Access to the Skull Base: Modular Facial Disassembly

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Abstract: Access to the skull base is not new. The different modules of the facial skeleton can be removed to give access to the skull base based on target zones, which were first described by Grime et al in 1991. However, the vertical plane is not considered, and this article adds to the original classification and develops a decision-making algorithm for preferred access to identified lesions of the skull base.

Key Words: Skull base access, skull base, tumors of skull base, craniofacial access, maxillofacial access

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The complex anatomy of the skull base makes surgical access challenging and potentially associated with morbidity. This article aims to demystify surgical access to the skull base and will provide a summary of the available techniques. It will review a simplified method of locating the skull base tumor and then go on to relate the location to the range of techniques available for anterior skull base access. By the end of the article, the reader will be able to classify the location of a skull base tumor and use this to select an appropriate access procedure. This article follows a similar format to that by Grime et al[1,2] in 1991, adds to the evidence base by exploring the newer development, and adds a further classification to include the vertical component since the article was written 22 years ago.

HISTORY

Access to the skull base is not new. Biblical texts describe the first written descriptions of access to the skull base through the accounts of the deaths of Sisera, Abimelech, and Goliath[3,4] (Fig. 1). F1

"Then Jael Heber's wife took a nail of the tent, and took an hammer in her hand, and went softly unto him, and smote the nail into his temples, and fastened it into the ground: for he was fast asleep and weary. So he died Sisera lay dead, and the nail was in his temples."

"… she smote off his head, when she had pierced and stricken through his temples."[5]

Differences in the translation infer variations in access to the skull base, either from the temple, from the frontal bone, through the midface, or transorally, all of which have been used in the current modern-day practice and will be the mainstay of discussion of this article.[6,7]

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CLASSIFICATION AND TUMOR LOCATION

It is well known that the craniofacial skeleton is an osteoplastic structure with an excellent blood supply. It is most commonly anatomically divided into skeletal modules, each of which can be mobilized with low morbidity (Fig. 2). Once a procedure is completed, the module is reassembled using osteosynthesis devices. F2

Kumar et al[8] in 1986 classified skull base tumors anatomically into 3 distinct regions: midline cranial base, infratemporal, and petrotemporal complex groups. Despite this simple anatomic delineation, there still remains an array of confusing terminology regarding access procedures (Figs. 3, 4). F3 F4

The anatomic boundaries of lesions can be delineated by dividing the skull base into lateral compartments and a central region using the internal carotid arteries as they traverse the temporal bone. The central components include the clivus and the cervical spine, whereas the lateral components will include areas such as the lateral wings of the sphenoid bone, the petrous temporal bone, and the posterior cranial fossa. The lateral compartment can also be divided into anterior, middle, and posterior regions. In 1991, Grime et al[1] selected the most appropriate surgical approach by first identifying certain target zones (Fig. 4).

The vertical plane is not considered in these descriptions, and this article adds to the classification. The main focus of this article is to add the vertical dimension into the decision-making process for treatment planning and access, for anteriorly based lesions (Figs. 5, 6; Table 1). F5 F6 T1

ACCESS PROCEDURES

Access based on the anatomic region of the tumor can be divided into 4 main categories:

Fronto-Orbital Osteotomy and Craniotomy

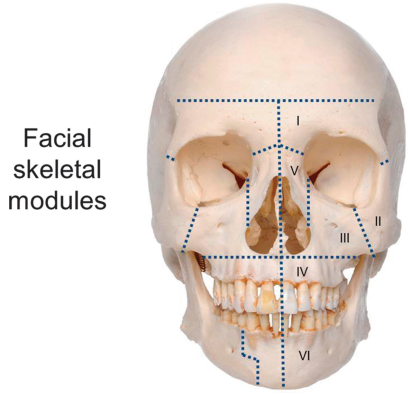
- Fronto-naso-orbital osteotomy and craniotomy (± zygomatic osteotomy)
  - Transfrontal
  - Transfrontal-nasal
  - Transfrontal-nasal-orbital

For more than 70 years, anterior skull base tumors have been removed via an anterior craniofacial resection, as described by Dandy in 1941 and Unterberger in 1958. However, developments in techniques of mobilizing the frontal bar by Tessier in 1967, Marchac in 1978, Marchac and Reiner in 1987, and Mühling in 1984 and 1987[9] are more commonly used in access techniques, many of which have also been adapted for the correction of craniosynostosis and allow for reduced brain retraction. This is further reduced by the addition of a nasal osteotomy with the orbital bar (also called the transfrontonasal orbital, transglabellar–subcranial, subcranial, modified subcranial, extended transbasal, extended subcranial, subfrontal, or extended anterior subcranial approach). This group of approaches provides excellent access to zones 4 and 5 and the anterior cranial fossa (central and lateral compartments) (Fig. 4).

Fig 1 4/C

FIGURE 1. Amigoni Jacopo c.1739.

Fig 2 4/C



AQ4 **FIGURE 2.** Facial skeletal modules.

Later access developments have been described by Lello et al[10] in 1997 who described access via a coronal flap, a zygomatic osteotomy, a craniotomy, and a skull base craniofacial osteotomy (in that order, described the "Batman's mask" in shape). This gives access from the foramen cecum anteriorly to the petrous temporal ridge posteriorly, thereby giving the operator access to the anterior and middle cranial fossae, together with extensions into the infratemporal fossa. Lello et al[10] also commented that the anterior craniofacial osteotomy involving the orbits can also include the nasal bones to provide greater access to more caudally placed lesions (Fig. 7). F7

This technique is similar to that described by Zoller et al[11] in 2001 and Feiz-Erfan et al[9] in 2005. As this was a modification of the transbasal approach, it was coined the radical transbasal approach/

Fig 3 4/C

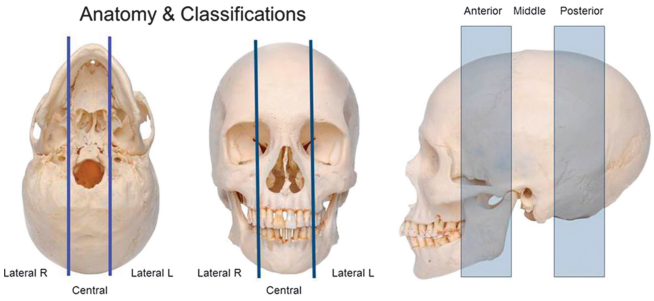


FIGURE 3. Classifications in the coronal and sagittal planes.

Fig 4 4/C

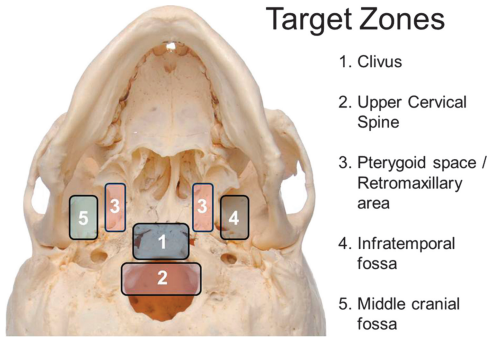


FIGURE 4. **AQ5**

fronto-orbito-nasal osteotomy as it involved osteotomies of the nasal, medial, and lateral orbital bones, providing increasing access to the midline and paramedian skull base structures and maxillary sinus. Feiz-Erfan et al reviewed the procedure on 41 patients and reported complications in 59.1% of the patients mostly consisting of CSF leakage with a mortality rate of 6.8%. The inclusion of the zygoma improves access to the posterior part of the anterior cranial base and the middle cranial fossa (fronto-orbito-zygomatic osteotomy). **AQ6**

For smaller tumors of the anterior (middle) cranial base and paranasal sinuses and orbit, the modification as described by Raveh et al[12] in 1988 is useful (subcranial approach). It still uses coronal access approach in conjunction with a smaller osteotomy of the fronto-orbitonasal region. The procedure allows intradural and extradural tumor removal, access for optic nerve decompression, and repair of CSF leakage. Raveh and Vuillemin's[13] experience of 104 cases reported a

Fig 5 4/C

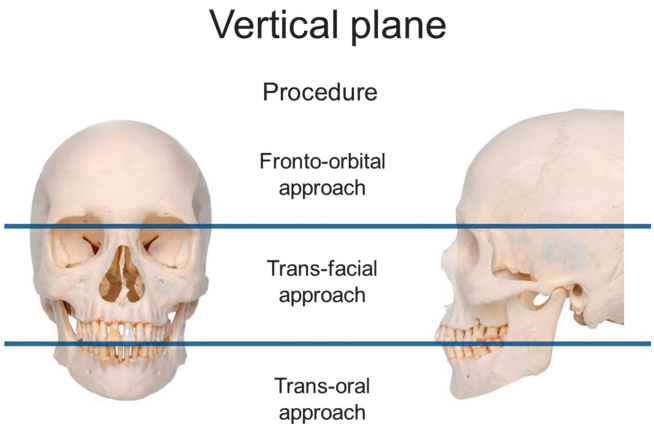


FIGURE 5. Addition to classification: vertical plane consideration.

Fig 6 4/C

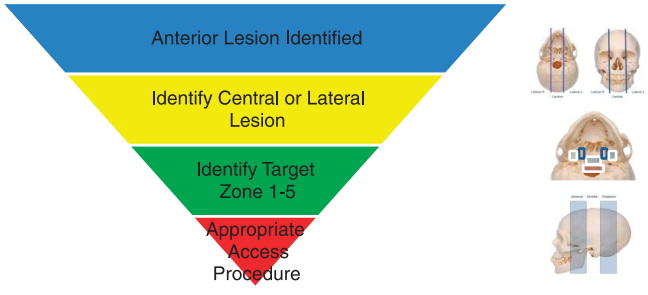
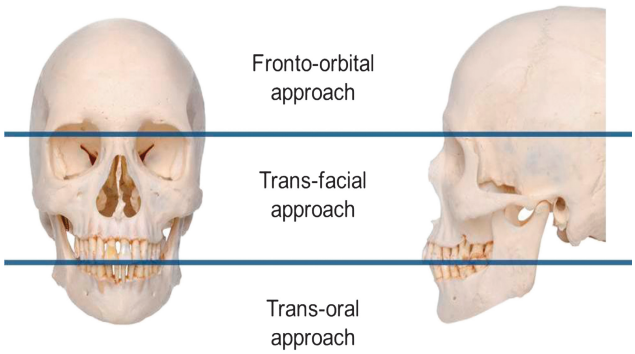


FIGURE 6. Decision-making process for access to anterior skull base tumors. **AQ7**

TABLE 1. Summary of Access Procedures Used Based on the Location of Lesion When Considered in the Vertical Plane

Vertical plane	• Approach
Fronto-naso-orbital osteotomy and craniotomy (± zygomatic osteotomy)	• Transfrontal ○ Transfrontal-nasal ○ Transfrontal-nasal-orbital
Transfacial	• Maxillotomy • Facial swing procedures • Transzygomatic
Transoral	• Le Fort I downfracture (± palatal split) • Transpalatal approach • Direct transoral • Transmandibular approaches ○ Lip-split mandibulotomy ○ Attia et al's type of mandibulotomy ○ Ramus osteotomies (VSS)
Combinations of the above	



reduced complication rate from CSF leak and infection compared with the wider exposure techniques described previously; however, all cases involved sacrifice of the olfactory nerve. They reported that their technique also reduces the traction placed on the frontal lobe and the lateral traction of the globes, with better access overall from a caudocranial approach to the sphenoidal and maxillary sinuses as well as the soft palate, epipharynx, and clivus, therefore obviating the need for a transfacial approach. The authors did comment that they used fascia lata and pedicled pericranium approaches to seal the anterior skull base defect. In an attempt to reduce injury to the olfactory nerve, Spetzler et al[14] in 1993 further modified the approaches described previously by osteotomizing the cribiform plate. These techniques allow for mobilization of modules 1, 2, and 5; however, limits to access are seen when the tumor is also located beneath the orbits in the superolateral aspect of the maxillary sinus.

Kinnunen and Aitasalo[15] in 2006 reviewed 59 patients treated for lesions of the anterior cranial base using the subcranial approach and found that 44 patients had olfactory nerve dysfunction, 4 patients had diplopia, and 2 patients had enopthalmos. Nasal cavity scar tissue and trigeminal nerve dysfunction were also reported in 4 patients. Their cohort of 59 patients also included trauma patients with persistent CSF leak (tumor, 63%; trauma, 32%; CSF leak, 5%). The authors of the article also commented that this approach is not suitable for lesions involving the cavernous sinus, the carotid artery, or the optic chiasm or lesions with brain invasion (Fig. 8).

F8

Transfacial Procedures

- Transfacial
  - ○ Maxillotomy
  - ○ Facial swing procedures
  - ○ Transzygomatic

In essence, this is any procedure involving a facial incision. Transfacial procedures can be broken down into those that involve a maxillotomy and those that involve other facial swings, therefore mobilizing modules 2, 3, 4, and 5 (Fig. 2). The first displacement of the maxilla was performed by Cheever more than 100 years ago. All the techniques provide access to zones 1 to 4 and to the central and lateral compartments of the skull base.

Altemir[16] in 1986 and Curioni et al[17] in 1984 were the first to describe midfacial swing techniques. Altemir described his technique as a procedure where "the incision extends from the vermilion of the upper lip vertically along the philtral crest of the side to be operated on, around the nose upwards to the inner canthus, preserving it, becoming horizontal then and passing laterally to the outer canthus and curving slightly downwards over the zygomatic process."

Fig 7 4/C

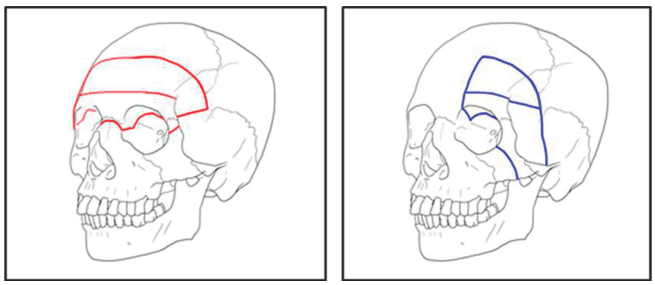
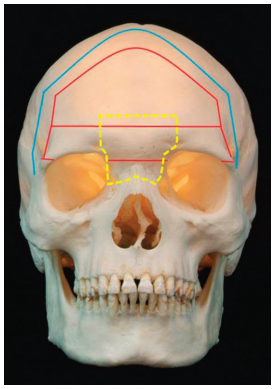
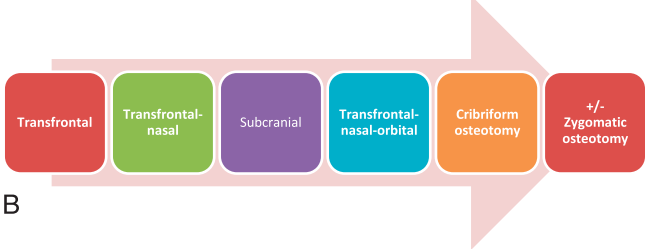


FIGURE 7. Fronto-orbital osteotomy access.

Fig 8 4/C



A

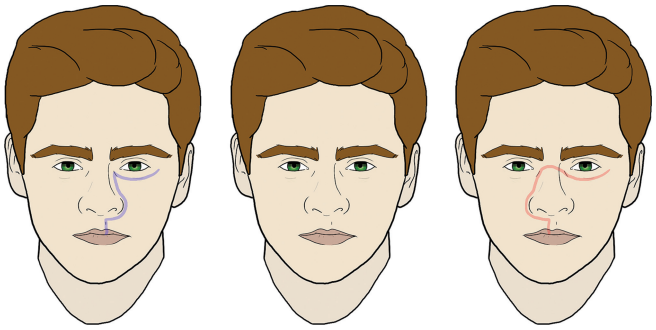


B

FIGURE 8. A, Blue lines indicate soft tissue cuts; red, bony cuts; and yellow, smaller fronto-orbitonasal osteotomy (Raveh). B, The figure above shows the progression through time of access techniques. Each progression carries with it an increasing level of surgical access and reduction on morbidity.

AQ8

Fig 9 4/C



AQ5 FIGURE 9.

TABLE 2. Clauser et al's Description of Lesions and Suggested Approaches

Module	Lesion	Suggested Approach	Optional
1	Ethmoid, sphenoid, upper nasaopharynx, and anterior cranial base	Nasal cheek flap + Le Fort I	Nasal MCF
2	Retropharynx and clivus	Nasal MCF ± contralateral MCF	
3	Retromaxilla and/or pterygomaxillary space	MCF	
4	Parapharyngeal space, infratemporal fossa	MCF or mandibular cheek flap	Combination of the two

Advantages to this technique include good access and minimal damage to any structure, which is not recoverable (apart from the infraorbital nerve), and that no dental structures are sacrificed and the risk of necrotic changes is minimized by the soft tissue pedicle over the bony maxilla. The article also made comment on that most tumors can be removed en bloc and the ability of this access procedure to be performed bilaterally at the same time.

Curioni et al described a naso-maxillo-cheek flap (NMCF) and a maxillo-cheek flap (MCF) (Clauser et al[18] in 2000), which gives wide access to paranasal sinuses, posterior nasal space, clivus, and retromaxillary areas. The technique of Curioni et al differs to that described by Altemir in that the palatal mucosa is not detached from the "palatal lamina" and remains attached to the dismantled bone flap. In 2003, the inclusion of an orbital swing was also described by Moreira-Gonzalez et al as part of their case series of 8 patients (a mix of mandibular and midfacial swings), allowing access to lesions located in the infraorbital region, retrobulbar region, infratemporal fossa, nasopharnyx, midline of the skull base, and the superior half of the clivus. The article commented on that this approach is best used for extradural lesions as watertight closure is difficult (although they only published the result of 1 case). Each of the transfacial swing procedures had temporary diplopia.

Incisions used to access the midfacial region most commonly cited include the Webber-Ferguson incision with the Dieffenbach and zygomatic extensions (Lynch). All descriptions of these include a stepped mucosal incision in relation to the bony cuts but involve sacrifice of the infraorbital nerve, which can later be repaired with reported good recovery of the nerve in approximately 18 months to 3 years[17]. Sagittal osteotomies of the alveolar process may be in the midline or paramedian.[19–22]

The documented types of approach include the following:

- MCF (not involving the piriform aperture)
- Nasal cheek flap
- NMCF
- Contralateral MCF (open book using NMCF on opposite sides) (Figs. 9, 10)

F9 F10

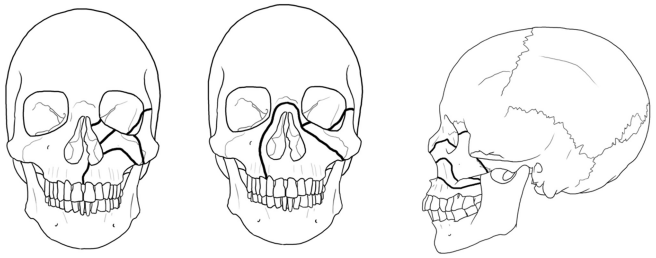


FIGURE 10. Transfacial osteotomy.

The choice of approach will depend on operator experience, histologic diagnosis, and tumor behavior and volume. Clauser et al[18] in 2000 described 4 types of lesion and suggested an approach for each of the different levels of tumor (Table 2, Fig. 11). AQ9 T2 F11

The lateral approach to the infratemporal fossa was first described by Obwegeser[23] and involves the use of a coronal flap and exposure of the zygomatic arches with subsequent osteotomy of the bone to gain sufficient access to the lateral skull base compartments including intracranial tumors with inferior extensions (when used in combination with skull access). The summary article by Grime et al[2] in 1991 described 3 points for osteotomizing the zygoma and displacement of this bone inferiorly pedicled on the masseter. This same osteotomy can be combined with a temporalis reflection from above to provide access to the middle cranial fossa or by reflecting the temporalis superiorly (after sectioning the coronoid process) to provide access to the pterygoid space. The use of this technique as an extension of the Webber-Ferguson incision and maxillotomy has also been described (the maxilla and zygoma can be retracted as 1 piece), but this access sacrifices the infraorbital nerve as well as the terminal branches of the zygomaticofacial trunk of the facial nerve. Alternatives to this approach to access the same area include the lip-split

Fig 11 4/C

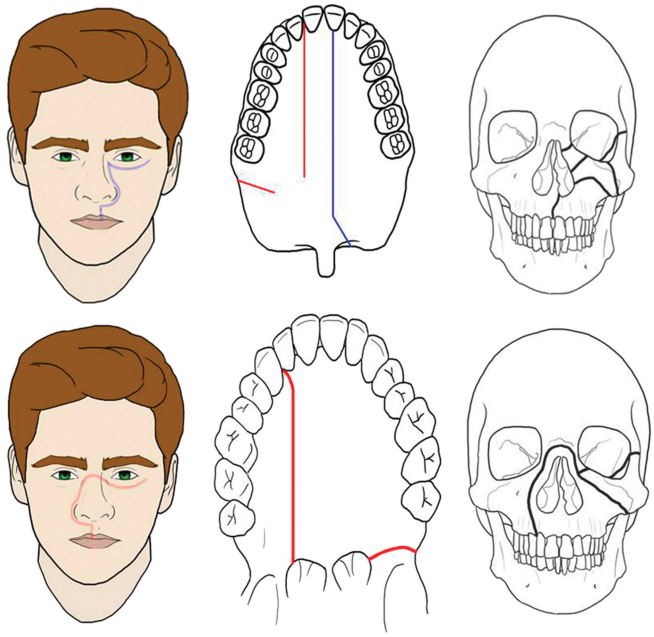


FIGURE 11. Summary of access procedures with cutaneous, bony, and palatal access incisions/cuts. Offset palata cuts and incisions allow for mucosal closure over sound bone.

mandibulotomy extending into the maxillary sulcus area and Attia et al's[24] modification of the mandibulotomy (see below).

Swearingen et al[25] in 1994 described a lateral rhinotomy incision to provide access to the nasal cavity as a single case report. Once the septum and the medial maxillary walls are removed, access is also gained to the ethmoid, sphenoid posterior nasopharynx, and upper oropharynx. This approach does involve a facial incision, and the case described resulted in exposure of the arachnoid that was later sealed with tensor fascia lata, fat, and Gelfoam (Pfizer Ltd, Pharmacia & Upjohn; Fig. 12).

F12

Transoral Procedures

Transoral procedures fall into the category of any procedure involving access via an oral approach. As listed previously, they include the following:

- Le Fort I downfracture (± palatal split)
- Transpalatal approach
- Direct transoral
- Transmandibular approaches
  - Lip-split mandibulotomy
  - Attia-type mandibulotomy
  - Ramus osteotomies (VSS)

AQ10

The Le Fort I downfracture technique was first used by Von Langenbeck in 1859 and Cheever in 1867 and mobilizes units 4 and 5 of the facial skeleton (Fig. 2). However, despite these early descriptions of access techniques, the Le Fort levels, as they are known today, were not described until 1901. Archer et al[26] in 1987 pioneered skull base access and noted that the Le Fort I approach provided good access to central compartment tumors (zones 1, 2, and 3) (Fig. 4) but had limited access to the lateral compartments (zones 4 and 5) and that access to the lower clivus may be poor. The Le Fort I mobilizes unit 4 of the facial skeleton. When combined with a midpalatal split,

FIGURE 12. The lateral rhinotomy incision curves around the right ala, across the columella, to the base of the left ala. The nasal pedicle is raised, and the septum is resected.

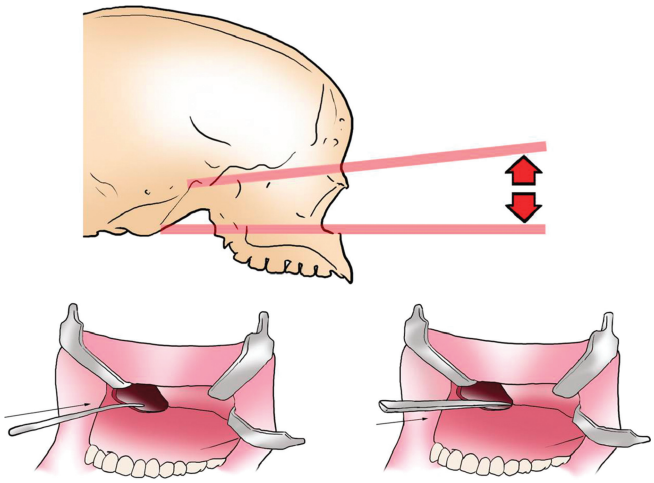


Fig 13 4/C

FIGURE 13. Transoral Le Fort I approach.

access can be gained to tumors both above and below the foramen magnum (Fig. 13).

F13

Cadaveric studies by Balasingam et al[27] measured the access gained to the extracranial clivus in 12 unenbalmed cadavers via simple transoral, transoral-with-a-palate-split, Le Fort I osteotomy (LFO), and median labioglossomandibulotomy approaches. On the basis of these findings, greatest access to the extracranial clivus was gained by the LFO followed by the transoral-with-a-palate-split approach. They also found that the median labioglossomandibulotomy and simple transoral approaches provided good exposure of the craniocervical junction (but poor access to the extracranial clivus).

Midfacial degloving was described by Casson et al[28] in 1974 for its application in remodeling cases of fibrous dysplasia and, later, trauma to the region. Kyoshima et al[29] in 2002 described an approach to the central cranial base and clivus area using a combination of midfacial degloving, Le Fort I downfracture of the maxilla, and nasomaxillary osteotomies. Their case series of 13 patients had no complications, and the authors of the article suggested that this approach provided better access, without breaching the oropharyngeal mucosa, to tumors down to the level of C2 and had a reduced risk of wound breakdown. In addition, breeching the dura was not necessary, which therefore reduced the risk of CSF leak. In their case series, they did not experience loss of vitality of teeth.

Another use of the midfacial degloving technique in 4 patients was described by Fliss et al[30] in 2000 who described a combination approach combining a subcranial approach (ie, frontal bone via coronal

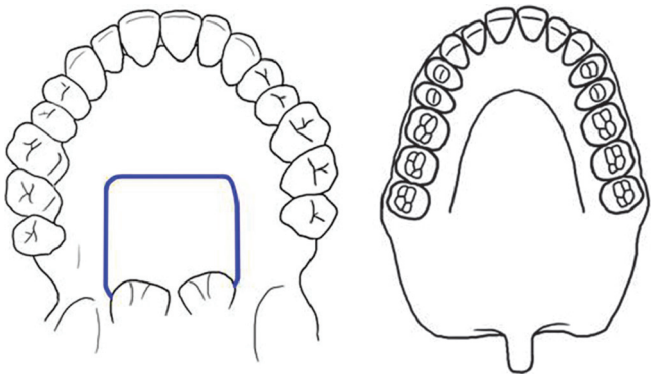


Fig 14 4/C

FIGURE 14. Transpalatal approach.

Fig 15 4/C

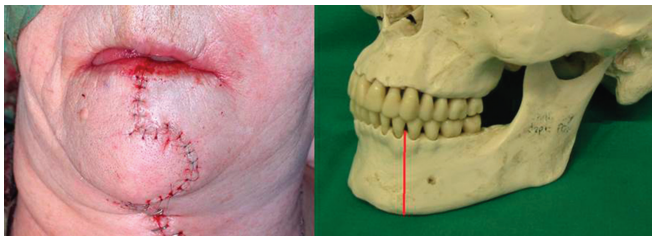


FIGURE 15. Transmandibular access and mandibulotomy.

flap) with midfacial degloving to gain access to lesions in the anterior cranial fossa extending caudally into the inferior and lateral nasal cavity as well as the surrounding sinuses. The advantage of this approach is that external incisions such as the Webber-Ferguson are not used and that the inferior orbital nerve is spared. However, in the 4 patients reported with this technique, 2 reported anosmia (one lesion had completely eroded the skull base), and 1 reported that temporary numbness of the upper lip also occurred.

The transpalatal approach involves an osteotomy of the hard palate, which is mostly ideal for small tumors providing access to the midline upper and middle clivus and craniovertebral junction, as described by Liu et al[31] in 2008 and Lawton et al[22] in 1999. It has advantages in that it uses minimal facial disassembly with minimal morbidity to the surrounding structures.

Liu et al's[31] 2008 article first described an approach that uses an entirely oral approach to the midline using a Spetzler-Sonntag transoral retractor system, giving access to the lower one third of the clivus to C2.The article also described the use of this approach with other procedures such as LFO and midline palatal split to improve access cranially and laterally (they describe the latter as an "open door" maxillotomy). Access to lesions from C2 to C4 can be obtained by combining a mandibular swing and glossotomy. All of the extensions of the transpalatal approach are accompanied by increasing morbidity to the patient. Palatal access procedures were criticized in the 1960s for their poor exposure and illumination, but the advent of the operating microscope and miscrosurgical instruments has made the palatal approach practical again. Liu et al also commented that access to intradural components such as the lower pons, medulla, cervicomedullary junction, and vertebrobasiliar artery can be obtained but is not recommended as the operative field would become contaminated with oral commensal pathogens. Therefore, this approach is best suited for extradural lesions. Advantages of this approach include the lack of a visible facial scar and the lack of retraction of the brain, but its drawbacks include difficulty in closure of the dural layers and subsequent CSF leak if it occurs as well as reduced access obtained as a consequence of the patient's limited mouth opening. The issue of stability of the occipitoatlantal or atlantoaxial joints must also be addressed because of the involvement of lesions

Fig 16 4/C

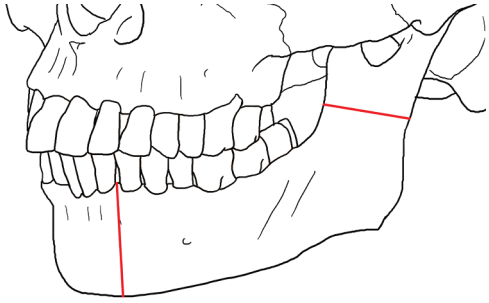


FIGURE 16. Transmandibular osteotomy and the mandibulotomy of Attia et al (red).

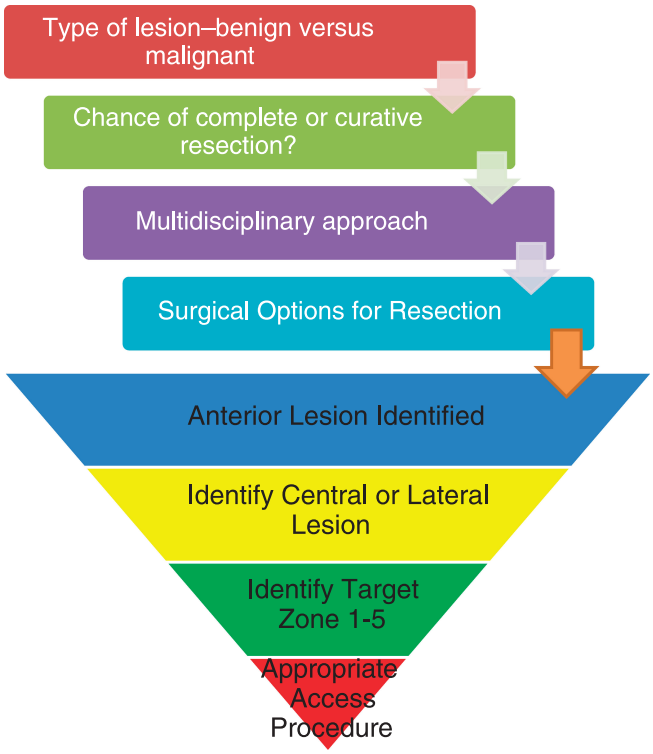


Fig 17 4/C

FIGURE 17. Decision-making tree for modular facial access procedures based on lesion location.

with the surrounding ligaments, with the operator making a decision to stabilize this before or after the surgery (stabilization before the approach reduces the risk of cord damage but can restrict extension of the neck and, therefore, access to the tumor; Fig. 14). F14

Transmandibular approaches for access to tumors are a commonplace for head and neck oncology surgeons, providing excellent access to the tongue, fauces, and pharynx. Division of the mandible for tumor access was first described in 1836, and the lip-split mandibulotomy was later described by Spiro et al[32] in 1981 and Krespi and Sisson[33] in 1984. Moreira-Gonzalez et al[34] in 2003 described the use of the mandibular swing for access to the nasopharynx, oropharynx, parapharyngeal space, base of the tongue, pterygomandibular space, and infratemporal fossa (when the lesion lies medial

TABLE 3. Summary of Procedures and Descriptions of Vertical Component for Access to Target Zones

Procedure	Compartment	Target Zone
Fronto-naso-orbital approach		
Transfrontal	C (L)	4, 5, anterior fossa
Transfrontal-nasal		
Transfrontal-nasal-orbital		
Transfacial		
Maxillotomy	L	3, 4
Facial swing	C, L	1, 2, 3, 4
Transzygomatic	L	3, 4, 5
Transoral		
Le Fort I ± palatal split	C	1, (2)
Transpalatal	C	1
Transoral	C	1, 2
Lip-split mandibulotomy	C, L	1, 2, 3, 4
Attia et al's mandibulotomy	L (C)	3, 4

AQ11

to the cervical carotid artery and does not extend above the floor of the middle cranial fossa) and when the midline skull base (extracranial and intracranial) is involved. This approach also allows access to the neck for lymph node sampling and control of the great vessels. Temporary numbness of the lingual nerve is a common finding postoperatively, as is the incidence of temporary dysphagia, tongue weakness, and TMJ symptoms with improvement 2 to 5 months after surgery[1,2,34] (Fig. 15).

A further variation in the form of the Attia et al's[24] type of mandibulotomy in 1984 is also described, involves a second osteotomy of the ramus of the mandible, and provides increased exposure of the pterygoid and parapharyngeal spaces including the deep lobe of parotid tumors. Various modifications of these have been reported with osteotomy cuts including the coronoid and condylar neck.[35] The technique of Attia et al provides excellent access to the parapharyngeal space from the skull base to the hyoid without damaging the inferior dental nerve; however, it carries with it a risk of infection from the oral cavity, the scarring of a lip split, and the morbidity associated with the use of a tracheostomy. In relation to skull base tumors, the mandibulotomy provides access to zones 4 and 5 (pterygoid and infratemporal fossa; Fig. 16).

PROCEDURE SELECTION

Procedure selection for patients must follow consideration of the type of lesion (benign versus malignant). This is most reliably decided on by a thorough history and examination, followed by special tests that may or may not include a biopsy. All decisions should be made with the patient and in conjunction with the discussion with a multidisciplinary team, who should consider the abovementioned approach and also the suitability of each patient for the access procedure planned. The following decision-making tree can be applied to each patient selection based on the previous descriptions (Fig. 17).

The table below allows the surgeon to choose the most appropriate approach for a targeted lesion as described in the earlier diagrams (Figs. 3–5, Table 3).

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