Value of radiologic imaging and computer assisted surgery in surgical decisions of the anterior skull base lesions*

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SUMMARY *The role of radiologic imaging in surgical decision making of anterior skull base lesions has been found to be critical in the endoscopic surgical management of these lesions. The non-invasive radiologic imaging may include the use of CT scans, MRI scans, MRA scans and their subtraction technique. The imaging offers an understanding of the vascularity of the lesion, the relationship to the nearby neurovascular structures and the type of tissue density of these lesions. The addition of image guided applications offers one a sagittal reconstruction and a 3-D imaging capacity which has immensely improved the accuracy and precision in endoscopic surgical applications in these areas.*

Key words: anterior skull base, computer assisted surgery, radiologic imaging

INTRODUCTION

Anterior skull base imaging has undergone extensive changes in the recent past. The imaging paradigm has progressed from plain films and tomograms to high resolution modalities such as helical CAT scan and MR imaging. This ability to depict normal and abnormal sinus and anterior skull base anatomy has provided the endoscopic surgeon with a "road map" in the management of these lesions. This has led to a wide spread acceptance of endoscopic management of lesions of anterior skull base and sinus surgery with maximum safety and efficacy.

The surgical endoscopic anatomy has consistent landmarks in the nasal cavity and paranasal sinuses. In the absence of these landmarks, either due to disease or prior surgery, the critical anatomy in these areas at the base of the skull may potentially be altered and mislead the endoscopic surgeon at the time of the resection. This clinical scenario led to the development of computer assisted surgery as it provides an intra-operative imaging guidance by using CT scans or MRI and reconstructing the anatomical landmarks with reference to fixed anatomical points. Stereotactic principles were first described by RH. Clarke and the first stereotactic instrument was designed in 1906. The earliest stereotactic surgical procedure was performed by Spiegel and his associates in 1947 (Kelly PJ, 1988). The availability of first, the CT scans and more recently the MRI and MRA scans have provided new insight into the biologic behavior of anterior skull base tumors and also brought about a renaissance for stereotactic computer assisted surgery.

Today stereotactic computer assisted surgery for anterior skull base lesions and complex sinus disease are commonplace in their surgical management. The ability of computers to do a 3-D reconstruction of CT scans and MRI imaging has provided the surgeon an ability to view the surgical site in stereotactic space. In combining the improved visualization using endoscopes or microscopes and preoperative CT scans, the computer assisted surgery has proven to be a valuable tool in organizing one's surgical planning at the base of the skull.

MATERIAL AND METHODS

The system used most commonly for computer assisted surgery in our series was the Instatrak system (Wilmington, Massachusetts, USA) and Stealth technology (Sofamor-Danek Systems, Colorado, USA) based on electromagnetic position sensing and optical sensing respectively. During surgery the Instatrak system displays the position of the probe in the surgical field either on a two dimension set or a 3-D image. The accuracy of this system is within 1 mm.

Technology

After appropriate medical treatment, CT scans are used to determine the type of sinus surgery and use of computer assis-

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Figure 1. The VTI system with work station.

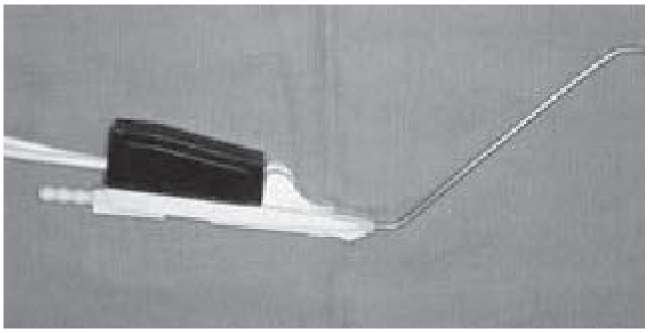

Figure 2. The VTI system suction probe.

Figure 3. Patient wearing the VTI head set at the time of the preoperative CT scan.

Table 1. Patient profile, Imaging performed and use of computer assisted surgery (CAS).

Name	Age	Sex	Disease	CT scan	MRI	MRA	CAS
CP	61	M	Mucocele Sphenoid	Y	Y	Y	N
CL	41	F	Mucocele Sphenoid	Y	Y	Y	N
BS	35	F	Mucocele Sphenoid	Y	N	N	N
LM	56	F	Mucocele Sphenoid, Preexisting Blindness	Y	Y	Y	N
LJ	55	F	Pansinusitis, Revision	Y	N	N	N
GW	46	F	CSF leak, Multiple Surgery	Y	Y	N	N
FH	51	M	Mucocele Sphenoid	Y	Y	N	Y
TT	44	M	Pituitary adenoma, CSF leak	Y	Y	N	N
FJ	36	M	Mucocele Sphenoid, Revision	Y	N	N	N
OD	17	F	Pansinusitis, Mucocele Sphenoid	Y	N	N	N
FP	17	M	Pansinusitis, Revision surgery	Y	N	N	N
FE	64	M	CSF leak, Nasal Surgery	Y	Y	N	N
LJ	37	M	Neuroendocrine tumor Sphenoid	Y	Y	N	Y
LW	63	M	Inverting Papilloma Sphenoid	Y	Y	N	N
BM	30	M	Mucocele Sphenoid	Y	N	N	Y
SN	67	M	Mucocele Sphenoid, Revision	Y	N	N	Y
PL	41	M	Pansinusitis, Revision	Y	N	N	N
RR	48	M	Mucocele Sphenoid, Revision	Y	N	N	N
RA	59	M	CSF leak	Y	N	N	N
KJ	55	F	Pansinusitis, Revision	Y	N	N	Y
SN	78	M	Frontal Mucocele, Revision	Y	Y	N	N
FB	61	F	CSF leak	Y	Y	N	Y
LJ	50	M	CSF leak	Y	Y	N	Y
KM	37	M	Pansinusitis, Revision	Y	N	N	N
MA	54	M	Pansinusitis, CSF leak	Y	N	N	N

ted surgery. If computer assisted image guidance is required, the patients underwent a new CT scans with a special headset with fiducial makers.

The surgery may be performed under general anesthesia or local anesthesia with sedation in a supine position. The plastic headset with fiducial makers in placed on the head of the patient and the source transmitter is fixed to the frame. The sensor is attached to an interchangeable hand piece which can accommodate a straight or curved suction aspirator. The unique arrangement of this system's source and sensor leads to minimal interference by metallic instruments, dental amalgams or other environmental influences (VTI guidance system)(Figures 1-4).

The Sofamor-Danek System uses a light emitting diode system which transmits signals from a hand piece to a 3-D camera which then processes the information in a Silicon Graphics workstation. The identification probe is still based on the X-Y axis and the 3-D reconstruction offers a variety of cut away scans which localize the position of the probe in a dramatic manner. The cut aways presently available are a combination of sagittal-coronal, coronal-axial, and axial-sagittal (Figures 5-7).

Clinical Data

We present 25 cases with interesting clinical conditions which required the advanced imaging or the use of image guided surgery. All surgeries were performed without a complication. In addition we demonstrate two clinical cases each with both the VTI and Sofamor-Danek Systems. In the VTI system both patients presented with a CSF leak following base of skull trauma. The first patient developed a large encephalocele lateral to the middle turbinate on the right side following non-penetrating trauma to skull base (Figure 8). The X-Y axis with the 5 mm grid that is seen in the clinical data reveals a large encephalocele with specific measurement in all axiss. In the second patient the CSF leak developed secondary to endoscopic ethmoidectomy in the region of lamina dura which is clearly seen in the illustration (Figure 9) with the tip of the probe touching the encephalocele.

In the Sofamor-Danek System the first patient presented with a CSF leak following nasal polypectomy. The clinical illustration with sagittal and coronal cut away reveals the encephalocele in the region of the lamina dura on the left side (Figure 10). In the second clinical situation the patient presented with a CSF leak

Figure 4. The VTI system head set with transmitter intraoperative on the patient.

Figure 5. The Sofamor-Danek System with Silicon Graphics workstation.

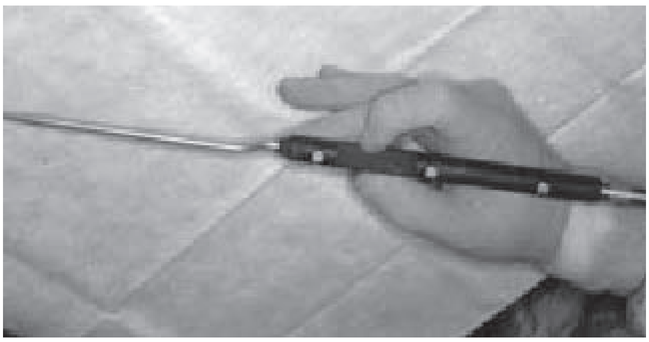

Figure 6. The Sofamor-Danek System localization wand.

following sinus surgery and the illustration on the system with sagittal and coronal cut away localizes the site of the leak to be at the junction of lamina papyracea and lamina dura on the left side (Figure 11).

RESULTS

In our series of 25 patients, 7 required computer assisted surgery using the Instatrak system or the Stealth technology system and 12 required advanced imaging which included MRI or MRA scanning. The registeration was consistent, repeatable and always in the range of less than 1 mm. No complications were encountered in our series. There was preexistent blindness in one of the patients due to a large sphenoid sinus mucocele, which stretched the optic nerve.

Figure 7. The Sofamor-Danek System head set on the patient with LED emitters.

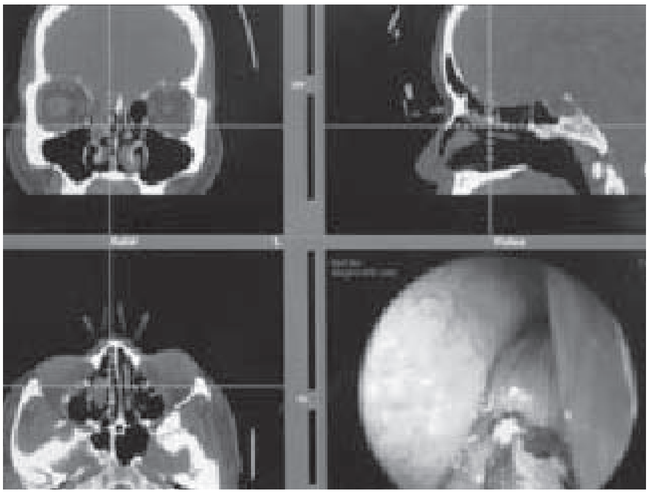

Figure 8. A large encephalocele lateral to the middle turbinate on the right side.

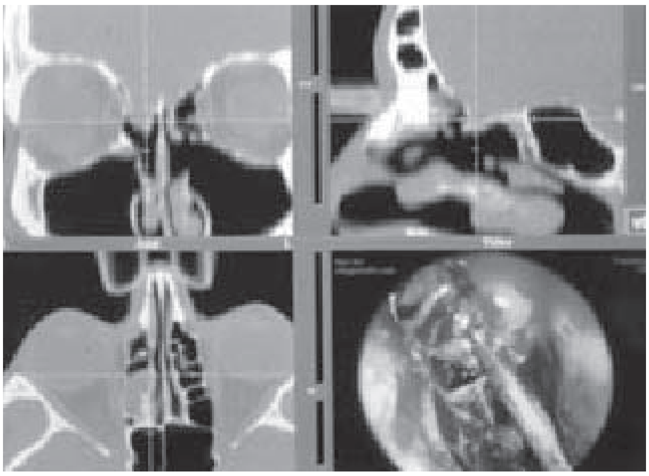

Figure 9. A lamina dura defect with tip of the probe touching the encephalocele.

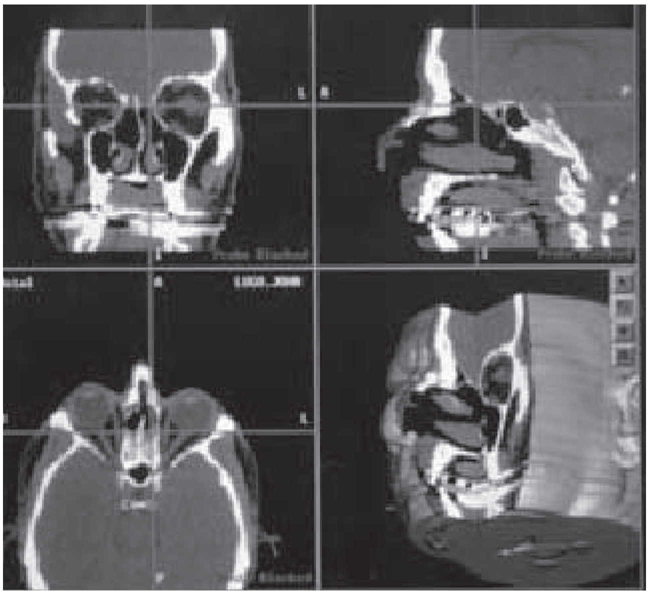

Figure 10. Illustration with sagittal and coronal cut away revealing an encephalocele in the region of the lamina dura on the left side.

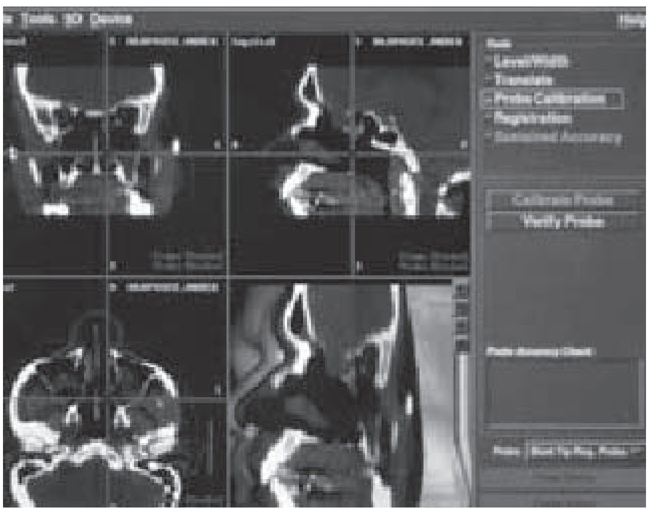

Figure 11. Illustration on the system with sagittal and coronal cut away localizing the site of the leak at the junction of lamina papyracea and lamina dura on the left side.

DISCUSSION

Imaging of the sinuses and anterior skull base has progressed from plain films to intra-operative real time CT scans and MRI imaging. Plain films are not reliable enough to be an integral part of the clinical and surgical decision process. The clear inadequacies, availability of superior techniques and medical cost containment has reduced the utilization of plain radiographs in the past 10 years.

Today CT scans with MRI scans are the main stay of anterior skull base and sinus imaging. CT scans have a distinct advantage: its ability to depict bone, bone-air and bone-soft tissue interface. One of the distinct advantages of CT scans and MRI scans is in imaging of patients with fungal sinus disease. CT scans are considaribly cheaper than MRI and is universally available. MRI scans provide for better soft tissue contrast which helps in distinguishing inflammatory disease from adjacent neoplasm. MRI scanning has become the radiologic imaging of choice in complications of sinus disease such as intra-cranial, intra-orbital or deep spread of disease. The multiplanar imaging of MRI helps in 3-D reconstruction of images. The disadvantages of MRI scanning are depiction of bone as a signal void is problematic in problematic sinus disease and anterior skull base lesions (Philips CD, 1997).

MR angiography is another option available for visualization of the carotid vasculature as well as tumor vascularity. This helps to differentiate between carotid displacement by anterior skull base disease and tumor encasement of the carotid artery.

The introduction of a 3-D navigation system to anterior skull base has demonstrated a new method of anatomical orientation. The clinical advantage is specially useful while operating in the vicinity of the orbit, the internal carotid artery and the anterior skull base floor or in absence of reliable anatomical landmarks such as revision paranasal sinus and anterior skull base surgery. Computer assisted surgery involves the blending of imaging devices with digitizing sensors with an intra-operative computer system to provide for intra-operative guidance using triplanar axial, coronal and sagittal views. To provide for real time guidance, the location of the coordinate digitizer needs to be continuously determined. Four different types of technology for tracking are used at the present time. They are electromagnetic, sonic, electromechanical and optical systems (Table 2). The technology used in systems for use in otolaryngologic surgery use either electromagnetic or optical technology. The 3-D stereotactic surgery systems in use in otolaryngology are mostly derived from neurosurgical systems. Neurosurgical systems usually use rigid frames which are fixed to the skull with the help of pins or skin fudicial markers for real time guidance. The disadvantage with these systems is the use of Mayfield pins which may be unacceptable to the patient for benign sinus disease and skin makers have a tendency to move and alter the calibration (Hauser R, 1997; Gunkel AR, 1997).

The systems used in USA include the ISG viewing wand (Mississauga, Ontario, Canada), Stealth station (Sofamor-Danek Systems, Colorado, USA) and the Visualization Technology (Wilmington, Massachusetts, USA) Instatrak system. These systems use special headsets with either light emitting diodes (LED) or electromagnetic markers which provide reliable and reproducible localization (Fried MP, 1997). These headsets are

Table 2.

	Optical sensors	Magnectic sensors	Sonic sensors	Mechanical sensors	Ultrasound	Real Time CT scan	Imaging MRI scan
Resolution	good	good	fair	good	fair	good	good
Reproducibility	good	good	fair	good	fair	good	good
Orientation	good	good	good	good	fair	good	good
Access	good	good	good	fair	good	fair	fair
Pre-op imaging	yes	yes	yes	yes			
Setup Time	short	short	short	short	short	long	long
Ease of use	good	good	fair	fair	good	fair	fair
Size of Unit	small	small	small	small	small	large	large
Availability of Instruments	yes	yes	yes	yes	yes	yes	no
requires echogenic borders	no	no	no	no	yes	no	no
echogenic room holes	no	no	no	no			
temperature and humidity control in OR	no	no	affected	no	no	no	no
echogenic interference by machinery	no	no	affected	no	no	no	yes
line of sight and displacement of scrub nurse	no	no	no	yes	no	yes	yes
shielding of device from interference	no	required	no	no	no	no	yes
intraop scan time					short	short	long
intraop transfer time					short	short	long
sterility of scanner or device					yes	no	no
radiolucent headframe					no	yes	yes
narrow OR table					no	yes	yes
OR staff Protection Requirements	no	no	no	no	no	yes	yes

worn preoperatively by the patient who then undergo CT scans or MRI imaging. The ISG system and the Stealth system use an optical digitizer, where as the Instatrak system uses electromagnetic position sensing. The accuracy of both these systems is approximately 1.0 mm (Annon JB, 1997; Freysinger W, 1997).

The inadequacies with these systems are the absence of real time imaging to compensate for shift of markers and volumetric shifts due to current surgery. An ideal guidance system should have good resolution and reproducibility of registeration, low error in localization, real time intra-operative imaging, ability to use standard operating room equipment and instruments. It should be user friendly and easy to set up as well as not to expose the patient or the operating room staff to radiation or undue danger (Sandeman DR, 1994).

The future of computer assisted surgery is in simultaneous real time or periodic intra-operative imaging and real time guidance using intra-operative CT scans or MR imaging to compensate for volume shifts due to surgery.

CONCLUSION

Current imaging of the anterior skull base and sinuses using MRI and CT scans have a significant contribution in management of pathology of this region. A close working relationship is essential between the surgeon and the radiologist to optimize the information gained. Computer assisted surgery helps in managing skull base pathology with minimal morbidity and maximizes patient safety and efficacy.

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