Evaluation of the Contribution of CAS in Combination with the Subcranial/Subfrontal Approach in Anterior Skull Base Surgery

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ABSTRACT

In this study, 31 cases with different anterior skull base lesions mandating broad exposure, including the sphenoidal, parasellar, and clival region, were surgically treated using the frameless computer assisted surgery (CAS) system. The contribution of navigated surgery in relation to the broad exposure and direct visualization of this region rendered by the subcranial-subfrontal approach was evaluated. In group I, consisting of extensive tumors, the contribution of CAS was only given in five cases for the exposure of the tumor extensions located to the parasellar sphenoclival complex with concomitant distortion of the anatomic landmarks. No advantages were experienced in the more anterior locations along the ethmoidal compartment and frontal sinus. In the cases in group II, consisting of congenital anomaly implying fronto-orbital advancement and a meningoencephalocele as well as extensive mucocoeles, the CAS was only helpful in those cases with an extremely aberrative anatomy in these regions.

KEYWORDS: Anterior skull base tumors, subcranial/subfrontal approach, navigated skull base surgery

The subject of this article is to evaluate the contribution of navigated surgery for the management of different lesions mandating a broad exposure of the anterior skull base, including the

parasellar and the sphenoclival region. To provide an adequate objective evaluation of the value and the indications of the navigated computer-assisted surgery (CAS) system, cases with different lesions,

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including tumors, extensive mucocoeles, and teleorbitism, were included in this series. In recent years, various CAS systems have been introduced and described for different locations, approaches, and indications. The innovative aspects and the achievements are both impressive and undisputed. Accordingly, the trend to use these systems in a rather unrestrictive manner is high. By contrast, the aim of this study is to provide guidelines for consideration of a more selective evaluation with respect to those locations in which this performance does not attribute significant advantages.

The CAS system we used was developed at the Maurice E. Mueller Institute, University of Bern, in cooperation with the Departments of Neurosurgery, Wayne State University, Detroit, Michigan, and Orthopedic Surgery in Bern¹⁻⁴—and the literature cited therein—for spinal and pelvic surgery as well as for skull base surgery.⁵ This frameless system is a combination of image-guided stereotaxis with an optoelectronic sensor device enabling real-time navigation and visualization of the surgical activities and location of the instruments on the monitor. The system was acquired in 1997 for the interdisciplinary use of neuroradiology, otolaryngology, and our discipline. The system was used mainly for transnasal endoscopic procedures for the exploration of the paranasal-ethmoidal region, polyposis, and biopsies in a rather unrestrictive manner.^{6,7} With respect to the subject of this study, a detailed review and comparison with the various different systems are neither indicated nor relevant.

In all cases, the subcranial/subfrontal approach was performed. This approach was developed by us in 1978 for the exposure and management of the anterior skull base in severe injuries, congenital anomalies (including teleorbitism and tumors as described in our previous publications⁸⁻¹⁶), and the literature cited therein. In the past, we used these and further different terms, but the approach and concept are the same. The major advantage of this concept compared with other traditional approaches consists of the extended ante-

rior broad exposure under direct vision of all the skull base planes, including the complex parasellar cavernous and sphenoclivar regions. This concept gained popularity and was confirmed by others.¹⁷⁻²⁴ Thus, in particular, this approach considerably reduces the indications for navigated surgery and represents an important parameter for the evaluation.

MATERIALS AND METHODS

Preoperative Evaluation and Material

Evaluation and planning were performed in a team approach consisting of the neuroradiology, neurosurgery, and our team. The lesions in our domain include the craniofacial and the anterior skull base, sphenoclivar, parasellar, and cavernous region, as well as the midface and the lateral area. The petrosal complex is the domain of a different team and is not included in this study.

Preoperative angiography and, if indicated, endovascular embolization, as well as the carotid occlusion test, were performed, including computed tomography (CT) scans in all the cases. All the pre- and postoperative magnetic resonance imaging (MRI) were performed using a 1.5-tesla unit with T₂ and T₁ spin-echo techniques both before and after the administration of gadolinium DTPA. In addition, the fat saturation technique enabled an optimal selective evaluation of the tissue enhancement.

The neurosurgeons in all cases are on standby. Those cases with extensive intradural, brain tissue, or lateral involvement were managed in close cooperation. The approaches and exposure of the skull base by the subfrontal or lateral access were performed by our team.

Since November 1997, 31 patients manifesting an array of different anterior skull base lesions and locations were selected and treated according to the preoperative protocol by the subfrontal ap-

proach in combination with the CAS system. This series includes two groups. Group I included 19 tumors with intracranial and/or parasellar sphenoclivar involvement. Group II consisted of 12 cases with different lesions, involving the fronto-orbital and skull base region. The various lesions and the approaches are listed in Table 1. The structures involved are depicted in Figure 1.

Approaches

The subcranial/subfrontal approach, as well as combinations with the intraoral, Le Fort I, and lateral approaches are listed in Table 1. The fronto-orbital osteotomies in the tumor cases are tailored in relation to the tumor extension, as illustrated in Figure 2A,B. The same concept and approach,

Table 1 Navigated Anterior Skull Base Surgery: Diagnosis and Approaches

Anterior Skull Base Tumors	Approach			No. of Cases
	Subfrontal	Subfrontal and Intraoral	Subfrontal and Lateral	
Group I				
Benign				
Adenoma	1			1
Angiofibroma	2	1		3
Fibrous dysplasia			1	1
Giant cell tumor		1		1
Meningioma			2	2
Osteoma	1			1
Malignant				
Adenocarcinoma	2			2
Chordoma	1			1
Esthesioneuroblastoma	2	1		3
Melanoma	1	2		3
Rhabdomyosarcoma	1			1
Total	11	5	3	19
Group II				
Craniofacial deformities: subcranial/subfrontal approach				
Late posttraumatic fronto-orbital asymmetry and hypertelorism				3
Acromegaly with fronto-orbital malformation				1
Congenital anomaly: fronto-orbital malformation and teleorbitism				1
Total				5
Extensive mucocele: subcranial/subfrontal approach				
Frontal sinus				1
Frontal sinus and orbit				3
Ethmoidal-seller compartment				2
Total				6
Meningoencephalocele: lateral pterional approach				1
Total cases				31

Figure 1 Structures involved in 19 tumor cases with intracranial and/or parasellar, sphenoclivar involvement. Group I of 31 patients treated according to the preoperative protocol by the subfrontal approach combined with the CAS system.

with different osteotomies are performed for the management of skull base injuries including optic nerve decompression or extensive lesions such as mucocèles and meningoencephalocèle, as well as skull base exposure and osteotomy for the correction of craniofacial anomalies with teleorbitism. The major advantage of the subfrontal approach is that it provides extended anterior broad exposure under direct vision in all directions of the lesion/tumor borders along the anterior skull base complex, avoiding frontal lobe retractions. This includes intracranial extensions, as well as the optic nerve, chiasm, internal carotid artery (ICA), cavernous sinus, the sphenoclivar region (Fig. 2C,D), and nasal lumen/maxillary sinus extensions. Particularly in tumors, this optimal visualization permits en bloc tumor removal, in contrast to traditional transfrontal or transfacial approaches such as the lateral rhinotomy, midface splitting, and osteotomies implying skin incisions and damage to intact uninvolved structures, and yet not providing a similar visualization. Significant advantages include reduction of the complication and morbidity rate sparing unnecessary damage to the optic nerve, chiasm, and ICA, CSF leaks, and further

functional disorders provided by this concept. The combination with Le Fort I osteotomy or the lateral approach are only indicated for the assessment of retromaxillary or lateral area involvement. For further details concerning the technique, we refer to the literature cited. The CAS system was used in all the cases in this series.

The frameless system is illustrated in Figure 3A with the portable camera and the central control unit hosting the computer hardware. Preoperative helical CT was used, enabling the segmentation and 3-D reconstruction defining the optimal trajectories. Markers can be applied or, as in most of our cases, reference points such as the nasion or the frontozygomatic suture are defined on the CT scan. In an effort to establish a rigid body defining, visualizing, and pursuing the inserted instruments' position and track, a carrier serving as a dynamic reference is integrated. There are various possibilities to achieve this. In our cases, as advocated and developed by the first author, we used an upper jaw splint (Fig. 3B) or a carrier fixed to the calvarial bone by three screws (Fig. 4). The carrier rod is equipped with four infrared light-emitting diodes (IRED). This permits free movement of the head during surgery, enabling accurate real-time visualization of the instrument on the monitor. Further technical aspects related to this system and the comparison with others have been described in detail.¹⁻⁵

Representative Cases

GROUP I: SKULL BASE TUMORS

Case 1 In case 1, an angiofibroma was resected elsewhere by the endonasal-endoscopic procedure, leaving the distal part of the tumor unremoved, as shown in Fig. 5A,D,F. The tumor was located on the right side to the sphenoid/parasellar area effacing the intracavernous part of the ICA, as well as extensions to the pterygopalatine fossa. Endovascular

Figure 2 (A) Subcranial-subfrontal approach, including the various fronto-nasal and combined lateral osteotomies. These can be deliberately extended and are tailored in relation to the tumor extension and location. Dotted line, nasal frame osteotomy with or without preservation of an anterior bridge. (B) Before the osteotomies, the dura is dissected through the burr holes. (C) Removal of the frontonasal segment enables optimal exposure and visualization of the skull base planes including the nasal and maxillary sinus lumen. (D) Cadaver dissection illustrating the exposed frontal lobe (L), the posterior border of the resected sphenoidal plane and the exposed sella (S), carotid (C), optic nerves and chiasm (O), as well as the posterior sphenoidal wall and clivus (star), globe (G).

embolization was performed. The ICA and the cavernous sinus were exposed. These locations and the inserted instrument were visualized on the CAS system monitor as depicted in Figure 5C. The CAS was useful as confirmation that the structures were exposed correctly, and that the pterygopalatine fossa was not bypassed. The radical removal of the tumor was achieved (Fig. 5B,E,G). Tabotamp was applied to the anterior section of the cavernous sinus and the skull base including the sphenoid was aligned with fascia lata and fibrin glue. The postoperative course was uneventful. Treatment in the intensive care unit (ICU) was limited to 12 h, and the hospitalization period included an additional 7 days.

Case 2 In case 2 (Fig. 6A–M), an extensive giant cell tumor with an accentuated exophthalmus and diminished loss of vision were manifested. The preoperative MRI (Fig. 6A,G,I,K) illustrates the tumor evading the orbital cone on the left, effacing the optic nerve along with destruction of the ethmoidal roof, partial resorption of the sphenoidal plane, extending intracranially and infiltrating the dura at this location, as well as extensions toward the sphenoclival region. Further extensions of the tumor included the nasal lumen, as well as the maxillary and retromaxillary, infratemporal, and pterygopalatal area along with resorption of the palate, the anterior maxillary sinus wall, and the infraorbital rim and floor. The tumor extended up to

Figure 3 (A) The system including the portable infrared camera and the central control unit. (B) The upper jaw splint with attached IRED carrier, serving as a dynamic reference to permit free movement of the head.

the subcutaneous anterior skin layers. Posteriorly, the tumor did not directly efface the ICA or the cavernous sinus, yet, the partial resorption of the bone at this location implied the exposure of both.

Preoperative endovasal embolization of the tumor was performed. The tumor was assessed by the subfrontal approach, keeping a safe distance toward the tumor borders. The infiltrated section of the dura along the resorbed ethmoidal-sphenoidal plane was resected. In regard to the relatively limited dura involvement, the neurosurgeons were on standby but did not have to intervene. The tumor extensions toward the left globe and optic nerve, which was fully exposed, were identified and removed and the histology confirmed the tumor-free borders. The tumor was encapsulated at this location; thus, only a limited resection of the perior-

bital tissue was indicated, enabling preservation of the eye. Up to this stage, in regard to broad exposure providing direct visualization of the adjacent structures, and as expected, the CAS did not attribute any advantages.

For further exposure of the sphenoidal and clival region, as well as the anterior section of the cavernous sinus, particularly in regard to the resorption of the bone, the CAS proved to be helpful. Although direct visualization of these structures was provided by this approach, further real-time visualization of the instruments' location (Fig. 6C) provided the confirmation that the correct distance toward the tumor borders, as well as the vital structures was kept, avoiding a *via falsa* or penetration of the tumor. The extent of the destruction along the ethmoidal roof and the sphen-

Figure 4 For an indication similar to that in Fig. 3, a carrier is fixed with three screws to the skull. The frontonasal frame is already removed and the instrument equipped with IRED is inserted. L, frontal lobe; G, globe. Arrow, the left globe is retracted and the posterior skull base exposed.

noidal planes are visible on the monitor. The posterior remnants of the sphenoidal plane were resected up to the anterior border of the sella and the tumor was dissected first exposing the ICA as well as the cavernous sinus, in regard to the erosions of the bone. The intraoperative stage after en bloc removal of tumor (the further steps are described below) is illustrated in Figure 6D with the instrument pointing at the posterior sphenoidal wall corresponding with the real time position (Fig. 6E). The posterior sphenoidal wall and clivus are fully exposed (Fig. 6F). All these steps along the skull base including the nasal lumen were performed by the subfrontal access. Further resection of the max-

illary and posterior infratemporal tumor component, including the pterygopalatal area, were performed by the intraoral and lateral approach enabling the en bloc tumor removal. At this location, the CAS did not contribute any advantages.

Histologic examination confirmed that all the tumor borders were free, as demonstrated by the postoperative MRI as well (Fig. 6H,J,L). The dura defect was managed by suturing a fascia lata patch; an additional two layers were applied for the alignment of the anterior, as well as the sphenoclivus area. External table grafts were harvested for the reconstruction of the nasal frame, the palate and the zygoma-orbital complex on the left. Further details of this extensive reconstruction are beyond the scope of this article and will be described elsewhere. The patient regained vision in the left eye, and no diplopia was manifested. The postoperative course, apart from a slight hemodilution, was uneventful and no complications occurred. The patient's view is shown in Figure 6M.

GROUP II: CONGENITAL ANOMALY

In this case, a congenital anomaly with hypertelorism, asymmetry of the zygoma-orbital cone complex and the frontal bone were manifested (Fig. 7A–D). In comparison with the transfrontal and other traditional approaches, the subcranial/subfrontal approach provides significant advantages, permitting optimal exposure and osteotomy of the fronto-orbital area, as well as the skull base (Fig. 7E,F), sparing the midline structures and avoiding frontal lobe retraction. This enabled a significant reduction of the complication and morbidity rate. In regard to the advantages of this approach, a routine integration of the CAS in such cases is not indicated. In this particular case, with respect to the deformity of the frontal bone and the aberrative configuration of the frontal sinus, we decided to use the system, so as to facilitate the dural dissection along the posterior frontal sinus wall, avoiding unnecessary dural ruptures during the osteotomies. The instrument pointing toward the

Figure 5 Case 1. Endoscopic removal of an angiofibroma elsewhere, leaving the posterior part of the tumor (see text). (A) Preoperative coronal MRI depicting the tumor in the sphenoid effacing the parasellar intracavernous section of the ICA (arrow) on the left. (B) Corresponding postoperative MRI illustrating the absence of the tumor, preservation of the ICA, and the presence of the fascia layers. (C) Visualization of the instrument's position on the monitor. Axial view, the tumor in the sphenoid (S) and instrument pointing at the lateral aspect. Sagittal view, the instrument and the arrow depicting the tumor extensions toward the pterygopalatine fossa. The tumor in the sphenoid is visible. Coronal view, the instrument points at the parasellar cavernous border. (D) Preoperative axial MRI. Arrows, ICA. The tumor extensions are illustrated. (E) Corresponding postoperative axial MRI. Absence of the tumor, presence of the fascia layers and preserved ICA. Arrows, no enhancement of the cavernous sinus following the packing and alignment with fascia lata.

Figure 5 (Continued) (F) Further section of the preoperative axial MRI. (G) The corresponding postoperative MRI, clear of tumor. The fascia and Tabotamp layers in the unaffected contralateral side of the tumor are obvious.

Figure 6 Case 2. Extensive giant cell tumor with intracranial, orbital, maxillary, and lateral extensions. All the following MRI images are T₁-weighted gadolinium-enhanced and fat suppressed (see text). (A) Preoperative axial MRI. The tumor expands toward the orbital cone effacing the optic nerve. Exophthalmus. (B) Postoperative MRI. Absence of the tumor and manifested fascia lata layers aligning the medial orbital aspect and the posterior sphenoid wall clivus, as well as the intraoperatively exposed ICA and cavernous sinus on the left. See text. (C) Intraoperative visualization of the instrument's position at the posterior sphenoidal wall. Arrows, note the eroded remnants of the sphenoidal plane. (D) The corresponding intraoperative view after tumor removal (see text) with the instrument on the monitor pointing at the posterior sphenoidal wall. S, sphenoid; C, clivus; G, globes. Arrows, the posterior border of the resected dura, as well as following removal of the rest of the resorbed sphenoidal plane. ICA and cavernous sinus were exposed (see text).

Figure 6 (Continued) (E) The instrument's position visualized on the monitor pointing at the posterior rest of the eroded sphenoidal plane (arrow). Absence of the anterior part, as well as the ethmoidal roof. (F) Both globes (G) are retracted, the intact bone of the posterior sphenoidal wall (S) and clivus (C) are illustrated. L, frontal lobes. The broad access to the nasal lumen is visible. (G) Preoperative coronal MRI illustrating the tumor extensions. Intracranial penetration and dura involvement, as well as the extensions toward the orbital cone, nasal lumen, maxillary sinus, and resorption of the palate are manifested. (H) Corresponding postoperative MRI. Absence of the tumor contrast enhanced fascia lata layers (arrows) along the skull base and orbital cones. The eye was preserved (see text). (I) Preoperative axial MRI. The tumor involves the nasal lumen. The retromaxillary and lateral extension, as well as the destruction of the anterior maxillary wall, pterygoid and orbital floor, infraorbital rim and the sphenoclival region are manifested.

Figure 6 (Continued) (J) Postoperative MRI after tumor removal including all the extensions. The distal area is packed with Tabotamp and fascia. (K) Preoperative sagittal MRI showing the tumor extensions and the intracranial involvement (see text). (L) Corresponding postoperative MRI. Absence of the tumor and presence of the fascia lata layers, including the sphenoid-clivus with several layers toward the cavernous sinus. The brain tissue reaction after the dura resection is manifest. (M) Postoperative view of the patient following the reconstruction of the orbital-zygoma and nasal complex with bone grafts. Normal vision.

Figure 7 Case 3. Congenital teleorbitism. (A) Preoperative view and the hypertelorism. Arrows, concave deformed frontal bone, asymmetry of the orbital cones and hypoplasia of the zygoma on the left. (B,C) Arrows depicting the orbital asymmetry and the concave frontal bone. (D) Same patient. 3-D CT reconstruction. Arrows depict the disconfiguration of the frontal bone and the asymmetry of the orbital cone and the zygoma on the left compared with the right. (E) Schematic illustration of the osteotomies. Removal of the paramedian bone and the optic nerve decompression (arrows) are performed by the subfrontal approach (see text).

Figure 7 (Continued) (F) Intraoperative view. The burr holes and the osteotomy of fronto-orbital (FO) zygoma complex on both sides, as well as removal of the paramedian bone segments, exposure of the frontal lobes (F) and optic nerve decompression are performed, avoiding the traditional craniotomy and frontal lobe retraction. (G) Intraoperative visualization of the instrument on the monitor. Axial view depicting the instrument pointing toward the distal portion of the optic nerve canal, which is removed (see text). Sagittal view, showing the instrument in the sphenoid. Coronal view, the instrument is located at the posterior end of the medial optic nerve canal. (H) Intraoperative view after mobilization of the osteotomized fronto-orbital segments (FO). Exposed globes (G). (I) Status following the skull base alignment with fascia, the orbital medial advancement and the reduction of the interorbital distance. The fixation is performed with Stryker Leibinger titanium miniplates. Arrows depict the degree of the medial advancement of the orbits. (J,K) Preoperative frontal and lateral view of the patient 4 weeks postoperatively with slight edema and not yet fully resorbed hematoma of the right upper eyelid.

distal end of the medial nerve canal is visualized on the monitor (Fig. 7G). Yet in regard to the broad exposure rendered by this access no advantage was provided by the CAS system at this location. The intraoperative view (Fig. 7H,I) illustrates the fronto-orbital advancement, mobilization toward the midline and the fixation with titanium miniplates (Stryker Leibinger). The duration of the ICU was limited to 8 h, and the hospitalization period was 8 days. No anosmia or diplopia was manifested and no further complications or morbidity were observed. A view of this patient, 4 weeks postoperatively, is illustrated in Figure 7J,K. As a result of the postoperative accentuated haematoma on the right, the corresponding reaction and slight edema are still visible along the upper eyelid. The hypertelorism as well as the orbital-zygoma asymmetry and the frontonasal angle, have been corrected.

RESULTS

Group I: Anterior Skull Base Tumors

Follow-up evaluation of the resected tumors is listed in Table 2. According to the follow-up protocol, all patients had CT scans and MRI performed 10 days postoperatively and after intervals of 3 and 6 months. If no suspicious locations were manifested further MRI were performed every 8 to 12 months. One case with a chondroma, was classified as malignant with manifested aggressive (grade 2) growth. The extensions destructing the sphenoidal plane and the sellar-sphenoidal bone were radically resected. The component penetrating the clivus toward the brain stem along with dural involvement was exposed and visualized by the subfrontal approach, as well as by the CAS, and was removed. Yet, according to the postoperative MRI, suspicious tissue enhancement at the posterior section was manifested. Up to now, 19 months postoper-

atively, there is no evidence of further growth, the patient is free of symptoms and followed up accordingly. In a second 84-year-old patient (Table 2) with anterior skull base melanoma along with resorption of the medial orbital wall without further involvement of the orbital tissue, the patient insisted on preservation of the eye. The resection included the periorbital tissue leaving the globe intact. The histology confirmed the radical resection with tumor-free borders. Repeated MRI controls showed no suspicious locations or enhancement, but a further control 11 months later showed recurrence located in the orbital cavity. The patient rejected any further surgery or exenteration and died 10 months later.

The complication rate is listed in Table 3. With respect to the watertight alignment, as well as avoiding frontal lobe retraction complications, such as: CSF leaks, meningitis and brain edema were reduced to a minimum. Secondary correction of the diplopia-enophthalmus or insufficient reconstruction of the fronto-orbital frame was indicated in only two cases. Anosmia was manifested only in 12 cases in group I and in no cases in group II. In contrast to the transfrontal approach, preservation of the olfactory filaments, even if only on one side, is provided by the subfrontal access.

The CAS system was integrated in all cases. The contribution was limited to the distal parasellar and sphenoclival complex in five tumors with concomitant resorption of the bone and distortion of the anatomic landmarks. In these cases the CAS provided a real contribution and was helpful in identifying the tumor borders and the adjacent or involved structures. In six further cases, the CAS was only partially helpful, enabling the visualization of the structures after exposure and resection of the tumor, but not rendering an actual contribution to the procedure as such (Table 4). The results in terms of radical tumor removal and reduction of the complication rate by the subfrontal approach remained the same as in our previous series without the use of the CAS.

Table 2 Navigated Surgery in Anterior skull Base Tumors (n = 19)

Histology	State of Disease				No. of Cases
	A&W	AWD	DOD	DOC	
Benign					
Adenoma	1 (13)				1
Angiofibroma	3 (22)				3
Fibrous dysplasia	1 (8)				1
Giant cell tumor	1 (12)				1
Meningioma	1 (17)			1 (1)	2
Osteoma	1 (4)				1
Total	8			1	9
Malignant					
Adenocarcinoma	2 (20)				2
Chordoma		1 (19)			1
Esthesioneuroblastoma	2 (13)		1 (10)		3
Melanoma	2 (12)		1 ^a (21)		3
Rhabdomyosarcoma		1 (13)			1
Total	6	2	2		10
Total cases	14	2	2	1	19

A&W, alive without disease; AWD, alive with disease; DOD, died of disease; DOC, died of other causes.

Numbers in parentheses indicate mean follow-up period in months.

^aRecurrence was observed 11 months postoperatively (see Results).

Group II: Craniofacial Deformities/Teleorbitism

For craniofacial anomalies/teleorbitism, in group II, the indication of the CAS is limited to only those cases with extreme disconfiguration of the anterior skull base and the frontal region, helping identify the borders toward brain tissue, and the adjacent structures avoiding ruptures of the dura during the dissection. This advantage was also given in the case with a meningoencephalocele facilitating the exposure. Apart from these two cases in group II, the CAS did not provide any advantages in the additional mucocoele cases.

The measured accuracy of the CAS system was 0.25 to 1.5 mm, with a mean of <0.5 mm. In both groups, the outcome and the complication rate remained unchanged in comparison to our previous series managed by the subcranial/sub-frontal approach without navigated surgery.

DISCUSSION

Navigated surgery and the development of quite efficient sophisticated systems in recent years are impressive, explaining the temptation to use this for less convincing indications. The real-time intraoperative tracking and visualization of the instruments on the monitor are a convincing confirmation, as well as a documentation that the various structures have actually been assessed. This can also serve as evidence in the case of complications or legal controversies. Further, the intraoperative provided information undoubtedly represents a contribution for less experienced surgeons in the process of training. Yet, in consideration of the costs, as well as the time-consuming preparation, acquisition, and installation, we opt for a more restrictive evaluation of the indications. Accordingly, we report on our experience using the navigation in lesions located to the anterior skull base in relation

Table 3 Postoperative Complications (n = 31)

Complications	No. of Cases
Early	
CSF leak	0
Meningitis	0
Frontal lobe contusion/edema	1
Optic nerve dysfunction	1
Pneumocranium	1
Late	
Cranial nerve dysfunction	
Olfactory	12
Trochlear	1
Optic	0
Diplopia	2
Epiphora	1
Frontal sinus dysfunction	2
Insufficient reconstruction	1
Secondary surgery	2

to the actual contribution. In this series, the extent and location of the lesions implied a broad exposure excluding endonasal-endoscopic procedures. The degree of the CAS contribution is highly dependent on the choice of the approach. At the frontal and ethmoidal compartment, including the intracranial cavity at this location, this aspect is, in regard to the clear and easily visualized anatomic landmarks, less significant and the indication for CAS is quite limited. Accordingly, only in rare cases, in which the anatomic configuration is distorted at this area, as manifested in only two cases in group II (i.e., an extended meningoencephalo-

cele and the congenital anomaly), the CAS contributed to a more secure dissection of the dura. In group I, the contribution of the CAS for the removal of the tumors at this specific location was not given in any of the cases.

A different situation is represented in tumors (group I) located to the sphenoclivar, parasellar and lateral extensions, as depicted in cases 1 and 2. At this complex area, the subcranial approach avoiding frontal lobe retraction provides a broad exposure by the anterior route under direct vision in all directions of the lesion borders. This includes the adjacent or involved optic nerve, chiasm, cavernous sinus, ICA, and clivus, as well as the paranasal compartments. This in contrast to other traditional approaches such as the lateral rhinotomy/Weber Fergusson, the transethmoidal access, midline splitting and further midface osteotomy modifications, which do not provide a similar direct broad exposure. Apart from damage to uninvolved intact structures, these methods often imply—particularly in tumors—a stepwise tumor resection or a piecemeal removal, to assess the posterior locations. The transfrontal, as well as the frontolateral or frontosupraorbital, approaches necessitate frontal lobe retraction and as the exposure is performed by the superior to the inferior direction, the visualization of the posterior complex is limited compared with the direct anterior subfrontal access. Using this route, exposure of the paranasal, nasal lumen, and maxillary spaces is insufficient. Using these approaches, the indication

Table 4 Contribution of the CAS System in 31 Cases

	None	Partly Helpful	Helpful	No. of Cases
Group I				
Anterior skull base tumors	8	6	5	19
Group II				
Craniofacial deformities	2	2	1	5
Extensive mucocoele	5	1		6
Meningoencephalocele			1	1
Total cases	15	9	7	31

as well as the contribution of CAS are accordingly higher. By contrast, the advantages of the subcranial approach reduced the contribution of the CAS in this series to only a limited number of cases. This included tumors effacing or enclaving the ICA, adjacent to the optic nerve/chiasm or penetrating the cavernous sinus along with an aberrative anatomic configuration including extensive clival bone resorption. The CAS attributed to a safer and more secure performance and particularly in tumor extensions toward the retromaxillary, pterygopalatine fossa, to avoid bypassing the same. In more lateral infratemporal located tumor extensions, the combined lateral or Le Fort I approaches usually provide a sufficient broad exposure.

Apart from the two cases in group I, the CAS proved helpful in a further five cases in group II with manifested distortion of the anatomic configuration of the posterior complex. In all the remaining cases at this location, the anatomic landmarks permitted optimal exposure and the CAS was practically applied after tumor removal for training and documentation purposes. Yet, a relevant contribution in terms of a more secure procedure was limited to 23% of cases. The outcome in the various categories as included in the groups I and II remained the same as in our previous series as a comparison, we refer to the literature cited. Undoubtedly, for approaches providing less broad exposure and visualization of these locations, the indication of the CAS is more intensive, to avoid unnecessary damage, permitting better orientation. Yet, in tumors or other lesions located to this complex area, the radical en bloc removal of tumor, often including the osteotomies of the involved bone, mandates a broad exposure and direct visualization of the adjacent and involved structures. The real-time position of the instrument does not provide sufficient information for these additional steps along the vital structures. The real time should not be confused with the real stage of the actual tumor removal. Accordingly, the choice of the approach and of the method at these locations is decisive for the outcome. The indications for

combined CAS should be more selective and restricted to only those cases in which a real contribution to the safety of the procedure is expected.

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