

Combined Subcranial Approaches for Excision of Complex Anterior Skull Base Tumors

Dan M. Fliss, MD; Avraham Abergel, MD; Oren Cavel, MD; Nevo Margalit, MD; Ziv Gil, MD, PhD

Objective: To present our method for excision of complex anterior skull base tumors via combinations of the subcranial approach.

Patients: Of 120 anterior skull base tumor resections, 41 that included 27 (66%) malignant and 14 (34%) benign lesions were performed via combinations of the subcranial approach. Unilateral or bilateral medial maxillectomy was performed using the subcranial approach alone for 13 tumors infiltrating the anterior skull base, ethmoid bones, and medial maxillary wall. A combined subcranial-transfacial approach in 2 lesions or a combined subcranial-midfacial degloving approach in 14 lesions was performed for tumors involving the skull base and the lower or lateral segments of the maxilla. A combined subcranial-transorbital or transfacial-transorbital approach was used for 5 tumors invading the orbit. An extended subcranial-orbitozygomatic approach was used for 6 tumors invading the middle cranial fossa or involving the cavernous sinus. A combined subcranial–Le Fort I down-fracture approach was used for 1 dedifferenti-

ated chordoma invading the anterior skull base and lower clivus. The surgical results, patient quality of life, survival, and complications were measured.

Results: Thirty-seven of 41 tumors (90%) were completely resected. Fifteen patients (35.5%) had perioperative complications. There were no postoperative deaths. Two-year overall and disease-free survival in patients with malignant tumors who underwent combined approaches was 66% and 60%, respectively. There was no significant difference in the quality of life between patients operated on via combined or classic subcranial approaches.

Conclusion: Combinations and modifications of the subcranial approach for excision of complex anterior skull base tumors yield surgical results, survival, quality of life, and complications similar to those found with the classic subcranial technique.

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THE SUBCRANIAL APPROACH IS a single-stage procedure used in cases of tumors involving the anterior skull base. The concept of a broad subcranial approach to the entire anterior skull base was first introduced by Raveh¹ for treatment of traumatic injuries and was later adapted for surgical extirpation of tumors involving this anatomical region.²⁻⁴ The extent of exposure of the subcranial approach includes the frontal sinus anteriorly, the clivus posteriorly, the frontal lobe superiorly, and the paranasal sinuses inferiorly. Laterally, the boundaries of this approach are both superior orbital walls. The subcranial approach has several major advantages: (1) it affords broad exposure of the anterior skull base from below rather than through the transfrontal route; (2) it provides excellent access to the medial orbital walls and the sphenoidal, nasal, and paranasal cavities; (3) it allows

simultaneous intradural and extradural tumor removal and safe reconstruction of dural defects; (4) it does not require facial incisions; and (5) it is performed with minimal frontal lobe manipulation.

The subcranial approach involves coronal incision and osteotomy of the nasofronto-orbital bone segment, which allows access to the intracranial and extracranial compartments of the anterior skull base. Although the subcranial approach permits complete tumor resection in most cases, there are still situations in which the inferior, lateral, or posterior aspects of the tumor are not adequately exposed. These include malignant neoplasms with extensions to the maxillary antrum and palate caudally; the cavernous sinus posteriorly; the orbital apex, pterygopalatine fossa, or the infratemporal fossa laterally; and involvement of the nasopharynx and inferior aspect of the clivus inferoposteriorly. Such cases require a combination of the subcranial approach with other approaches

Author Affiliations: Departments of Otolaryngology–Head and Neck Surgery (Drs Fliss, Abergel, Cavel, and Gil) and Neurosurgery (Dr Margalit), Tel-Aviv Sourasky Medical Center, Sackler Faculty of Medicine, Tel-Aviv University, Tel-Aviv, Israel. Dr Gil is now with the Head and Neck Service, Memorial Sloan-Kettering Cancer Center, New York, New York.

as a single-stage procedure. In these combined approaches, a second approach is added (eg, midfacial degloving, orbitozygomatic, transfacial, Le Fort I downfracture, or transorbital approach) to enable proper exposure and tumor extirpation. These combined approaches require additional incisions and osteotomies, depending on the type and extent of the tumor.

We describe combinations of the subcranial approach used by our group for extirpation of complex tumors extending out from the anterior skull base to involve the maxillary antrum, palate, cavernous sinus, orbital apex, pterygopalatine fossa, infratemporal fossa, nasopharynx, or inferior aspect of the clivus. The surgical and oncologic results and patient quality of life (QOL) were evaluated and compared with those of the classic subcranial approach.

METHODS

This retrospective study was based on a review of the hospital medical records and outpatient clinical and radiologic data for 120 consecutive patients operated on at our institution between January 1, 1994, and March 4, 2005. All resections and reconstructions were carried out by means of the classic subcranial approach to the anterior skull base.¹ The subcranial approach was combined with other approaches in 41 cases in which exposure was inadequate with the classic approach.

PATIENT POPULATION

Sixty-four male and 56 female patients aged 2 to 81 years (mean age, 42 years) were enrolled in this study. All of the patients were evaluated preoperatively by a head and neck surgeon, a plastic surgeon, and a neurosurgeon. Radiologic evaluation included axial and coronal computed tomography and magnetic resonance imaging. Neuroangiographic evaluations were also performed when indicated.

Broad-spectrum antibiotic therapy consisting of a combination of cefuroxime sodium and metronidazole hydrochloride was instituted perioperatively. All operations were performed with the patient under general anesthesia in the supine position and without shaving the hair at the surgical site. No tracheostomies were performed. A lumbar spine catheter was inserted for 5 days for cerebrospinal fluid drainage to facilitate frontal lobe retraction and to reduce the risk of postoperative cerebrospinal fluid leakage. Patients were hospitalized for a mean of 13 days.

SURGICAL TECHNIQUE

Classic Subcranial Approach

The surgical technique using the classic subcranial approach has been described in detail elsewhere.^{1,3-5} In brief, after induction of anesthesia, the skin is incised above the hairline and a bicoronal flap is created in a supraperiosteal plane. A flap is elevated anteriorly beyond the supraorbital ridges and laterally superficial to the temporalis fascia. The pericranial flap is elevated up to the periorbits and the supraorbital nerves and vessels are carefully separated from the supraorbital notch. The lateral and medial walls of the orbits are then exposed, and the anterior ethmoidal arteries are clipped or ligated. The pericranium is elevated above the nasal bones and the flap is rotated forward and held over the face throughout the remainder of the procedure. Titanium miniplates are applied to the frontal bones and removed before the osteotomies to ensure the exact repositioning of the bony segments at the end of the opera-

tion. An osteotomy of the anterior or the anterior and posterior frontal sinus walls, together with the nasal bony frame, part of the medial wall of the orbit, and a segment of the superoposterior nasal septum, is then performed. For a type A osteotomy, the anterior frontal sinus wall and the nasal frame are osteotomized and removed en bloc. If a type B osteotomy is planned, bur holes are made and the posterior frontal sinus wall is resected after the dura has been detached from the frontal, orbital, and ethmoidal roofs. A part of the distal nasal bone is preserved to support the nasal valve. In cases of lateral invasion of a tumor, the osteotomy lines can be extended to include segments of the orbital roofs. After the nasofronto-orbital bone segment is osteotomized, it is stored in saline solution until the reconstructive procedure. Bilateral ethmoidectomy and sphenoidotomy are then performed that enable exposure and assessment of the tumor in its entire circumference. The tumor is extirpated at this stage, and the dura or brain parenchymas are also resected if there is tumor involvement. Frozen-section specimens are obtained during surgery to ensure tumor-free margins. One or both sides of the cribriform plate and olfactory filaments are preserved when possible.

Medial Maxillectomy

Unilateral or bilateral maxillectomy was performed via the subcranial approach for tumors infiltrating the medial or superior walls of the maxilla. Radical ethmoidectomy and sphenoidectomy were performed after removal of the nasofronto-orbital segment and cribriform plate. Removal of the ethmoidal cells opened an entrance to the nasal cavity and medial maxillary wall from above, enabling exposure of the caudal aspect of the tumor. A medial maxillectomy was then performed, exposing the maxillary antrum. We also used this approach for benign tumors extending to the maxillary antrum and for selected malignant lesions without palatal infiltration.

Subcranial-Transfacial Approach

Malignant tumors infiltrating the lower, lateral, anterior, or posterior maxillary walls were exposed and extirpated via a combined subcranial-transfacial approach. The subcranial approach was performed as just described. The transfacial approach included a Weber-Fergusson incision and partial or radical maxillectomy. This approach enabled wide exposure of the superior and inferior aspects of the lesion and its complete en bloc resection.

Subcranial-Midfacial Degloving Approach

The subcranial-midfacial degloving approach⁶ was used for resection of benign tumors involving the anterior skull base and the inferior wall of the maxillary sinus (**Figure 1**). After resection of the tumor from above, a bilateral gingivolabial incision was made that extended to the maxillary tuberosity on each side. The soft tissue of the cheek was raised from the anterior surface of the maxilla, taking care to preserve the infraorbital nerves and vessels. Intracartilaginous incisions were made, similar to the classic closed rhinoplasty, and continued into a full transfixion incision around the limen vestibulae circumferentially. The nasal skeleton was then undermined, enabling degloving of the soft tissue of the lower face and exposure of the anterior maxillary walls bilaterally. It was then possible to perform partial maxillectomy (ie, medial or anterior maxillary walls or both), gaining access to the inferior aspect of the tumor both in the lower nasal cavity and in the maxillary sinus. We used this approach for highly vascular tumors infiltrating into the maxillary sinus.

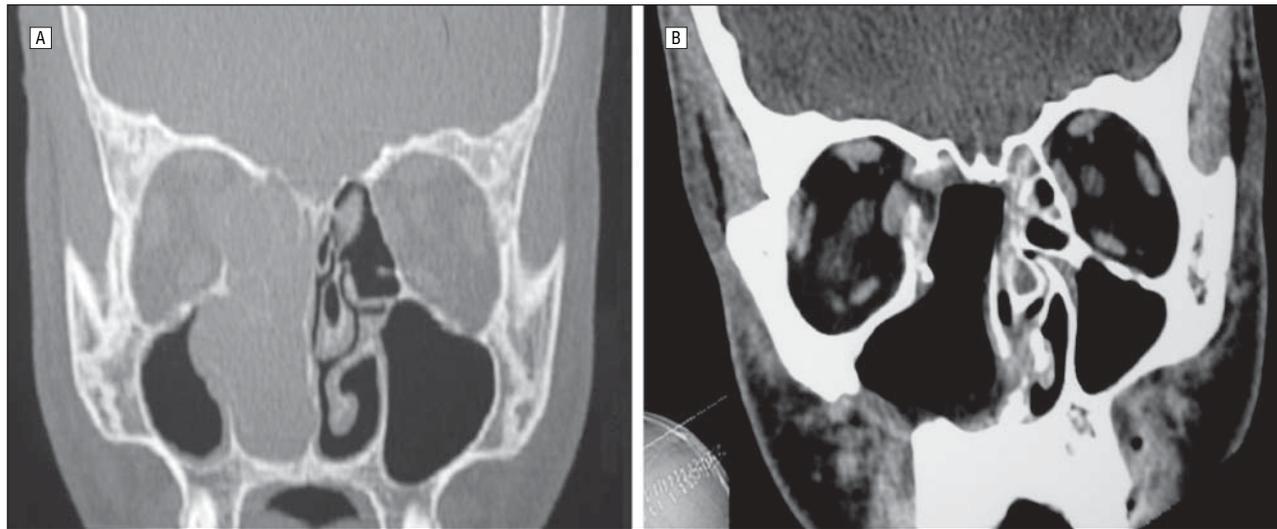


Figure 1. Preoperative (A) and postoperative (B) coronal computed tomographic scans from a 20-year-old patient with juvenile nasopharyngeal angiofibroma. The tumor was extirpated via the combined subcranial-midfacial degloving approach.

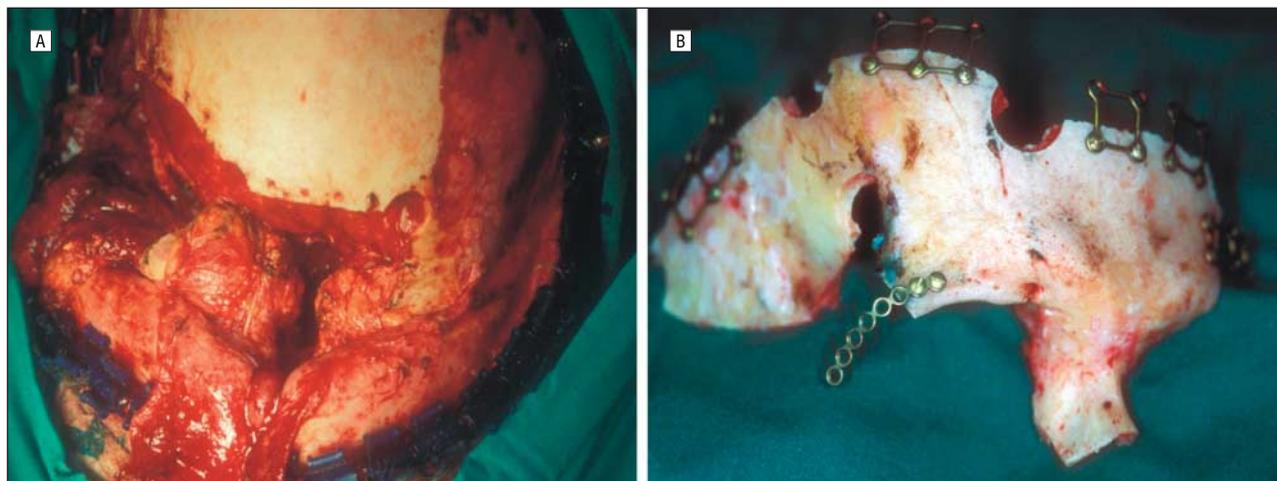


Figure 2. Intraoperative views in a 63-year-old patient with adenocarcinoma operated on via the combined subcranial-orbitozygomatic approach. The tumor involved the cribriform plate and also invaded the cavernous sinus. A, Exposure of the tumor after osteotomy. B, The osteotomy involved 1 bone segment including the nasofronto-orbital segment and the orbitozygomatic bone segment.

Subcranial-Orbitozygomatic Approach

This approach is a combination of the subcranial approach and the orbitozygomatic approach (**Figure 2**).⁷ A coronal incision is performed, and the skin flap elevation continues down to the level of the fat pad overlying the zygoma, above the temporalis fascia. On the ipsilateral side, the remainder of the dissection dips below the level of the temporalis fascia from the horizontal line above the arch and continues as a fasciocutaneous flap, as described by Yaşargil et al.⁸ The muscle is detached anteriorly and superiorly, exposing the temporal fossa. The next stage includes osteotomies in both the frontal and pterional regions. The osteotomy line includes the anterior and the posterior table of the frontal sinus, part of the medial orbital walls, and the superior aspect of the nasal septum. The osteotomy can be extended laterally, as required, to include a portion of the orbital roof. The bone segment is then removed in 1 or 2 pieces, exposing the orbital, ethmoid, and sphenoid roofs, the cribriform plate, the temporal fossa, and the parasellar area. The osteotomized segment may be removed as 1 large frontolateral bone flap or as 2 separate bone flaps.

We added a unilateral pterional approach to the subcranial approach to expose the more lateral aspect of the orbit, the retro-orbital region, the cavernous sinus, the pterygopalatine fossa, the chiasmatic region, or the infratemporal fossa.⁹ Large central nervous system tumors with extracranial extent, such as meningiomas involving the orbit or upper nasal and sinus cavities, can also be resected via this combined approach.

Subcranial-Transorbital Approach

A combined subcranial-transorbital approach was used for tumors that penetrated the bony orbit and periosteum and infiltrated the anterior orbital content (T4a) or orbital apex (T4b). The subcranial approach was performed as described, and the orbit was exenterated with meticulous dissection from both sides of the bicoronal-facial flap. The upper and lower eyelids may be spared if there is no tumor involvement, thereby allowing a better cosmetic result and future insertion of an orbital implant. A combined subcranial-transorbital-transfacial approach was performed with a total maxillectomy, allowing en-

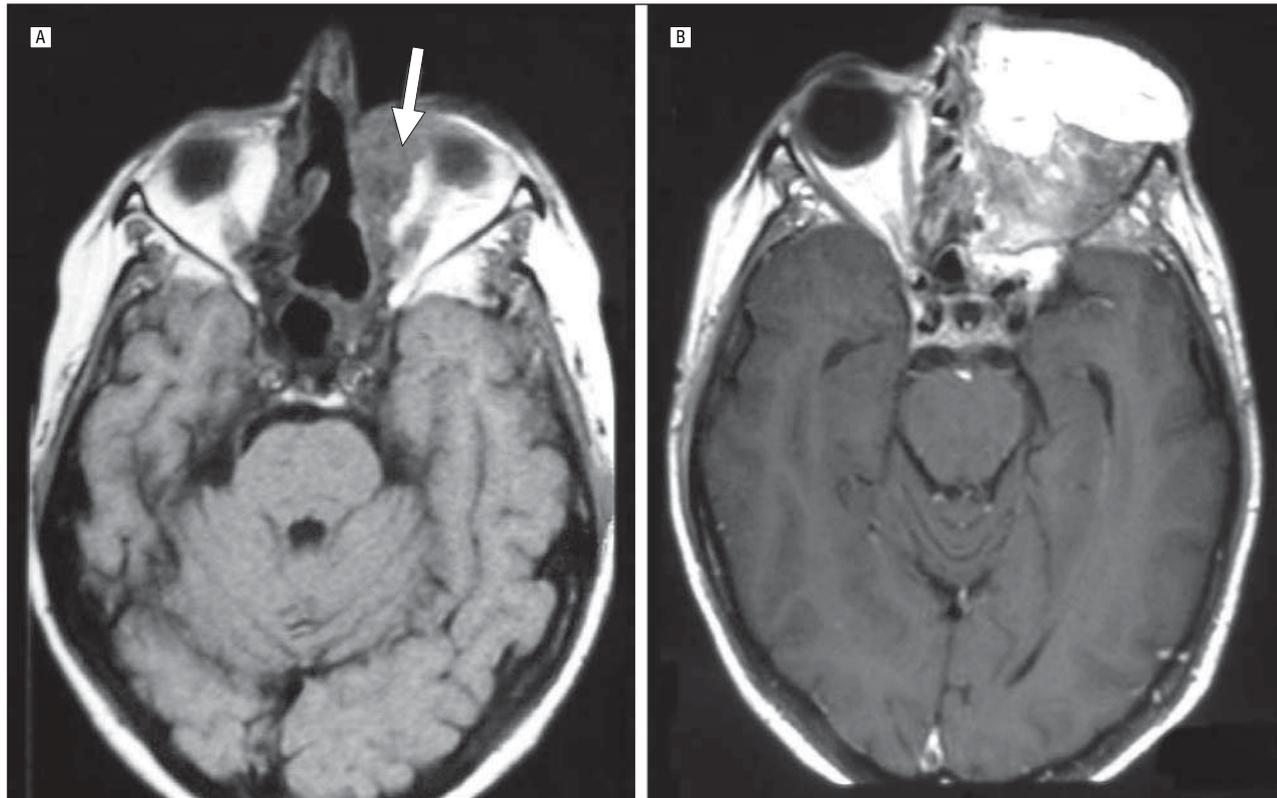


Figure 3. Preoperative (A) and postoperative (B) axial T1 magnetic resonance images in a 55-year-old patient with recurrent esthesioneuroblastoma infiltrating the left orbital apex (arrow). The tumor was extirpated via the combined subcranial-transfacial-transorbital approach. Resection included extended radical maxillectomy and orbital exenteration. Reconstruction was performed with a musculocutaneous rectus abdominis muscle free flap.

blow resection when the tumor extended from the orbit to the maxilla (**Figure 3**).

Subcranial–Le Fort I Approach

The combined subcranial–Le Fort I approach enables wide exposure of the tumor from the cribriform area to the lower part of the clivus. After the subcranial approach, an osteotomy and down-fracture of the upper alveolus are performed via a gingivobuccal incision. With this combined approach, it is also possible to perform a partial maxillectomy (ie, medial or anterior maxillary walls or both) to gain access to the inferior aspect of the tumor and its extension to the lower nasal cavity and clival region. This is the approach we used to extirpate large chordomas or chondrosarcomas originating in the clivus with intracranial extension. Specifically, we used the subcranial approach, which provides excellent exposure of the tumor and its circumference, for anterior skull base tumors that involved the sphenoid clivus. We chose a combination of the subcranial approach with a Le Fort I down-fracture osteotomy when the tumor extended from the anterior skull base inferiorly to involve the lower part of the clivus.

RECONSTRUCTION

Dural and anterior skull base reconstruction was performed with the double-layer fascia lata technique. Fibrin glue was used to provide additional protection against cerebrospinal fluid leakage. Reconstruction of the medial orbital walls was performed only when total removal of this segment was necessary or if the periorbit had been resected. In such cases, we used a split calvarial bone graft, a fascia lata sling, or 3-dimensional titanium mesh covered with pericranium. Septal cartilage can be

used for reconstruction of limited defects of the inferior orbital wall.

We used a temporalis muscle flap and a split-thickness skin graft to cover the orbital socket in cases of orbital exenteration. In cases of a radical maxillectomy with or without orbital exenteration, we used a lateral-thigh free flap or a rectus abdominis musculocutaneous free flap to obliterate this large defect and to support the obturator.

After surgery, patients were immediately transferred to the critical care unit for 24 hours. The lumbar drain was removed 3 to 5 days after the operation and the nasal packing was removed on the eighth postoperative day. All patients in the present study were followed up regularly for 3 to 50 months after discharge (mean follow-up, 26 months).

PATIENT QOL

The Anterior Skull Base Surgery Quality-of-Life Questionnaire was used for retrospective and prospective evaluation of QOL in patients who had undergone surgery via the classic subcranial and combined subcranial approaches. The questionnaire, including its reliability and validity, are described elsewhere.¹⁰⁻¹³ Six relevant domains were used, including role of performance (6 items), physical function (7 items), vitality (7 items), pain (3 items), specific symptoms (7 items), and effect on emotions (5 items).

STATISTICAL ANALYSIS

The *t*, log-rank (Mantle-Cox), and Breslow (generalized Wilcoxon signed rank) tests were applied as appropriate. *P* < .05 was considered significant.

Table 1. Summary of Surgical Approaches Used for Excision of Multicompartmental Anterior Skull Base Tumors

Tumor Extension	Surgical Approach	No. of Patients
Anterior skull base; frontal, ethmoidal, or sphenoidal sinuses; sphenoid clivus; planum sphenoidale	Classic subcranial	79
Medial or superior maxillary walls and periorbit	Subcranial with ipsilateral/bilateral partial maxillectomy	13
Benign tumors extending to the maxillary sinus compartment, with or without involvement of the PPF or nasopharynx	Subcranial-midfacial degloving	14
Malignant tumors extending to the inferior, anterior, or lateral maxillary walls	Subcranial-transfacial	2
Extension to the lateral skull base, cavernous sinus, middle fossa, or ITF	Subcranial-orbitozygomatic	6
Extension to the lower clival region	Subcranial-Le Fort I	1
Orbital apex or intraorbital extension	Subcranial-transorbital	2
Malignant tumors extending to the maxillary sinus with intraorbital extension	Subcranial-transfacial-transorbital	3
Total		120

Abbreviations: ITF, infratemporal fossa; PPF, pterygopalatine fossa.

RESULTS

The surgical outcomes in 120 patients who had undergone skull base tumor resections via the subcranial approach, alone or in combination with other approaches, were analyzed. The subcranial approach is the primary method used at our institution for excision of anterior skull base tumors. We identified 41 patients in whom we used a second approach or a modification of the classic subcranial approach for tumor resection. A combined approach was used for tumors involving more than 1 compartment apart from the anterior skull base (ie, lateral skull base, clivus, and maxillary sinuses). Twenty-seven of these patients (66%) had malignant tumors and 14 (34%) had benign tumors. The most common tumor was squamous cell carcinoma, in 8 patients. Twenty patients had stage IV disease, 7 had stage III disease, and 14 had stage II disease. **Table 1** gives a summary of the underlying pathologic findings in the study patients. Initial Karnofsky scores (scale of 100 to 0, where 100 is perfect health) were estimated in 40 of 41 patients operated on via combined approaches. The median Karnofsky score was 80 (range, 60-90) (**Figure 4**).

Fourteen patients (35%) had undergone at least 1 previous operation. Twenty-four patients (58%) underwent perioperative radiation therapy (preoperative in 4 and postoperative in 20), of whom 4 (10%) had also undergone at least 1 previous operation. The subcranial approach was combined with a midfacial degloving procedure in 14 patients, medial maxillectomy in 13, orbitozygomatic approach in 6, transorbital approach in 5, transfacial approach in 2, and Le Fort I down-fracture

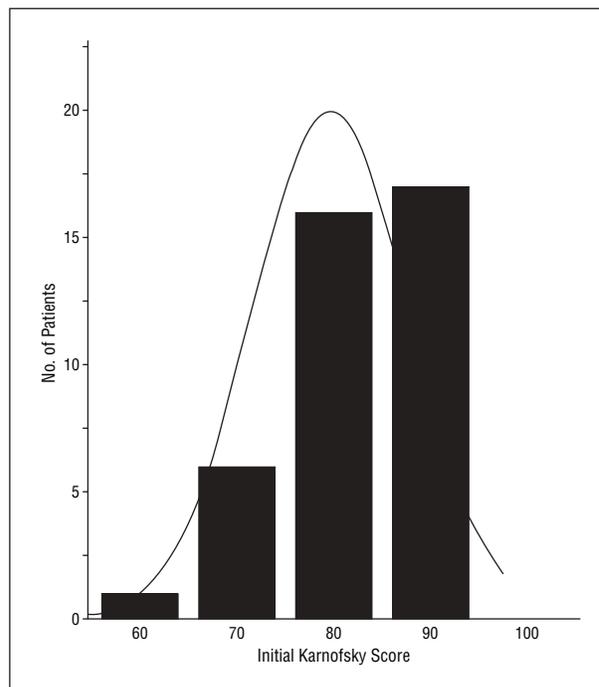


Figure 4. Initial Karnofsky scores (scale of 100 to 0, where 100 is perfect health) in patients operated on via combined approaches. The median Karnofsky score was 80 (mean \pm SD, 82 \pm 8; range, 60-90). The line graph is the normal curve fit.

in 1. The specific approaches used for each malignant neoplasm are given in **Table 2**.

Complete tumor resection was achieved in 37 patients (90%). Four patients (10%) underwent subtotal tumor resection. In these patients, the tumor involved the cavernous sinus, orbital nerve, or trigeminal ganglion, with intracranial extension. The principal skull base reconstruction procedure was performed by means of a double-layer fascia lata in 35 patients. The tumor extended to the dura mater in 20 of these patients. We used the temporalis muscle flap in 5 patients in whom orbital exenteration was performed, and used the same method of double-layer fascial flap for anterior skull base reconstruction in these patients.

A bony reconstruction was required if tumor resection produced a substantial bony defect of the orbital walls, nasal bone, or anterior frontal sinus wall. This was achieved by applying a split calvarial bone graft in 4 patients or a posterior sinus wall in 3 patients. A titanium mesh covered with a pericranial flap was used for reconstruction of the medial orbital walls and to cover extensive calvarial defects in 3 patients. Four patients in this series had substantial defects in the maxilla and anterior skull base, and the rectus abdominis muscle was used as a free graft in those reconstructions.

Postoperative complications occurred in 15 patients (35.5%). Six patients had more than 1 complication. Intracranial-related complications occurred in 5 patients, cranial complications in 4, and orbital complications in 2. **Table 3** gives the various postoperative complications occurring in patients after combined subcranial resections. For comparison, postoperative complications in patients operated on via the classic subcranial approach

Table 2. Histopathologic Findings in Anterior Skull Base Tumors and Surgical Approach

Pathologic Finding	Combination of Subcranial Approaches						Total
	MMX	MFD	TFC	TOR ^a	ORZ	LFI	
A-V malformation	...	...	...	...	2	...	2
JNA	...	2	...	...	...	...	2
Meningioma	1	...	...	...	...	...	1
Pituitary adenoma	...	...	...	...	1	...	1
Chordoma	...	...	...	...	1	...	1
Squamous cell carcinoma	2	3	...	3	...	...	8
Esthesioneuroblastoma	3	...	...	1	...	...	4
Sarcoma	1	1	2	...	...	...	4
Adenocarcinoma	2	...	...	...	2	...	4
SNUC	...	1	...	1	...	...	2
MPNST	2	...	...	...	...	...	2
Hemangiopericytoma	1	...	...	...	...	...	1
Dedifferentiated chordoma	...	...	...	...	...	1	1
Adenocarcinoma	1	...	...	...	...	...	1
Inverted papilloma ^b	...	6	...	...	...	...	6
Encephalocele	...	1	...	...	...	...	1
Total No. of tumors	13	14	2	5	6	1	41

Abbreviations: A-V, arteriovenous malformation; JNA, juvenile nasopharyngeal angiofibroma; LFI, Le Fort I down-fracture; MFD, midfacial degloving; MMX, medial maxillectomy; MPNST, malignant peripheral nerve sheath tumor; ORZ, orbitozygomatic; SNUC, sinonasal undifferentiated carcinoma; TFC, transfacial; TOR, transorbital; ellipses, not applicable.

^aIncludes 3 patients operated on via a combined subcranial-transorbital-transfacial approach.

^bInverted papilloma with intracranial extension.

Table 3. Complications of Skull Base Resection Procedures

Complication ^a	No. (%) of Events
Wound infection	3 (7.5)
Deep vein thrombosis	3 (7.5)
Meningitis	3 (7.5)
Osteoradionecrosis and fistula	2 (5)
Epiphora	2 (5)
Mucocele	2 (5)
Pneumonia	2 (5)
Tension pneumocephalus	1 (2.5)
Cerebrospinal fluid leakage	1 (2.5)
Nasal bone absorption	2 (5)

^aSix of the 15 patients had more than 1 complication.

alone occurred in 24 of 69 patients (35%) and included wound complications in 10 patients (14.5%), central nervous system–related complications in 6 (8.7%), orbital complications in 5 (7.2%), and systemic complications in 3 (4.2%). There was no statistical difference between the 2 groups.

We analyzed the overall and disease-free survival for all patients with malignant tumors operated on with combinations of the subcranial approach. The mean \pm SD follow-up time was 33 ± 4 months. Two-year overall and disease-free survival was 66% and 60%, respectively (**Figure 5**).

To gain insight into the QOL in patients undergoing the combined subcranial approach, we analyzed their QOL using a disease-specific questionnaire (see “Patient QOL” subsection in the “Methods” section). The QOL in these patients may be lower than in patients undergoing the

classic subcranial approach alone because of a larger extirpation and increased morbidity. Therefore, we analyzed and compared the QOL scores in both groups. The QOL for 13 patients who were operated on via combinations of the subcranial approach and for 23 patients operated on via the classic subcranial approach alone were assessed retrospectively using the Anterior Skull Base Surgery Quality-of-Life Questionnaire.¹¹⁻¹³ The results are given in **Table 4**. The overall QOL for both groups was similar ($P = .40$). The scores recorded for the group who underwent combined approaches for the role of performance, physical function, vitality, pain, and effect on emotion domains closely resembled those for the group who underwent the classic subcranial approach. There was, however, a significant difference in the disease-specific domain between the 2 groups ($P < .001$).

COMMENT

The route of spread of tumors originating in the anterior skull base and paranasal sinuses is determined by the complex anatomy of the craniofacial compartments. These tumors may invade laterally to the orbit and middle fossa, inferiorly to the maxillary antrum and palate, posteriorly to the nasopharynx and pterygopalatine fossa, and superiorly to the cavernous sinus and intracranial space.¹⁴ The recent improvements in endoscopic technology enable resection of most benign neoplasms and early malignant tumors with minor dural involvement. For larger tumors, the classic subcranial approach has emerged as an excellent surgical technique, enabling extirpation of tumors that involve the anterior skull base and midfacial region. In cases of tumor extension caudal or lateral to these areas, however, the subcranial approach alone

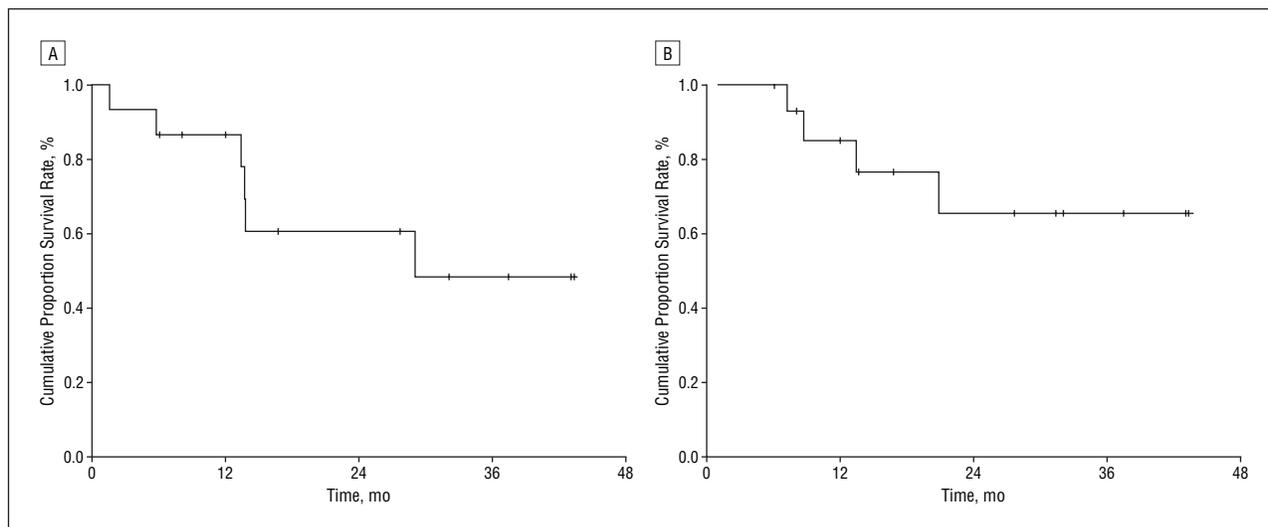


Figure 5. Kaplan-Meier estimates of disease-free (A) and overall (B) survival in patients operated on via combined approaches. Two-year overall and disease-free survival rates were 66% and 60%, respectively.

Table 4. Quality-of-Life Domain Scores for Classic and Combined Subcranial Approaches^a

Approach	Role of Performance	Physical Function	Vitality	Pain	Specific Symptoms ^b	Effect on Emotions	Overall
Combined (n = 13)	2.4 ± 0.6	2.5 ± 0.3	2.4 ± 0.7	2.8 ± 0.3	2.2 ± 0.7	2.7 ± 0.8	2.55 ± 0.4
Classic subcranial (n = 23)	2.7 ± 0.7	2.7 ± 0.4	2.8 ± 0.6	2.8 ± 0.3	2.8 ± 0.4	2.6 ± 0.7	2.88 ± 0.6

^aQuality-of-life scores range from 1 (worse) to 5 (best).

^bP = .004. The only statistically significant value when comparing combined with classic approaches.

cannot provide adequate exposure of the tumor and other supplementary techniques are needed to provide vascular control and preserve vital structures, thereby allowing safe resection of the tumors. To our knowledge, our series is the first describing the application of the classic subcranial approach in combination with other conventional surgical techniques in such settings.

We propose a comprehensive approach for excision of multicompartimental tumors based on the exact anatomical localization of the lesion (Table 1). The cases presented in this series included tumors involving the anterior skull base that also extended to an adjacent anatomical compartment laterally, inferiorly, or posteriorly.

The conventional exposure of the infrastructure or suprastructure of the maxilla involved lateral rhinotomy or Weber-Fergusson incisions along with bifrontal craniotomy (craniofacial approach).¹⁵ This technique has several limitations. Lateral rhinotomy with or without Dieffenbach or Lynch incisions may be associated with contractures of the lateral margins of the nostrils and ectropion. A Weber-Fergusson incision also may lead to upper lip retraction and asymmetry. To prevent facial incisions with the intent of improving cosmesis, we suggest 2 modifications of the subcranial approach based on our experience. We performed a unilateral or bilateral medial maxillectomy from above via the subcranial approach to enable direct visualization of the maxillary antrum, the maxillary floor, and the lateral maxillary walls. With this approach, it was possible to safely and reliably access benign tumors involving the medial or superior

walls of the maxilla and even resect selected malignant lesions that were not invading the hard palate. We achieved complete resection of tumors such as hemangiopericytoma, squamous cell carcinoma, and esthesioneuroblastoma that extended to the middle maxillary wall.

To expose larger tumors that impinged on the infrastructure (ie, the maxillary compartment and orbital floor), we combined the midfacial degloving approach as described by Casson et al¹⁶ with the subcranial approach. This permitted us to expose the entire circumference of the tumor from below and from above in a single operation without the need for facial incisions. This combined approach was used primarily for benign vascular tumors such as juvenile nasopharyngeal angiofibromas.

Malignant tumors infiltrating the lower, lateral, anterior, or posterior maxillary walls cannot be fully exposed via a combination of the subcranial and midfacial degloving approach and therefore should be resected via the subcranial-transfacial approach or with the conventional craniofacial resection. These approaches provide wide exposure of the tumor and its circumference, allowing en bloc resection of the intracranial and inframaxillary extensions of the tumors with free margins. For tumors involving the intraorbital content, the resection is performed via a subcranial-transfacial-transorbital approach in a similar manner. These approaches also enable proper reconstruction of the palate and skull base after tumor resection, with the use of composite free flap or obturator.

The subcranial approach provides limited access to tumors infiltrating lateral to the orbital roofs and to tu-

mors involving the cavernous sinus, greater sphenoid wing, pterygopalatine fossa, and infratemporal fossa. In such cases, retraction of the frontal lobes is necessary when using the classic subcranial approach, which may cause postoperative encephalomalacia and brain edema. Combining the orbitozygomatic approach with the subcranial approach, however, extends visibility to the operative field, gaining access to areas that were not accessible via the subcranial approach alone, minimizing frontal lobe retraction.

For tumors infiltrating the periorbit, the subcranial approach alone provides excellent exposure from above and below the orbit, enabling thorough resection of the tumor from the underlying orbital fat and muscles. Massive orbital involvement, with or without orbital apex infiltration, however, mandates orbital exenteration. In this case, a combined subcranial-transorbital approach allows safe exposure of tumor margins from both sides of the bicoronal flap and permits reconstruction with a temporalis muscle rotational flap within the same surgical field.

We resected tumors that involved both the anterior skull base and clivus using the classic subcranial approach, which allows simultaneous exposure of both compartments from above, averting the need for facial incisions. For tumors that extended to the lower margin of the clivus, however, the subcranial approach alone was not sufficient. In such cases of dedifferentiated chordoma, we added a Le Fort I down-fracture to the subcranial approach and achieved subtotal resection of the tumor that also involved the cavernous sinus.

Combinations of the craniofacial approach with the transfacial approach (ie, Weber-Ferguson, lateral rhinotomy, Lynch, subciliary, or transconjunctival incisions), facial degloving, and transorbital and middle fossa approaches have been described in detail by Fliss et al¹⁷ for large malignant tumors of the anterior skull base and paranasal sinuses. A combined facial translocation approach was also described and safely used by Hao et al¹⁸ for both malignant and benign tumors.

The complication rate in patients operated on via the combined approaches was similar to that with the subcranial approach alone despite the extensive resections required in patients with multicompartamental tumor involvement. An international study group recently published 3 articles on various characteristics in patients after craniofacial surgery.¹⁹⁻²¹ Their 36% rate of postoperative complications (433 of 1100 patients) is similar to the complication rate found in our study.²⁰ Nevertheless, Ganly et al²⁰ reported a 4.7% mortality rate compared with a 0% postoperative mortality rate (defined as <30 days after surgery) in our series.

Among the 27 patients with malignant tumors, our cohort study had 2-year overall and disease-free survival rates of 66% and 60%, respectively. The disease-free and overall survival rates for patients operated on via combinations of the subcranial approach did not differ from the survival rate for patients operated on with the subcranial approach alone (as reported by Fliss et al¹⁷), and they were also similar to the survival rates in other reports of patients with malignant tumors.^{19,21}

Patient QOL was estimated using the Anterior Skull Base Surgery QOL Questionnaire, a disease-specific in-

strument developed by Gil et al.¹⁰⁻¹² The data analysis showed that the overall QOL score for patients operated on via the classic subcranial approach did not differ significantly from that for patients operated on via combined approaches, although there was a trend toward lower QOL scores in the latter group. Most of our patients reported that the surgical procedure improved or did not affect their overall QOL. The only domain that showed a significantly lower QOL score was the specific symptoms domain, which includes questions on the functions of taste and smell, mastication, appearance, nasal secretions, and vision, which are expected to be affected by wide resections involving the hard palate (subcranial approach with radical or partial maxillectomy), the orbit (subcranial-transorbital approach), or both.

CONCLUSION

The techniques described are innovative combinations of various commonly used procedures. We propose a comprehensive approach for the resection of complex anterior skull base tumors with multicompartamental invasion. Using these combined approaches, tumors that previously might have been resected in multiple stages can be resected with a single-stage en bloc procedure with reliable reconstruction. The incidence and severity of perioperative complications, QOL, and survival associated with these techniques are similar to those found after the classic subcranial approach alone. Continuing improvement in the proposed approaches along with adjuvant therapy and improved imaging methods may promise better surgical and functional results for patients with anterior skull base tumors.

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Correspondence: Ziv Gil, MD, PhD, Head and Neck Service, Memorial Sloan-Kettering Cancer Center, 1275 York Ave, New York, NY 10021 (ziv@baseofskull.org).

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