Quantification of the Advantages of the Extended Frontal Approach to Skull Base

Rajesh Acharya, M.B., B.S., M.Ch.,¹ Mark Shaya, M.D.,¹ Ravi Kumar, M.D.,¹
Gloria C. Caldito, Ph.D.,² and Anil Nanda, M.D., F.A.C.S.¹

ABSTRACT

This anatomic study evaluated the extent that a fronto-orbital osteotomy (FOO) added to a bilateral frontal craniotomy widened the exposure to the midline compartment of the anterior, middle, and posterior cranial fossae. The goal was to determine if osteotomy would significantly increase angles for two targets: the foramen magnum (FM) and anterior clinoid process (ACP). Stepwise dissections were performed on five cadaveric heads. A bilateral frontal craniotomy was made, followed by FOO. After the ethmoids were removed, the planum sphenoidale was drilled to enter the sphenoid sinus. Further drilling exposed the anterior clivus, which was drilled down to FM. Excellent exposure of the basilar artery, vertebral artery, and brain stem was achieved. With and without FOO, angles of exposure were measured for two targets: the ACP and FM. The angle of exposure after FOO increased markedly with an average gain of 76% for the ACP and of 80% for FM. Compared with a conventional bifrontal craniotomy, the addition of FOO increased the surgical exposure and minimized frontal lobe retraction for accessing lesions of the anterior, middle, and posterior cranial fossae.

KEYWORDS: Brain tumor, extended frontal approach, operative approach, skull base, skull base tumor

Large skull base tumors have always been a formidable challenge to neurosurgeons and maxillofacial surgeons. Cushing, Dandy, and others proposed skull base operations,¹ but their enthusiastic attempts were often hampered by the absence of antibiotics and adequate instruments. Technical

advances (operating microscopes, micro-instrumentation, bipolar coagulation, and development of neuro-anesthesia); an improved understanding of skull base anatomy^{2,3}; and collaborative efforts of neurosurgeons, otolaryngologists, and plastic surgeons have led to the development of more

Skull Base, volume 14, number 3, 2004. Address for correspondence and reprint requests: Anil Nanda, M.D., Department of Neurosurgery, Louisiana State University Health Sciences Center in Shreveport, 1501 Kings Highway, P.O. Box 33932, Shreveport, LA 71130-3932. E-mail: ananda@lsuhsc.edu. Departments of ¹Neurosurgery and ²Biometry, Louisiana State University Health Sciences Center in Shreveport, Shreveport, Louisiana. Copyright © 2004 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662. 1531-5010,p;2004,14,03,133,142,ftx,en;sbs00399x.

extensive surgical approaches to the cranial base. The goal of such improvements is to permit the total or near total excision of such tumors with minimal patient morbidity.

The standard transbasal approach to the anterior cranial fossa (ACF) has been modified to include removal of the orbital roofs, nasion, and ethmoid sinuses.⁴⁻⁹ An extended frontal craniotomy has been performed to resect large skull base tumors involving the ACF.^{7,10} This approach was further advanced by Sekhar et al to excise even midline lesions of the middle and posterior skull base.¹¹ In this anatomic study, we re-evaluated and quantified the advantages of an extended frontal craniotomy in five cadavers with brain in situ and compared the angle of field view with and without FOO.

METHODS

The study was performed with five cadaveric heads that were embalmed, fixed, and injected with Microphil dye (Flowtech, Inc., Carver, MA). Red dye was used for the arteries and blue dye for the veins. The heads were preserved in a standard solution (pHA, Di-scan, and GX; The Champion Co., Springfield, OH). Dissection was performed using $\times 3$ to $\times 40$ magnifications.

Dissection Procedure

We followed the operative technique adopted by Sekhar et al.¹¹ The heads were fixed supine in a three-pin Mayfield clamp. A bicoronal skin incision extending from one zygomatic arch to the other was placed far enough posteriorly to assure that the galeal and pericranial flap was long enough for reconstruction (Fig. 1). The scalp and pericranial flaps were reflected anteriorly (in two separate layers) up to the orbital rims and nasions. After the supraorbital nerve and vascular bundle were separated from their foramina, the periorbital was stripped circumferentially. Periorbital was dissected

Figure 1 Bicoronal skin incision extending from one zygomatic arch to the other.

~2.5 cm posteriorly and extending medially up to the anterior ethmoidal artery. The temporalis muscles were reflected laterally, leaving a cuff of muscle on the bone flap to facilitate closure (Fig. 2).

The frontal bone was removed in two flaps by performing a bilateral frontal craniotomy. A speed drill was used to open a bur hole just to the right of the superior sagittal sinus (SSS) at the posterior edge of the wound. The frontal craniotomy, which extended anteriorly 15 mm above the orbital ridge and posteriorly along the convexity of the cranium, was then performed. After a unilateral frontal

Figure 2 Reflection of the pericranium. Temporalis muscle has been left attached to the temporal bone.

Figure 3 Pericranium has been dissected in preparation for a bifrontal craniotomy.

craniotomy that extended medially up to the SSS was performed, the SSS was separated under direct vision. Then a contralateral frontal craniotomy flap was elevated (Fig. 3).

Next, a bilateral FOO was performed. The orbital rims and the anterior two-thirds of the orbital roofs were removed, leaving the ethmoidal bone intact (Fig. 4). First, orbital roof cuts were made using a fine reciprocating saw from a superior to an inferior direction while the dura and periorbital were protected with malleable retractors. The last cut was made through the nasion from an anterior-to-posterior direction. The cut was angled slightly

Figure 4 Extent of bone removal in FOO.

Figure 5 Basal view of the skull showing the extent of bone removal in FOO.

upward so that it entered the ACF just in front of the crista galli. This FOO piece was loosened with an osteotome and removed (Fig. 5). When a fronto-orbito-ethmoidal-osteotomy (FOEO) is desired (for lesions in sphenoclivus area), the upper part of the ethmoid bone can be included with the bar of bone removed in the FOO (Figs. 6, 7). The coronal cut through the orbital roof may be extended through the posterior aspect of the ethmoidal bone, taking care not to penetrate to a depth of more than 2 or 3 mm. To obtain adequate exposure of the clivus, middle and posterior ethmoidal cells must be removed aggressively.

Figure 6 Basal view of the skull showing the extent of bone removal in FOEO.

Figure 7 Location of the bur holes and bone flaps.

The dural incision was made over each medial inferior frontal lobe, and the SSS was divided between two silk sutures. The falx was cut and the frontal lobes were retracted superolaterally. Self-retaining retractors were placed under the frontal lobes. The dissection was carried up to the posterior limits of the ACF, exposing the anterior clinoid process (ACP), entrance of both optic nerves into their canals, optic chiasma, and internal carotid artery (ICA; Fig. 8).

Figure 8 View of the optic nerves (ON), ACPs, and ICA. The pituitary stalk (PS) is also seen. The dashed circle shows the area of the planum sphenoidale to be drilled to reach the clivus.

Figure 9 View after the clivus has been drilled.

Dura at the base of the ACF anterior to the ACP was incised and preserved. The dura was incised and stripped from the planum sphenoidale (Fig. 9). As we drilled down the sphenoid, the sellar floor was visualized superiorly. The sphenoid mucosa was stripped and excised. After the anterior wall of the clivus was drilled superiorly to inferiorly, the basal dura in front of the clivus was exposed (Fig. 10). Opening this dura exposed the vertebral and the basilar arteries (Fig. 11). In the elderly the clival dura is usually thinned; care must be taken to

Figure 10 Anatomic photograph showing the vertebral (VA) and basilar artery (BA) after the clivus has been drilled and the dura opened.

Figure 11 Illustration showing the advantage in the angle of exposure gained with the addition of FOO in terms of the (A) ACP and (B) FM.

avoid injuring the basilar artery, its branches, or the brain stem. The lower limit of resection is the foramen magnum (FM), which can be extended laterally up to the hypoglossal canals.

The gain in space was evaluated by measuring the field of view angle (FVA) of given intracranial targets before and after FOO was performed. FVA was defined as the angle of exposure of the target with minimal brain retraction. Two intracranial targets were chosen for this approach: the ACP and the anterior rim of the FM.

Closure: If the frontal air sinus is entered while performing the craniotomy, its mucosa is removed and packed with fat or muscle. This approach warrants a meticulous dural repair to prevent cerebrospinal fluid (CSF) leakage and infection. Therefore, a wider craniotomy helps develop a pedicled dural flap from the frontal convexity for the dural repair of the skull base. The much-advocated watertight dural closure is possible in anterior fossa defects. The pericranial flap advanced from the forehead to the frontal skull base is approximated to the basal dura as posteriorly as possible to eliminate all communication between the nasal cavity (especially the frontal sinus) and the intradural space. When watertight closure is infeasible, a graft of fascia lata is used to cover the dural defective area of the middle and posterior cranial fossae and attached with sutures. The FOO bony segment is replaced and secured with titanium miniplates.

Measurements

The aim of the study was to determine if the FOO would significantly increase the angle for two targets (A = FM and B = ACP). Five skulls were measured before and after FOO. Angles θ were expressed in degrees and distances in millimeters. The following parameters were measured before and after performing FOO:

- (X) = the distance between the anterior lip of FM and the anterior margin of ACF
- (X') = the distance between the anterior margin of ACF and the ACP
- (Y) = the distance between the anterior margin of ACF and the anterior margin of frontal lobe (brain-bone, BB, distance) without FOO
- (Y') = the BB distance with FOO

Resulting FVAs were determined from the X and Y measurements using the tangent formula, that is, $\tan \theta = Y/X$ or $\theta = \tan^{-1} (Y/X)$.

A one-sided statistical test using the paired *t*-test was used to determine significant increases in angles A and B.

RESULTS

The FVA values measured in the specimens are detailed in Tables 1 and 2. After FOO was

Table 1 Measurement Results

S No.			BB distance (mm)		Angle (degrees)		Angle (degrees)	
	(FM to ACF)	(ACP to ACF)	Without FOO	With FOO	(Target = FM)		(Target = ACP)	
	X (mm)	X' (mm)	Y	Y'	AA (– FOO)	A' (+FOO)	B	B'
1	81	60	20	35	13.87	23.37	18.43	30.26
2	100	65	15	35	8.53	19.29	12.99	28.30
3	84	62	20	35	13.39	22.62	17.88	29.45
4	102	64	14	24	7.82	13.24	12.34	20.56
5	100	63	10	18	5.71	10.20	9.02	15.94

BB distance, distance between anterior margin of frontal lobe and anterior margin of anterior cranial fossa; ACF, anterior margin of anterior cranial fossa; +/– FOO, with/without FOO.

performed, the FVA increased from 9.86 to 17.74 degrees for FM and from 14.13 to 24.90 degrees for ACP. This corresponds to an average gain of 80% and 76% for these two targets, respectively (Tables 2, 3). The differences in the mean angle measurements before and after osteotomy were statistically significant, that is, FOO significantly increased the angle for targets A (FM) and B (ACP) in the cranium (Fig. 12).

DISCUSSION

Because of their location, the involvement of vital neurovascular structures, and their extensions into multiple cranial compartments, the total removal of cranial base tumors presents a formidable challenge. Lesions of the skull base, especially if large or deeply situated, require a wide bilateral retraction of the frontal lobes to obtain a sufficiently large operative field. However, excessive retraction of the frontal lobes risks subsequent frontal edema and serious neurological sequelae.

The concept of performing osteotomies to widen the surgical exposure is not new. Frazier advocated removal of part of the orbital rim to improve exposure of the pituitary gland and sellar area.¹² Derome et al described the “transbasal approach,” in which a bifrontal craniotomy is extended down to the orbital rim and the lesion is approached extradurally.¹³ The first transbasilar approaches introduced by Frazier and Derome et al were limited to exposure of the ACF.^{12,13} The use of orbital osteotomies was further developed by Jackson et al and Jane et al.^{14,15} Cophignon et al added an orbital osteotomy, coining the term “extended transbasal approach.”¹⁶ Kawakami et al described an “extensive transbasal approach,” wherein a bilateral frontal craniotomy was followed by an en bloc bilateral osteotomy of the frontal roofs and frontal sinus to obtain a large surgical field.¹⁰ The transbasal approaches have undergone many modifications and combinations.^{4,5,7–9,17,18} Craniofacial surgeons have incorporated both facial and anterior cranial approaches to visualize not only the anterior fossa but the middle fossa (cavernous sinus) and posterior fossa (clivus) as well.^{2,7,14,19–24} Teamwork between

Table 2 Interpretations

Target	θ (Before FOO)		θ (After FOO)		θ (After-Before)		p Value	Significance	% Gain
	Mean	SD	Mean	SD	Mean	SD			
FM (A)	9.86	3.59	17.74	5.80	7.88	2.75	0.0015	**	80
ACP (B)	14.13	3.97	24.90	6.33	10.77	3.31	0.001	**	76

**Highly significant difference ($p < 0.01$) was found on angle measurements before and after FOO.

Table 3 Skull Base Lesions in the Midline Compartment of Anterior, Middle, and Posterior Fossae (Anterior to FM) Accessible with the Extended Frontal Approach

Benign Lesions	Malignant Lesions
Meningioma of olfactory groove	Gliomas
Craniopharyngioma and pituitary adenomas	Chondrosarcomas
Schwannomas	Metastatic cancer
Neurofibromas	Olfactory neuroblastomas
Osteomas	
Chordomas	
Chondromas	
Giant cell tumors	
Planum sphenoidale	
Fibrous dysplasia	
Encephaloceles	
Nasopharyngeal angiofibroma	
Hemangiopericytoma	

Large CSF fistulas (defects > 15 mm) not easily accessible by endoscopes, not localized on imaging, and associated with multiple and transverse fractures of cribriform region.

head and neck surgeons and neurosurgeons using combined craniofacial resections has extended the frontiers of surgery to deal successfully with extensive tumors of the skull base.^{14,17,24–29}

Figure 12 Basal view of the skull showing the midline structures exposed by this approach.

Quantification of the additional exposure obtained after performing the osteotomies helps objectively assess the advantages of a particular technique. Alaywan and Sindou demonstrated that adding an orbitozygomatic osteotomy to a pterional craniotomy improves the field of view angle by 75% from 11 to 19 degrees.³⁰ The extended frontal approach, revisited in this study, is a modification of the transbasal approach of Derome and was described by Sekhar et al in 1992.¹¹ Although the earlier study mentioned the advantages of this approach, we calculated the exact advantage obtained from this approach in terms of gain in width of the angle of exposure after FOO was performed.

Damage to the olfactory nerve is inevitable during osteotomy of the anterior skull base and has been reported by Derome as the only complication associated with this procedure. To preserve the olfactory nerve, it seems necessary to restrict the anterior skull osteotomy to the anterior portion of the crista galli and to leave part of the dura mater affixed in the central anterior skull base. Spetzler et al²⁹ described en bloc removal of the cribriform plate with its attached dura and mucosa. Olfaction returned in all four of their patients 8 weeks after surgery, presumably because of the mucosal regeneration.³¹ Injury or damage to the frontal and supraorbital nerves can be prevented by carefully freeing the periorbital membrane and performing the osteotomy of the skull base under direct visualization.

Tumor Pathology

Neoplasms involving the skull base are rare, less than about 1% of intracranial tumors. They are usually benign or only locally malignant. They rarely metastasize and are refractory to radiotherapy or chemotherapy. Hence, radical resection should be the aim of treatment in their management. In case of recurrence, reoperation is the usual choice. Prolonged surgery with frontal lobe retraction is typically required for their radical excision. With the

Figure 13 Angles at brain targets (A) before and (B) after FOO. A, FM; B, ACP.

extended frontal approach, several skull base lesions in the midline compartment of anterior, middle, and posterior fossae (anterior to FM) can be reached (Fig. 12).

CONCLUSION

Advantages

In the five specimens, the angle of view increased after FOO (80% for FM and 76% for ACP). These figures suggest that retraction of the brain is required after FOO (Fig. 13). As the angle of view increases, an increasingly wider exposure is provided and the surgeon has more operative maneuverability. Midline lesions anterior to the FM can be excised safely with this approach (Table 3).

Disadvantages

This approach necessitates removing the crista galli and sectioning the olfactory rootlets with the associated risk of anosmia and CSF leakage and the need for complex reconstruction of the frontal floor. Spetzler et al modified the technique of handling the cribriform plate to preserve the olfactory unit.²⁹ Sacrifice of supraorbital nerve and artery can be avoided by using the technique ascribed by Jane et al.¹⁵ Dural defects need to be repaired satisfactorily, ensuring watertight closure to avoid postoperative CSF leakage and the risk of developing meningitis.

We quantified the exposure associated with the extended frontal approach to lesions of the skull base. Large tumors of the skull base may require excessive retraction of the frontal lobes to obtain adequate exposure for their interaction. The extended frontal approach provides additional exposure by removal of bone rather than by retraction of the brain. Careful separation of the periorbita and the basal dura, a precise osteotomy, decreased brain retraction, and meticulous reconstruction are essential. The addition of FOO to a conventional bifrontal craniotomy widens the working space, minimizes brain retraction, and improves the maneuverability of the surgeon. This technique may be invaluable in planning approaches to large midline tumors of the anterior, middle, and posterior cranial fossae (clival) with a minimum amount of frontal lobe retraction.

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Commentary

The authors have quantified the advantages of the extended subfrontal approach by careful measurements. Surgeons who perform subfrontal approaches to access both intradural and extradural lesions should strongly consider the addition of a fronto-orbital osteotomy and, when necessary, a cranial ethmoidectomy to improve exposure and to reduce brain retraction.

The olfaction-preserving approach proposed by Robert Spetzler et al does seem to work,¹ although smell may not recover for almost 3 months (presumably because the olfactory nerves must regenerate). This approach, however, reduces the exposure because a cribriform-frontal block of bone is preserved and retracted toward the frontal lobe. It also makes basal repair using a pericranial vascularized flap difficult. Consequently, I only use this approach if the risk of cerebrospinal fluid leakage is minimal.

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Laligam N. Sekhar, M.D.¹

Commentary

The authors performed an anatomic study to quantitate the advantage of the extended frontal approach compared with a conventional bifrontal craniotomy. They provide a clear description of the approach, which has also been described elsewhere.¹ They confirm that the addition of a fronto-orbital osteotomy widens the operative view.

As the authors mention, the advantages and disadvantages of the approach have been reported and illustrated in detail previously.^{1,2} Its advantages lie in improved exposure of the optic nerve, sphenoid sinus, and medial aspect of the cavernous sinuses and, if needed, the ability to unroof the medial wall of the orbit and intracavernous internal carotid artery. The lateral limits of exposure for the extended fronto-orbital approach were neither described nor illustrated. The dorsum sellae and

superolateral margin of the maxillary sinuses have been reported to be the anatomic blind spots in this approach.¹ The lower lateral portion of the orbit, located adjacent to the roof of the maxillary sinus, is another relative blind spot in the approach. These disadvantages were not mentioned in the text or diagrammatic representations (the authors' Fig. 11).

The authors' conclusion implies that midline lesions anterior to the foramen magnum (FM) can be excised safely through an extended fronto-orbital approach. However, the extended fronto-orbital approach should not be considered for approaching a tumor strictly localized in the region of the FM. It might be used for an extensive lesion involving the ethmoid and sphenoid sinuses as well as the clivus and FM.

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Necmettin Tanriover, M.D.¹

Albert L. Rhoton Jr., M.D.¹

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