, nasion, deepest point of mandibular ridge), SN–OCC (sella turcica, nasion, occlusal plane), and found no statistically significant difference in their pediatric cohort over time as compared to an age-matched reference cohort. To the best of our knowledge, there are no existing detailed cephalometric or craniofacial studies analyzing the craniofacial development of children post-open ASB surgery, using other methods (subfrontal approach, Le Fort I approach, etc). Compared to adults, the prognoses of children who have undergone open ASB surgery are good. This might be due to the higher amounts of benign tumors and congenital defects in children versus adults.[3,4] Lastly, besides the open approaches, ASB lesions may also be accessed via endonasal endoscopic approaches (EEA). However, the piriform aperture width is significantly narrower[16] in ages up to 6-7 versus adults. The mean width of the aperture is 17.2-19.2 mm from children less than 2 years of age and 7 years of age respectively, compared to mean 22.2 mm in adults.[16] Whether or not these decreased widths in children are detrimental to EEA approaches has not yet been objectively determined. Lesions that are in the extreme anterior skull base might be technically very difficult in small children, due to the tighter angles and smaller working space.[17] In such cases, the open approach is preferred. The open approach is also favored for malignant lesions, which require good surgical access and exposure.

In conclusion, there are a variety of open approaches to access the anterior skull base in children. Detailed preoperative planning, taking age-related considerations into account, is necessary in order to plan to type and extent of access and reconstruction.

Disclosure

The authors have no financial or other disclosures to declare.

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