ORIGINAL ARTICLE

Comparison of Intraoperative Portable CT Scanners in Skull Base and Endoscopic Sinus Surgery: Single Center Case Series

**David B. Conley, M.D.,[1] Bruce Tan, M.D.,[1] Bernard R. Bendok, M.D.,[2,3]
H. Hunt Batjer, M.D.,[2] Rakesh Chandra, M.D.,[1] Douglas Sidle, M.D.,[1]
Rudy J. Rahme, M.D.,[2] Joseph G. Adel, M.D.,[2] and Andrew J. Fishman, M.D.[1,2,4]**

ABSTRACT

Precise and safe management of complex skull base lesions can be enhanced by intraoperative computed tomography (CT) scanning. Surgery in these areas requires real-time feedback of anatomic landmarks. Several portable CT scanners are currently available. We present a comparison of our clinical experience with three portable scanners in skull base and craniofacial surgery. We present clinical case series and the participants were from the Northwestern Memorial Hospital. Three scanners are studied: one conventional multidetector CT (MDCT), two digital flat panel cone-beam CT (CBCT) devices. Technical considerations, ease of use, image characteristics, and integration with image guidance are presented for each device. All three scanners provide good quality images. Intraoperative scanning can be used to update the image guidance system in real time. The conventional MDCT is unique in its ability to resolve soft tissue. The flat panel CBCT scanners generally emit lower levels of radiation and have less metal artifact effect. In this series, intraoperative CT scanning was technically feasible and deemed useful in surgical decision-making in 75% of patients. Intraoperative portable CT scanning has significant utility in complex skull base surgery. This technology informs the surgeon of the precise extent of dissection and updates intraoperative stereotactic navigation.

KEYWORDS: Intraoperative imaging, portable scanners, skull base surgery, meningioma, acoustic neuroma

Precise and safe management of complex skull base and craniofacial lesions can be enhanced by intraoperative radiologic imaging which can be utilized to determine the extent of a resection, assess integrity of critical structures, and update the anatomy of the surgical field. Traditionally, image guidance has been based on preoperative scans. With intraoperative scanning, anatomic landmarks can be updated to image guidance systems in real time. Several portable computed tomography (CT) scanners are currently available. We present a comparison of our clinical experience with three distinct portable scanners in lateral and anterior skull base surgery. Pros and cons of each system are detailed.

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[1] Departments of Otolaryngology, [2] Neurological Surgery, and [3] Radiology, Northwestern University Feinberg School of Medicine, Chicago; [4] Hugh Knowles Foundation, Center for Communicative Sciences and Disorders, Northwestern University, Evanston, Illinois.

Address for correspondence and reprint requests: Andrew J. Fishman, M.D., Northwestern University Feinberg School of Medicine, Chicago, IL 60611 (e-mail: ajfishman@mac.com).

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Intraoperative CT has become feasible with the development of several compact, portable systems that can be used in the operating room. Currently, intraoperative CT scanners utilize one of two major technologies: the traditional multidetector CT (MDCT) scanner that utilizes a fan-shaped beam of X-rays detected by an array of multiple detectors, or the newer cone-beam CT (CBCT) scanners that utilize a conical-shaped X-ray beam which is detected on a single two-dimensional (2-D) flat panel detector.[1,2] In CBCT, a single rotation of the radiation source captures the entire region of interest, as compared with MDCT devices where multiple slices are stacked to obtain a complete image.[1,3] These differences make MDCT and CBCT fundamentally different technologies with individual advantages and drawbacks.

Generally, the CBCT is able to provide excellent resolution at high contrast tissue interfaces and provides sub-millimeter details of bony structures at decreased cost, with decreased radiation exposure and decreased artifact scatter in the presence of metallic objects when compared with MDCT.[2] These advantages have made CBCT a valuable tool in perioperative planning for orthodontic, spine, sinus, and temporal bone surgery.[3–9] In sinus surgery, intraoperative CBCT was found to be a useful tool altering the surgical plan in 30% of cases.[5] Unlike the CBCT, the MDCT is able to produce better resolution of soft tissue that can be further enhanced by the use of intravenous contrast. Furthermore unlike CBCT, the MDCT is theoretically not limited by the size of the flat panel detector and can scan a larger field of view. Reported applications of the portable MDCT have thus far included intraoperative applications in head and neck surgery and point of care scanning for patients in the intensive care unit (ICU).[10,11] This series details the utility of this technology during skull base and craniofacial surgery.

MATERIALS AND METHODS

This is a retrospective case review of 12 patients. An IRB exemption was granted. All patients were operated at Northwestern Memorial Hospital between July 2008 and September 2009. Three scanners were evaluated including one conventional (MDCT) CT and two flat panel (CBCT) devices.

The scanners were compared on the basis of size and dimensions; spatial resolution; imaging characteristics; ease of integration with image guidance systems; and radiation dose.

Clinical data collected included lesion; surgical approach; scanning system; method of fixation; navigation system; reference array; navigation instrumentation and technique; number and timing of scans; surgical outcome; specific utility of imaging; and shortcomings.

RESULTS

The scanners evaluated were the Xoran xCAT® (Xoran Technologies Inc., Ann Arbor, MI), Medtronic O-ARM® (Medtronic Inc., Minneapolis, MN), and NeuroLogica CereTom® (NeuroLogica Corporation, Danvers, MA). Table 1 details the physical characteristics and technical specifications of the scanners. Due to the inherently different nature of radiation (CBCT and MDCT combined with the different preprogrammed protocols utilized for scanning patients) direct

Table 1 A Comparison of Technical Features of Three Portable CT Scanners

Manufacturer	Neurologica Ceretom*,†	Xoran Xcat‡,§	Medtronic O-ARM**,††
Physical dimensions	60.3 in (1530.7 mm) × 52.7 in (1337.5 mm) × 28.7 in (728.7 mm)	32 in (812.8 mm) × 47 in (1194 mm) × 60 in (1524 mm)	79.6 in (2022 mm) × 32.0 in (813 mm) × 98.1 in (2490 mm)
Effective bore size	12.5 in (318 mm)	16 in (412 mm)	38 in (965 mm)
Weight	800 lb (362 kg)	520 lb (236 kg)	1950 lb (885 kg)
Technology	Eight-slice multisectional CT scanner	Cone-beam CT scanner	Cone-beam CT scanner
Detector	Eight 1.25-mm wide detectors	Single volumetric flat panel	Single volumetric flat panel
Scanning parameters	140 kV, 7 mA	120 kV, 6 mA	150 kV, 10 mA
Scan time	2–6 s/rotation	20 s	25 s
Recon output	512 × 512	640 × 640	512 × 512
Axial section thickness	0.625–10 mm	0.4 mm	0.83 mm
Radiation dose	In head CT mode	In typical sinus CT	Head scan in HD3-DCT mode
Absorbed dose (mGy)	24.7	9.7	21.25
Effective dose (mSv)	1	0.41	0.73
Chest X-ray equivalents	25	10	18

*NeuroLogica® Inc. CereTom® features and dimensions. Available at: http://www.neurologica.com/ceretom.html. In; 2009.
†Personal Communication Chen JF. Northwestern Hospital Physics Test on CereTom® portable CT Model #:NL3000. In; 2009.
‡Personal Communication Xoran Technologies® Inc. In; 2009.
§Xoran Technologies® Inc. xCAT® ENT Technical Specifications. Available at: http://www.xorantech.com/contentHTML/xcatent_tech-specs.php. In; 2009.
**Medtronic. O-ARM® Complete Multidimensional Surgical Imagin System Technical Guide. In; 2007.
††Medtronic. O-ARM® Complete Multidimensional Surgical Imaging System Dosimetry Report Summary July 2008.

comparisons of the radiation doses administered by the various scanners is difficult; but we have provided information based on manufacturer information and internal testing using settings that would typically be utilized for intraoperative scanning. In general, the MDCT based Ceretom administers a higher absorbed dose per scan than the CBCT. Among CBCT models, the Medtronic O-Arm administers a higher absorbed dose relative to the Xoran xcat, probably secondary to the larger bore utilized.

The O-Arm was used in five lateral and one anterior skull base procedures. The Ceretom was used in two complex frontoethmoid sinus procedures, one pituitary tumor, one complex maxillary sinus lesion, and one clival lesion. The Xoran xcat was used in a single complex revision frontal sinus procedure (Table 2).

The additional amount of time required for set up and acquisition of scanning was ~20 minutes per scan once a routine was established. We found it helpful to position the scanner at the beginning of the procedure before sterile prep and drape and after placement of monitoring systems and image-guidance reference array. Adjustments could then be easily made in patient position to accommodate the machinery.

Highlights, utilities, and shortcomings of each case are detailed:

Case 1: Sphenoid Wing Intraosseous Meningioma

O-Arm scan was automatically registered using FrameLock® (Medtronic Xomed Inc., Jacksonville, FL), a fixed reference array directly secured to calvarium after flap elevation. This resulted in extreme accuracy to bony landmarks when compared with visualized landmarks. Drilling was facilitated by registering a drill tip to the image guidance system. The technique allowed for safe and complete removal of bone near the orbital apex with good cosmetic result and preservation of cranial nerve function. Completeness of excision and ultimate placement of a reconstruction cranial prosthesis were also well confirmed with a completion scan (Fig. 1).

Shortcomings included the inability to clearly distinguish the PEEK Optima-LT™ (Synthes Inc., West Chester, PA) material of the reconstruction prosthesis due to its radiolucency; however, proper position was gauged by symmetry of orbital contents. This early case in the series required significant additional time to adjust operating room and table position to accommodate the scanner.

Case 2: Glomus Jugulare

Intraoperative O-Arm imaging was used to detect position of the petrous segment of the carotid artery, jugular tubercle, and completeness of dissection by placement of a radiolucent marker in the operative field. Three-dimensional (3-D) reconstruction of the skull and marker at the point of dissection were analyzed on the O-Arm station without the need to transfer to the stealth system.

Shortcomings included difficulty when attempting automatic merging with a preoperatively obtained stealth magnetic resonance imaging (MRI) on the TREON™ StealthStation® (Medtronic, Minneapolis, MN). This was ultimately abandoned as essential information could be obtained by analysis of the O-Arm postdissection 3-D reconstructions alone. Cranial nerves and hearing were preserved.

Case 3: Intratemporal Arachnoid Cyst of Petrous Apex

This patient underwent drainage and fat obliteration of a complex petrous apex intratemporal arachnoid cyst. Intraoperative O-Arm image confirmed relative location of lesion to critical surrounding anatomy. In this particular case; however, a preoperatively obtained high-resolution stealth CT would ultimately have accomplished similar utility. Additionally, large body habitus did require significant additional time to readjust headframe to allow for centering of the image in this patient. The outcome was symptomatic relief of headaches with transient trigeminal neuralgia relieved with corticosteroids by 2 months postoperatively.

Case 4: Retrolabyrinthine Resection of Vestibular Schwannoma with Hearing Preservation

Intraoperative O-Arm image was taken to assess the extent of internal auditory canal exposure. Cross-sectional images were analyzed on the O-Arm station which revealed near complete exposure of internal auditory canal with anatomic preservation of vestibule and posterior semicircular canal. This technology facilitated the dissection and execution of a novel approach of retrolabyrinthine removal of an acoustic neuroma with hearing preservation. Hearing was preserved and facial function was normal (Fig. 2).

Case 5: Neurofibromatosis Type 2 with Foramen Magnum Schwannoma

Use of intraoperative O-Arm was aborted due to the large body habitus of the patient and concern that lateral position would not be well supported by the available radiolucent headframe. The patient underwent complete excision without neurologic complications.

Case 6: Chronic Rhinosinusitis

Intraoperative CT scanning with the Ceretom identified a retained posterior ethmoid cell at the completion of

Table 2 Results of Clinical Case Series

Case	Lesion	Approach	Scanner	Fixation	Navigation System	Navigation Reference Array	Navigation Instrumentation and Technique	Initial	Post dissection	Completion	Scans (*n*)	Outcome	Utility of Scanner	Shortcomings
1	Intraosseous meningioma of sphenoid wing	Peritoneal/ OZ	O-Arm	Radiolucent pins	Treon stealthstation—realtime	Framelock to calvarium	Probe locator and referenced drill		X	X	2	Total removal, good cosmetic result, vision intact, EOM intact	Delineation of residual pathology after initial dissection; distinguished neurovascular canals within pathologic bone; real-time navigation near critical neural structures; morphologic assessment of adequacy of reconstruction; very accurate auto registration	Unable to visualize Peek optima-lt material due to radiolucency; time-consuming readjustments of table to O-Arm position in order to obtain adequate scan
2	Glomus jugulare	Transtemporal	O-Arm	Radiolucent horseshoe	O-Arm monitor 3-D recon Osirix 3-D Treon stealthstation MRI	Framelock transcutaneously applied but not used	Location assessed with placement of radio opaque marker offline transfer of 3-D reconstruction to Osirix on laptop	X	X		2	Planned partial removal, resolution of infections, hearing unchanged, cranial nerve function preserved	Readily assessed extent of bone removal toward carotid canal; radio opaque marker clearly delineated extent of tumor removal relative to jugular tubercle	Auto merge with stealth MRI highly inaccurate; manual merge of questionable accuracy and time-consuming; initial scan and MRI merge not practical due to technical considerations
3	Giant intrapetrous arachoid cyst	MCF/Kawasi	O-Arm	Radiolucent pins	Treon stealthstation	Fixed reference array on head frame	Probe locator	X			1	Drainage and fat obliteration, relief of symptomatic HA, transient trigeminal neuralgia	Confirmation of anatomic landmarks; would probably have been more useful if lesion were soft tissue and not cystic	Preop stealth CT would have been sufficient in this case; needed to reorient radiolucent pins in order to accommodate O-Arm
4	Vestibular schwannoma	Retrolabyrinthine	O-Arm	Radiolucent pins	None	None	Assessment of postdissection residual bone only; additional dissection performed based on measurements from visual inspection; real-time navigation not performed		X		1	Complete removal, hearing preserved, facial nerve HB grade I	Extent of internal auditory canal dissection clearly delineated; extent of dissection relative to vestibule clearly delineated; facilitated hearing preservation for novel approach	Decision made not to navigate in real time considered too cumbersome and time-consuming from prior experience to stealth drill in this case requiring delicate dissection
5	NF2 foramen magnum schwanomma	Far-lateral in lateral position	O-Arm	Conventional Mayfield pins	None	None	None				0	Total removal	n/a	Inability of the scanner to accommodate the patient due to body habitus and lateral decubitus position

Table 2 (*Continued*)

Case	Lesion	Approach	Scanner	Fixation	Navigation System	Navigation Reference Array	Navigation Instrumentation and Technique	Initial	Post dissection	Completion	Scans (*n*)	Outcome	Utility of Scanner	Shortcomings
6	CRS	FESS	Ceretom	Radiolucent headrest	LandmarX stealth	eNV passive array	eNV suction probe		x		1	Complete frontal, ethmoid dissection	Helpful in identifying a posterior ethmoid cell	Blood and remaining soft tissue difficult to differentiate
7	CRS with nasal polyps	FESS	Ceretom	Radiolucent headrest	LandmarX stealth	eNV passive array	eNV suction probe		x		1	Complete frontal, ethmoid dissection	Helpful in opening a complex frontal ethmoid cell	Blood and remaining polyps difficult to differentiate
8	Pituitary Tumor	Transsphenoid	Ceretom	Radiolucent headrest	LandmarX stealth	Pins with passive array, removed for the scan	eNV passive probe		x		1	Resolution of peripheral visual field loss.	Identified small focus of residual tumor	Required removal of neurosurgical pins and image guidance array
9	Lesion of clivus	Endoscopic	Ceretom	Radiolucent headrest	LandmarX stealth	eNV passive array	eNV suction probe				0	Good resection of the lesion	None	Failed to obtain planned scan due to patient's kyphosis and inability to fit in the bore of the scanner
10	Frontal recess stenosis	Endoscopic	Xcat	Radiolucent headrest	LandmarX stealth	eNV passive array	eNV suction probe		x		1	Complete removal of soft tissue and bone fragments	Helped identify all bone fragments for removal	None
11	Giant osteoma of orbit, frontal sinus, and skull bas	Endoscopic and transorbital	O-Arm	Radiolucent pins	LandmarX stealth	eNV passive array	eNV probes		x	x	2	Complete removal of osteoma, no CSF leak	Identified skull base with very accurate automatic registration of image guidance	Size of scanner and time arranging the room to accommodate it
12	Dentigerous cyst—maxillary sinusitis	Endoscopic	Ceretom	Radiolucent headrest	LandmarX stealth	eNV passive array	eNV probes			x	1	Complete curettage of cyst	Ability to confirm completion of cyst marsupialization despite inability to endoscopically visualize	None

CT, computed tomography; CRS, chronic rhinosinusitis; CSF, cerebrospinal fluid; EOM, extraocular muscles; FESS, functional endoscopic sinus surgery; MCF, middle cranial fossa; MRI, magnetic resonance imaging.

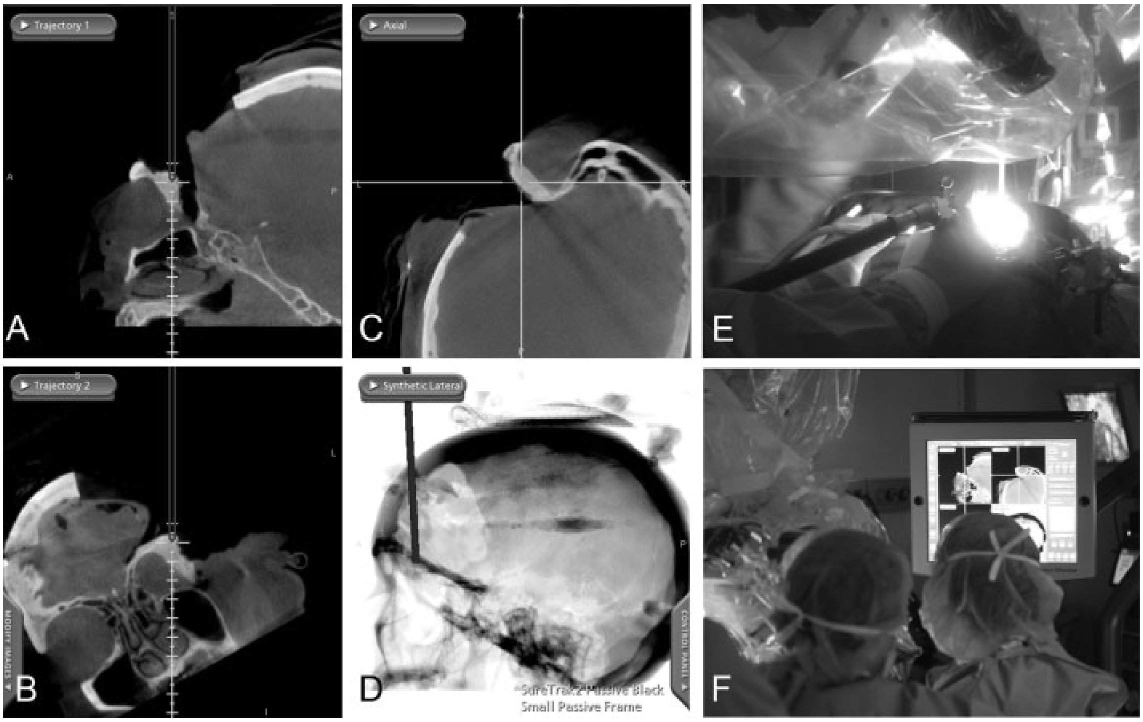

Figure 1 Orbital meningioma (Case 1). Real-time navigation from O-Arm intraoperative scan. Three plane screen capture from Treon Stealthstation reveals referenced drill tip position. Drill was registered with reference array. This technique requires a skilled assistant to ''copilot'' the surgeon using the microscope. The ''copilot'' must give verbal feedback to the operator using the microscope as there is no integration between the navigation and the view from the operating microscope.

functional endoscopic sinus surgery (FESS) that was not obvious when relying on preoperatively based image guidance alone. However, once visualized by intraoperative CT, it was still difficult to differentiate the retained ethmoid from pooled blood in the operative field. Outcome of surgery was complete and uncomplicated frontal and ethmoidal dissection.

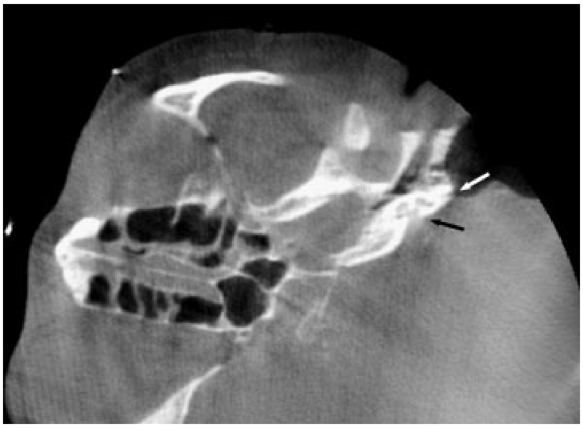

Figure 2 Retrolabyrinthine acoustic neuroma (Case 4). O-Arm scan taken after dissection of internal auditory canal via retrolabyrinthine approach. White arrow shows ''blue lined'' posterior semicircular canal. Black arrow shows small amount of bone at fundus remains. This scan allowed the operator to safely remove an additional small ridge of bone to achieve near complete exposure of internal auditory canal without violation of vestibule and hearing apparatus.

Case 7: Chronic Rhinosinusitis with Nasal Polyposis

The Ceretom provided updated CT scan images during dissection of a complex frontoethmoid cell and confirmed completeness of bone resection. However, it was difficult to differentiate remaining polyps from pooled blood. Outcome of surgery was complete with uncomplicated frontal and ethmoidal dissection.

Case 8: Pituitary Tumor

This Ceretom scan identified a small focus of residual pituitary tumor at the completion of the resection. This was possible due to the soft-tissue differentiation capability of a conventional (MDCT) CT scanner (Fig. 3). Shortcomings included the need to remove the neurosurgical pins and image guidance array before scanning. Outcome of surgery was excellent with resolution of peripheral visual field loss.

Case 9: Clival Tumor

An attempt to use the Ceretom to image the extent of clival resection failed due to the patient's body habitus

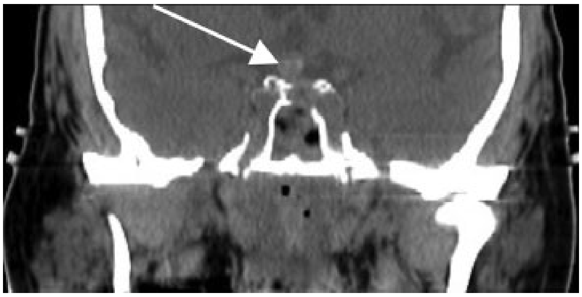

Figure 3 Pituitary tumor (Case 8). Ceretom intraoperative image from Case 8 depicting residual pituitary tumor after dissection (white arrow).

and kyphosis. The patient's head could not be brought in line flush with the headrest and thus exceeded the bore diameter of the scanner.

Case 10: Frontal Recess Stenosis

The Xoran xcat helped confirm the removal of small bone fragments in this revision frontal sinus procedure (Fig. 4). Note the metallic head image guidance reference array did not require removal for the scan, as flat panel devices do not generate large amounts of artifact.

Case 11: Giant Osteoma of Orbit, Frontal Sinus, and Skull Base

The intraoperative images acquired by the O-Arm were used to update the image guidance system during the resection of a giant osteoma of the anterior skull base. The O-Arm automatically registers the head reference array at the time of scan acquisition with direct data transfer to the Medtronic LandmarX image guidance system (Medtronic Inc., Minneapolis, MN). This provided image guidance with highly accurate tracking (Fig. 5).

Shortcomings of this early case included significant time required to arrange room to accommodate the large size of the scanner. Outcome was complete removal without cerebrospinal fluid leak or orbital injury.

Case 12: Dentigerous Cyst

The Ceretom scan confirmed successful curettage of a dentigerous cyst that arose at the floor of the maxillary sinus. The procedure was accomplished using angled curettes passed through a middle meatal antrostomy under 70-degree telescopic visualization and stereotactic navigation. The location of the cyst precluded direct visualization, and the Ceretom confirmed when the lesion was adequately marsupialized and the procedure should be terminated.

DISCUSSION

Advances in intraoperative CT hold great promise for the field of skull base surgery. Our preliminary experience suggests many benefits, but also illustrates challenges and opportunities that need to be addressed to facilitate better integration of these technologies into skull base operations.

While the technique described generates images in a similar manner as routine image guidance performed from presurgical images, it should not be viewed simply as an enhancement of this technique. The decision to use intraoperative imaging has to weigh the additional time and trained manpower required for setup and execution with consideration of the enhancement this technology can deliver. An argument can be made that the additional time spent in setup is recaptured by the efficiency of an improved surgical execution. The greatest utility of intraoperative CT scanning involves cases in which the extent of bony resection is critical to the successful

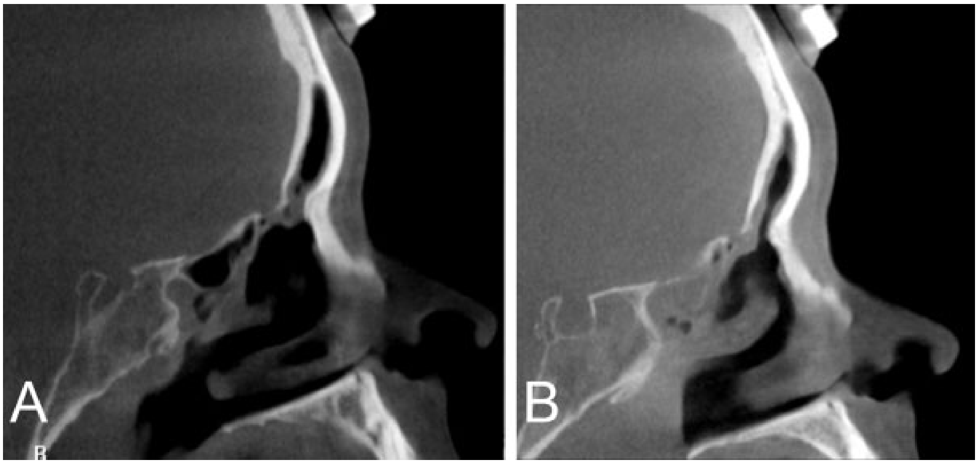

Figure 4 Revision frontal sinus recess (Case 10). Xoran xcat images from Case 10 before (A) and after (B) revision frontal sinus balloon dilatation and dissection of the frontal recess. Note the limited amount of artifact from the metallic head reference array.

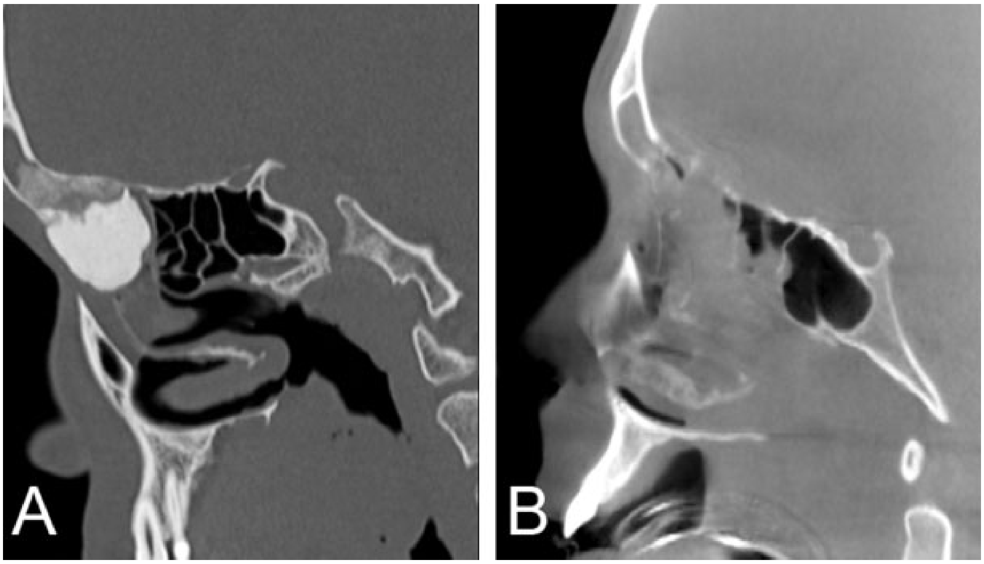

Figure 5 Giant osteoma (Case 11). (A) Conventional stealth CT and (B) intraoperative O-Arm CT demonstrating complete removal of osteoma with preservation of the skull base. This precise resection was facilitated by the high accuracy of the integrated intraoperative registration with image guidance system.

outcome of the operation. The case discussions we have provided are generally illustrative of this surgical need. While conventional image guidance can approximate this by sweeping the probe across the dissection bed, the operator must still update the changes in anatomy mentally. Obtaining an updated image reveals the highest level of detail reflecting the current extent of dissection. Additionally, the measurement tolerances of conventional image guidance may be too great for the surgical precision required in cases of this nature. Another theme that emerged is the application of intraoperative imaging in assessing the placement and contour of reconstruction hardware as illustrated in the case of the intraosseous meningioma. We could also envision this technology being applied for managing complex facial fractures and the reconstruction of congenital craniofacial anomalies.

The physical size of the machines described in this paper varies substantially, which impacts the arrangement and physical constraints of the operating environment. When using the largest scanner, the O-Arm, the room size may become a limiting factor. Conversely, we have found that the 12.5-in bore diameter of the NeuroLogica Ceretom could not accommodate a patient with kyphosis and may also be limited by fixation systems larger than the bore diameter. Another requirement for successful use of the Ceretom is related to the method that the Ceretom uses to move across the imaged field during the scan acquisition. The device rolls across the floor during the scanning to acquire length of the field imaged. Therefore, a flat and even floor surface is critical for acquisition of images without "motion" artifact. The flat panel scanners do not have this requirement as the images are acquired on a single rotation of the detector plate and the devices are parked in a fixed position during scan acquisition.

In the case of pituitary tumor resection, the Ceretom was selected specifically for its superior ability to resolve soft tissues. Intravenous contrast may also be used with this type of conventional scanner to further enhance soft tissues. The O-Arm and Xoran xcat provide high resolution bone imaging which is inherent to the flat panel technology. In addition, these flat panel devices do not suffer from large scatter artifact due to metal objects in the operative field. As a result, the reference arrays for image guidance can be left in place during the scan with these two devices as long as they physically fit in the scanner's bore. Finally, the O-Arm automatically integrates and registers the reference array with the updated CT scan. This process is efficient and highly accurate.

It is important to be aware of the radiation doses delivered by these devices. Overall, there is a significant difference in the effective radiation dose from flat panel scanners compared with conventional scanners. Although the particular scanning protocols may vary between devices and applications, the flat panel devices generally emit lower levels of radiation. However, the conventional MDCT scanner, which can provide superior soft-tissue differentiation, can also be operated at lower radiation levels. When so doing, they can provide images comparable to the flat panel devices providing good bone window detail (Fig. 6). Moreover, the conventional MDCT scanner is also used in our neurosurgical ICU for patients unstable for transport. The soft-tissue imaging capabilities of MDCT would be a useful in a trauma center. On the other hand, having the largest bore size, the O-Arm may be more practical for

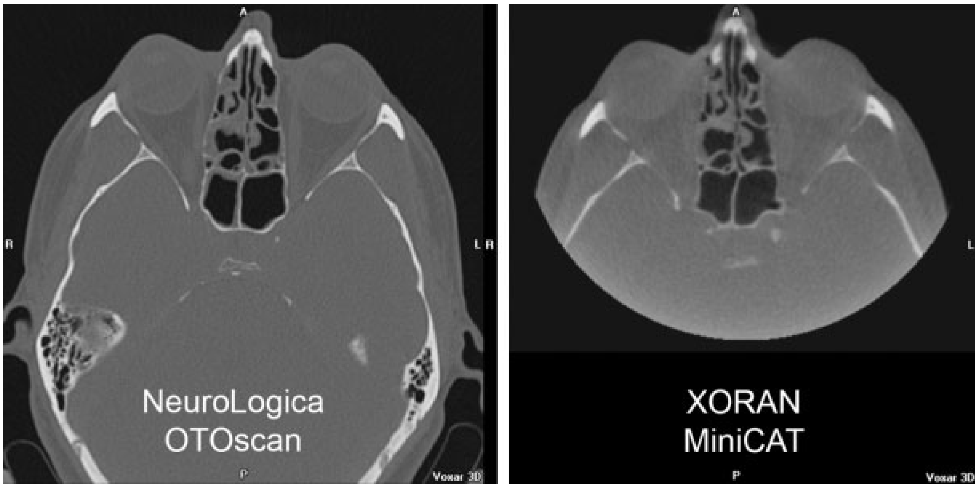

Figure 6 Comparison: Conventional scanner (MDCT) to flat panel scanner (CBCT). Head to head comparison of the NeuroLogica OTOscan conventional (MDCT) CT and the Xoran minicat flat panel scanner. This subject was scanned at the same 0.4 rad dose in each scanner. Images are set at window/level 4000/700. (These images are provided courtesy of Rob Smith, NeuroLogica.)

open lateral cranial base procedures with complex surgical fields. It will easily accommodate the Framelock fixed to the calvarium.

Unlike anterior skull base surgery, the use of intraoperative image guidance has only recently gained popularity in the field of lateral skull base surgery. There are restrictions on the type of head reference array that can be used in lateral approaches since the strap on these types of devices cross over the surgical field. Currently, solutions for this include pins with a reference array, or bone-anchored reference arrays. Another limitation in these patients has been the lack of integration of the navigation systems and the operating microscope. In our case series, intraoperative CT significantly facilitated three of the four cranial cases. The ability to navigate the drill near the orbital apex and check the final position of the reconstruction of orbital volume was a distinct asset to the final outcome and quality of the resection of the sphenoid wing meningioma (Case 1). The intraoperative scan was used to facilitate a novel approach (retrolabrynthine) to acoustic tumor removal by precisely delineating the extent of bony removal vis-à-vis the needed exposure. This would have been less certain, by standard means of caliper estimation. More confidence can be achieved by visualization of completeness of dissection than by factoring in the known error of registration to predissection scans.

Use of the intraoperative scanner was not possible in two of our cases. In both cases, the images were expected to augment the surgeon's ability to assess completeness of resection (cases 5 and 9). These cases highlight significant limitations of the intraoperative CT technology.

In one of these cases, use of the O-Arm was impossible secondary to morbid obesity, which precluded safe positioning of the patient in a decubitous position with the radiolucent headframe in place (Case 5). Another patient could not be properly placed into the Ceretom, secondary to the patient's kyphosis (Case 9) and the unit's bore diameter units, which is the smallest of the available intraoperative scanners. In one additional patient with a petrous apex cystic lesion, the intraoperative CT images were not considered advantageous when compared with the preoperative high resolution images, which anatomically localized the lesion. Should the lesion have required more extensive dissection, however, then the utility of a second intraoperative scan would most likely have been increased. Therefore, in the present series, intraoperative CT scanning was technically feasible and deemed useful in surgical decision-making in 9/12 (75%) of patients.

CONCLUSION

All three scanners, utilized in our case series, provide good quality bone window images that can also be used to update image guidance. The O-Arm integrates the Medtronic optical registration with the scanning process, thus significantly improving image guidance accuracy. The O-Arm's large bore accommodates a larger surgical field and was therefore selected for our open cranial and lateral skull base procedures. The Ceretom conventional (MDCT) CT is unique in its ability to resolve soft tissue. For this reason, it was selected for intraoperative evaluation of completeness of nonosseous tumor resection. The Xoran xcat has the smallest footprint of the three evaluated, is easily positioned, and has an effective bore size 3.5 in larger than Cereom.

The utility of these scanners may be limited by dimensions of surgical field, morbid obesity, kyphosis, patient position, and operating room size. In this series, intraoperative CT scanning was technically feasible and deemed useful in surgical decision making in 75% of patients. Choice of device requires thoughtful analysis of the specific needs for differing applications. Further refinements in these technologies would expand potential applications in anterior and lateral skull base surgery. Integration with heads-up display and the operating microscope would significantly enhance the utility of these technologies. Better ergonomic integration these technologies vis-à-vis room design, operating table design and patient anatomic factors are needed. More seamless integration of data derived from these technologies with image-guided systems and preoperative images are also needed to enhance efficiency.

NOTE

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