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Intraoperative Computed Tomography/Angiography Guided Resection of Skull Base Lesions

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Additional information is available at the end of the chapter

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1. Introduction

It can be said that the history of neurosurgery has been interdependent with the history of concurrent technology, making it one of the more avant garde fields of medicine. Since the advent of monopolar cautery more than one hundred years ago, neurosurgeons have been rapid to apply the most recent technological advances to intraoperative uses to make surgery safer and less invasive. Since the first brain computed tomography was done in October 1971, neurosurgeons have quickly started adapting commercially available computed tomography machines for uses in the operating room to access some of the most formidable problems in neurosurgery: skull base lesions. In fact it was only 7 years later that computed tomography was adapted for intraoperative use with neuronavigation of intracranial lesions. Early publications of CT guided surgery already demonstrated benefits of real time data integration: navigation of eloquent areas of the brain, lesion localization, maximal lesion resection, immediate recognition of intraoperative hemorrhage, improved confidence for post operative care. Much of the work done was with cortical and subcortical lesions. Early CT scanners were very large, and competed with precious limited operating space; often scanners were placed near and operating suit and not necessarily within the operating suite. This necessitated transferring patients from the actually operating suite to the CT scanner prior to the completion of the case, in essence moving patients with open surgical wounds, on full mechanical ventilation, and other calculated risks. With improved computing, CT scanners increased in resolution and decreased in size, making it possible to obtain true intraoperative computed tomography, without exposing patients to all the risks of transferring a patient.

Neuronavigation is an invaluable tool to the modern skull base surgeon. Its ubiquity allows for safer and more effective treatment of lesions in difficult regions of the skull and brain. However because of brain shift once the calvarium is open, its ubiquity has its limitations.

Several modalities of imaging have developed into intraoperative uses, each with their own advantages and disadvantages. When used correctly, these tools provide powerful real time data needed to guide decision making, direct surgical approaches, and reveal lesional remnants. For skull base lesions, soft tissue discrimination and boney anatomy are both integral and necessary to execute resection of the most formidable lesions, while preserving the brain and its cranial nerves. We illustrate the feasibility of intraoperative computed tomography (CT) and CT angiography (CTA) in the resection of different skull base lesions with the following examples.

2. Methods/Results

After the patient have undergone general anesthesia, a DORO head holder (ProMed Instruments, Freiburg, Germany) is used for head fixation, which is like the Mayfield except for radiolucent arms. The radiolucent arms are variable to fit the length of an individual's neck and are designed to fix the cranium but extend the fixation capability towards the shoulders. (Figure 1a). The shoulders are supported by the operating table, but the head and neck are suspended using the DORO head holding system to allow entrance into the CT gantry. Once a CT is warranted, the surgical field is draped with a large C-arm cover and the CT gantry is translated around the head. CT images are obtained, and reviewed within a few minutes as needed for integration into clinical management (Figure 1b).

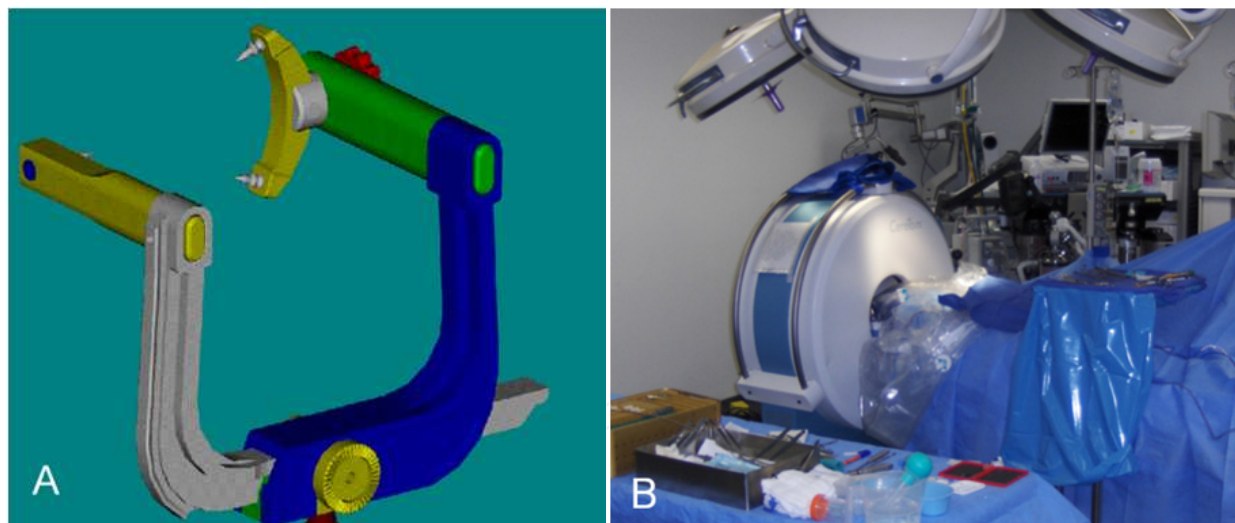


Figure 1. A. The DORO head holder is a Mayfield-type holder but with extensions that are radiolucent. B. Ceretom is translated over the patients head during surgery without moving patients.

Case 1

This patient is a 39 year old female who had noticed for at least eight years a growing hard prominence on the left side of her face. She also noted proptosis that had been getting worse for the last year accompanied by headaches that were increasing in frequency and intensity. Routine CT brain and MRI brain was consistent with an interosseous meningioma and a superficial biopsy confirmed the diagnosis. The tumor involved the left middle fossa and

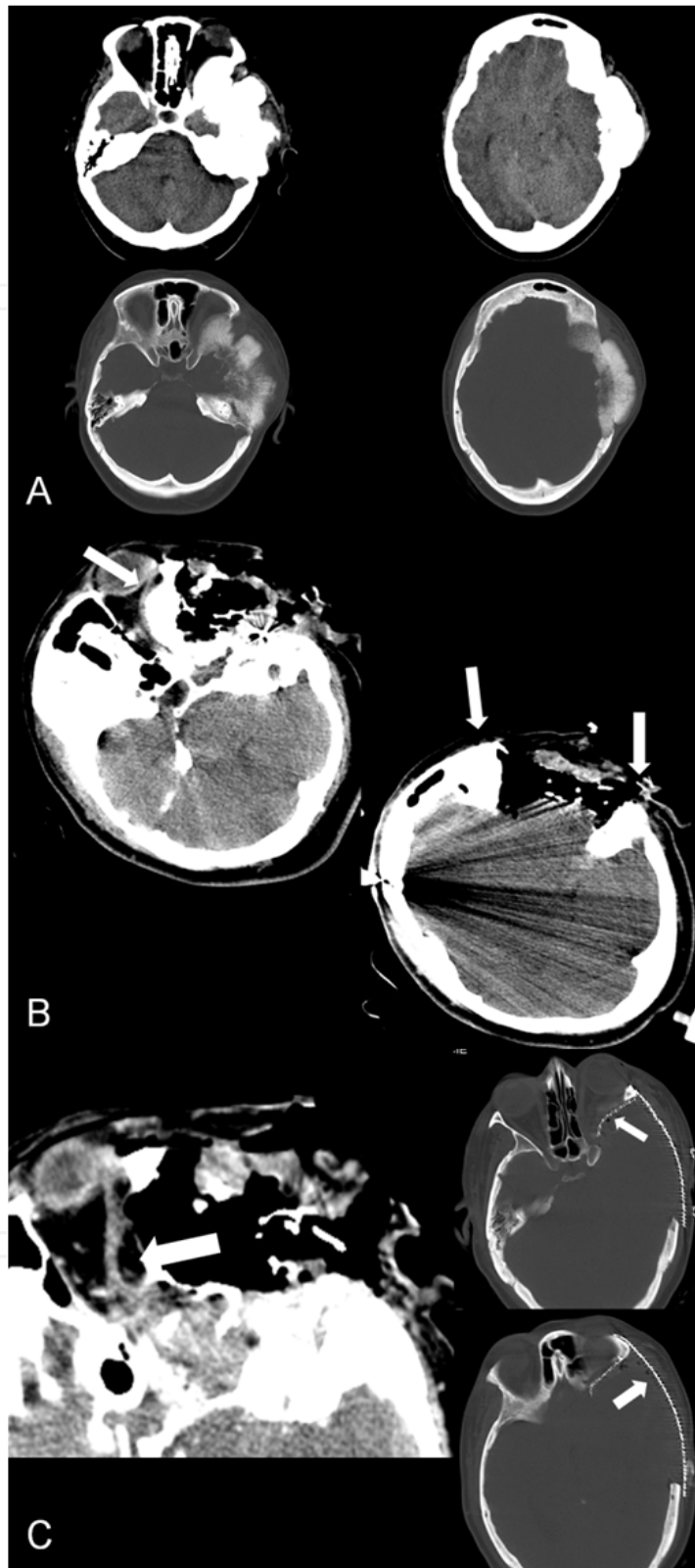


Figure 2. A. Interosseus meningioma invading the petrous temporal bone, squamous temporal bone, and lateral orbital wall. B. Intraoperative CT showing residual tumor along the lateral orbital wall and petrous apex (arrows). C. Repeat CT shows complete removal and reconstruction of lateral orbital wall and calvarium (arrows).

hyperostosis of the squamous temporal bone, the petrous temporal bone, sphenoid wing, the zygomatic process, and the lateral orbital wall.

The patient was placed in a supine position, with the head held in radiolucent arms. The interosseous meningioma in the middle fossa with 3 centimeters of extracranial extension and 2 centimeters of intracranial soft dural based tumor was directly attached (Figure 2a). A CT taken during surgery showed residual tumor along the petrous apex and it provided exact guidance on how extensively to decompress the orbital contents (Figure 2b). Once an adequate tumor removal was accomplished and validated by a second CT, the lateral orbital wall and cranial vault was reconstructed, again confirmed by CT prior to closing (figure 2c). For tumors that surgery is the primary modality of treatment and surgery can provide a cure, image guidance for total resection instead of debulking offer the best prognosis for treatment, rather than subtotal resection followed by radiation or chemotherapy. Intraoperative ct provided excellent soft tissue and bone discrimination.

Case 2

This patient is a 55 year old male with dizziness and balance problems for a year. A CT angiogram, followed by magnetic resonance imaging (MRI) of the brain, showed a left superior cerebellar arteriovenous malformation. Preoperative angiogram confirmed the lesion was a left cerebellar AVM that had multiple feeding vessels but primarily from the left superior cerebellar artery (figure 3a). The patient had undergone preoperative embolization. The next day, the patient was taken to the operating room for a left suboccipital craniectomy and resection of the AVM through a infratentorial supracerebellar approach. During surgery, a CT angiogram was obtained, which showed residual AVM just medial to the operative field (Figure 3b). The surgical approach was modified to resect the remaining lesion. Postoperative angiogram confirmed complete resection of the AVM (Figure 3c). For vascular lesions such as arteriovenous malformation, incomplete resection can lead to a delayed hemorrhage within the first 24 hours after surgery, often when the patient is in the intensive care unit leading to catastrophic results. Traditionally intraoperative angiograms are performed for these vascular lesions to ensure complete resection, however this case illustrates the technical difficulties of a prone angiogram; the femoral artery is not available to the interventionalist. Bringing a portable ct scanner provides the same information and does not require awkward positioning and technical difficulties of performing an angiogram in the prone position.

Case 3

This patient is a 63 year old male with worsening pressure-like headaches, loss of smell for six months. He was treated for frontal sinusitis but was refractory of antibiotic treatment. A CT positron emission tomography (PET) scan shows an anterior skull base tumor with invasion into the frontal sinus, through the anterior and middle ethmoidal air cells and down to the middle nasal concha.

The patient had a transnasal endoscopic biopsy which showed poorly differentiated invasive sinonasal adenocarcinoma. The patient underwent a combined transfacial and transcranial approach for tumor resection. The tumor had extended into the subfrontal

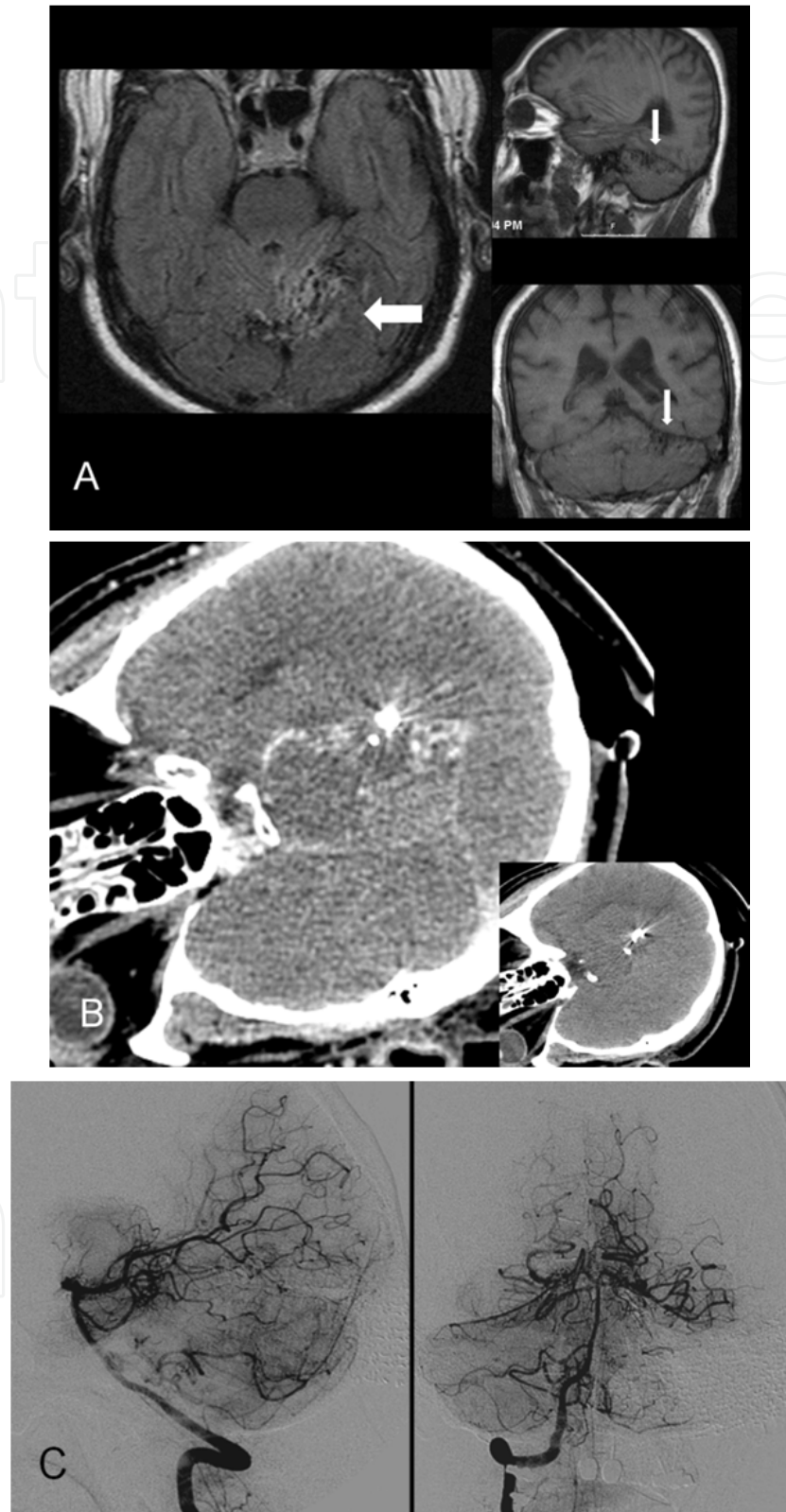


Figure 3. A. Left superior cerebellar AVM seen on T1 weighted MRI axial (left), sagittal (upper insert), and coronal view (lower insert). B. Intraoperative CT of partially resected AVM juxtaposed to preoperative embolization not visualized under microscope. C. Post operative cerebral angiogram confirms complete resection of AVM.

cortex and extended back past the middle ethmoid cells (figure 4a). After a bifrontal craniotomy, the frontal sinus was cranialized. Resection of the tumor from below allowed access to the bilateral medial orbital walls. A CT taken during surgery revealed tumor adherent to the right medial orbital wall (Figure 4b). Once the resection was

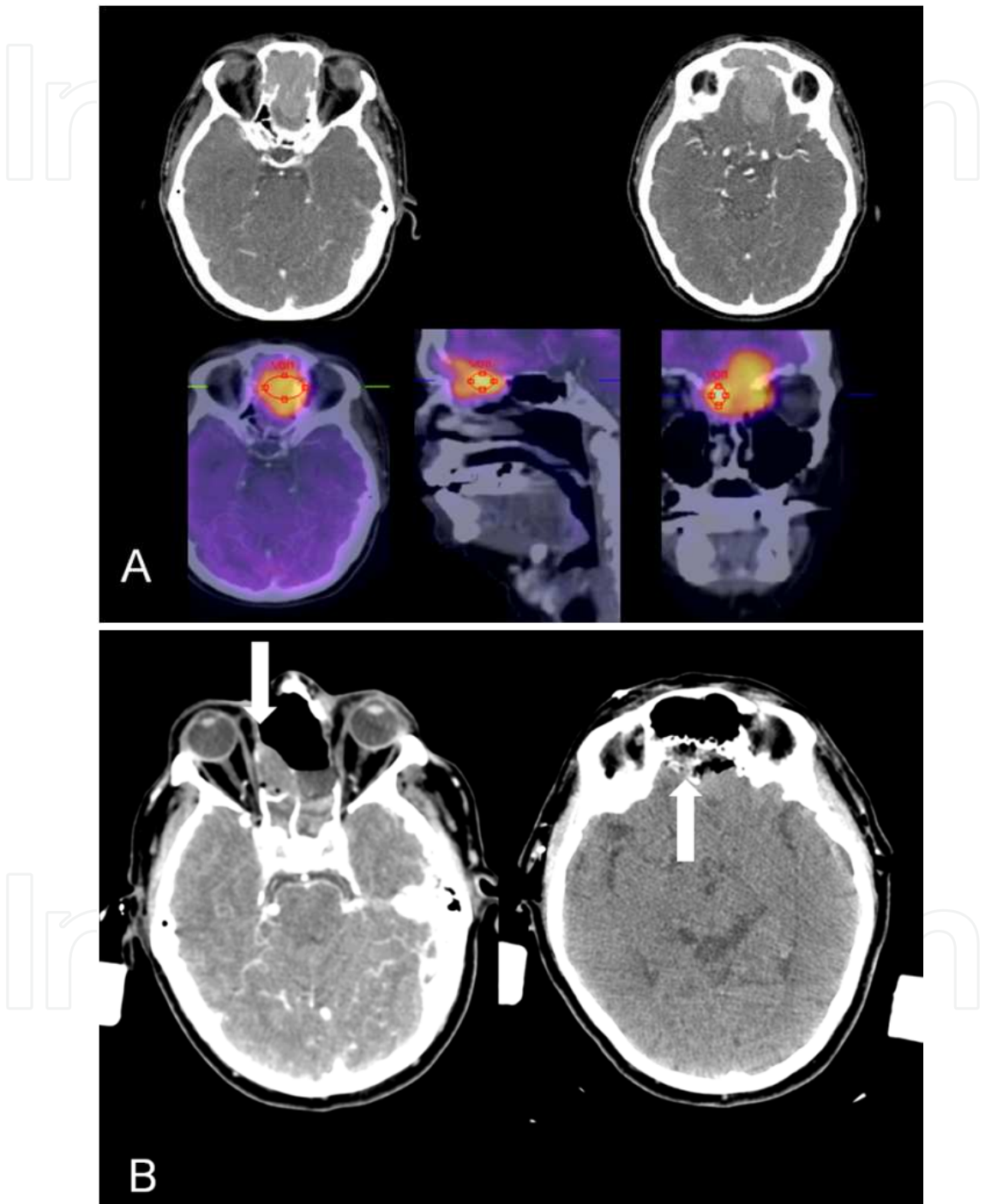


Figure 4. A Preoperative CT PET study shows tumor of anterior skull base extending down into middle nasal concha, back to posterior ethmoidal air cells, and into inferior frontal lobes. B. Intraoperative CT shows residual tumor adherent to right medial orbital wall (left), and reconstruction of anterior fossa floor with titanium mesh (right).

completed, reconstruction of the anterior fossa ensued with titanium mesh, fascia lata, and duraplasty. An aggressive resection of tumor and structural integrity of the anterior fossa reconstruction was confirmed by CT prior to closing the skin. For pathology of the skull base, reconstruction of the skull base is often technically challenging due to migration of prosthesis and brain shift. Confirming that the skull base is adequately reconstructed can prevent cerebral spinal fluid leaks leading to meningitis and devastating consequences.

The time required for obtaining intraoperative CT scans was less than 15 minutes with the data being immediately available for clinical integration. There were no complications from bring the portable CT scanner into the surgical field in each of these cases.

3. Discussion

Advancements in neuronavigation have mirrored advancements in microsurgical techniques, leading to less intraoperative and postoperative complications (1,2). This has led to smaller surgical exposures with increase accessibility to difficult regions of the head and neck. Since the early 1980's, neuronavigation systems have become ubiquitous and commonplace in the practice of neurosurgeons, ENT surgeons, and maxillofacial surgeons alike, all vying for use in the operating room (3). Many computer assisted neuronavigation systems require prescanned images, done the night before surgery, uploaded into the navigational computer at the time of surgery, and used for planning the skin incision and craniotomy. The problem with preoperative image guidance systems is that the static images become invalid once the cranium is open, CSF is lost and or a portion of the tumor mass is removed. Ultimately, the limitations with these neuronavigational systems is that they cannot adjust to brain shifts and lead to gross errors in anatomical localization, in addition to the inherent error that already exists in fiducial registration. Hence, the need for intraoperative imaging for real time evaluation becomes paramount.

Intraoperative MRI has the advantage of obtaining real time data, providing excellent soft tissue discrimination and allows the surgeon to accommodate to brain shift during surgery. However the feasibility of intraoperative MRI is still being determined with increasing medical costs (4). Existing surgical suites have to be retrofitted to accommodate the intraoperative MRI; specialized nonferromagnetic instruments must be used, and accessibility to the patient is limited by the MRI machine itself. For large intraoperative MRI, patient has to be moved in and out of the scanner during surgery (5). Smaller machines directly translate over the patient, restricting surgeon access to the surgical field.

Intraoperative 3D ultrasound technology has also found its use in the operating room. Ultrasound imaging allows for real time data requisition and does not require special instruments, but traditionally low quality images and cumbersome equipment has limited its uses. Recently, high quality ultrasound has made the image quality better but it is still cumbersome to use, requiring complete hemostasis of the field, distortion of the image the

further away you are from the wand, and requires a high learning curve for correlating surgical anatomy and ultrasound images (6).

Intraoperative CT technology was initially used in the 1980's but its reluctant use was due to radiation exposure, long scan time, and maneuverability in the operating room (Lunsford). For skull base pathology, the localization and removal of bone elements is vital to the success of the operation in order to minimize retraction of delicate neural structures. It is then critical that neuronavigation for these lesions include not only show soft tissue and vascular discrimination but also boney elements as well. This is the advantage of CT over MRI and Ultrasound.

The CereTom portable CT scanner (Neurologica, Danvers, Mass) has many advantages. It is small, compact, and can move freely in and out of operating suites. It does not require specialized equipment to use with the exception of a radiolucent arms and head holder and does not require retrofitting into existing OR suites. It has scanning capabilities that allow for multiple windowing, high resolution contrasted study for soft tissue discrimination, CT angiography, and 3-D rendering capabilities. Opponent of this technology point out the risk of radiation exposure, but Butler et al showed that actual risk is quite low (7). Radiation dose report for our institutional 64 slice CT scanner is approximately 68 mGY per routine 5 mm slice head CT. Radiation report from our portable scanner is 41mGY for low dose 5 mm slice head CT, and 117 mGY for high resolution 1mm slice head CT. Most of the intraoperative scanning required for even the deepest lesions is the lower resolution scan, a 27 mGY less than our traditional CT scanner. The higher dose/resolution scans are used for intraoperative CT angiography, reserved for vascular lesions, judiciously used because the cost of untreated vascular lesion is dire. Although no study has been done to assess the amount of total radiation exposure for any given patient with a skull base lesion, we have not increased the amount of CT scans obtained postoperatively since the use of the portable CT scanner. It would seem that the benefits of accomplishing what was intended in the operating room outweigh any theoretical and relatively small risk of radiation.

The risk of intraoperative CT cannot be weighed against the potential risk of injuring delicate neural structures along the complex skull base, leaving tumor/AVM residual leading to postoperative bleeding, or morbidity and cost of repeat surgery to the patient and the institution. Although no cost analysis has been performed specifically for intraoperative CT guidance, we know that intraoperative guidance with MRI reduces length of stay by 55% for patients with initial surgery versus traditional surgery, repeat surgery rates were much lower with intraoperative guidance and, and total overall hospital costs was a 46% lower for initial surgery versus traditional surgery and 44% lower for repeat surgery (8); it is possible that intraoperative CT can do the same. We have used the portable CT scanner for imaging convexity tumors, gliomas, intraventricular tumors, confirmation of ommaya reservoirs and shunt placement. Prior to closing the surgical wound, a CT is done for final confirmation; this obviates the need to perform post operative CT imaging, saving a transport of the

patient to the traditional CT scanner and minimizing risk to the patient, especially for critically ill patients and those needing mechanical ventilation.

4. Conclusion

These cases illustrate the feasibility of using intraoperative CT scanner during resection of skull base lesions. Windowing of already familiar CT images provide excellent soft tissue and bone discrimination. It can also provide CT angiogram data for evaluation of vascular lesions without the inherent risks of a conventional angiogram. Valuable real-time information is available without the need to move patients during surgery, guide decision-making for gross total resection and avoid reoperation for the removal of tumor remnants.

Author details

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