Computer-aided image-guided endoscopic sinus surgery in unusual cases of sphenoid disease*

Samuel M. Lam[1], Clark Huang[2], Jason Newman[1], Vijay K. Anand[2]

1 Department of Otolaryngology-Head & Neck Surgery, Columbia University College of Physicians & Surgeons, New York, NY, USA
2 Department of Otorhinolaryngology, Joan & Sanford I. Weill Medical College of Cornell University, New York, NY, USA

SUMMARY

The vital neurovascular structures that border the sphenoid sinus make extensive sphenoid sinus surgery hazardous despite the advent of endoscopic sinus surgery (ESS). Computer-aided image-guided endoscopic sinus surgery (CAIGESS) has facilitated safer surgery by providing real-time analysis of complex, three-dimensional anatomic landmarks. We present 6 cases of atypical sphenoid disease, which greatly benefited from the unique superiority of CAIGESS in avoiding surgical complications. Two cases of cerebrospinal-fluid (CSF) leak with concomitant meningoencephalocele of the sphenoid sinus were successfully managed with this technique. An inverting papilloma originating from the sphenoid sinus was successfully exenterated using CAIGESS. One patient, who experienced a lateral-rectus muscle palsy from sphenoid sinusitis, underwent successful sinusotomy with CAIGESS. Another patient, who had refractory left-sided sphenoid sinusitis despite 2 ESS procedures, was found to have an obliquely oriented intersinus septum which misled the previous surgeons to enter mistakenly the contralateral sphenoid sinus. CAIGESS allowed accurate identification and removal of the intersinus septum and relief of the sinusitis. Finally, a sphenoid-sinus mucocele that developed after a prior pituitary surgery was safely decompressed with CAIGESS. This surgical approach offers a new and effective adjunct to ESS in selected revision or difficult sinus cases and has proven invaluable in complicated sphenoid cases where the surrounding neurovascular anatomy could otherwise be jeopardized.

INTRODUCTION

The advent of endoscopic techniques and modern imaging modalities has revolutionized the surgical approaches to the posterior-ethmoid sinuses since the introduction of computed tomography (CT) and magnetic resonance imaging (MRI) scans in the 1980s. While these advances were revolutionary, they still had inherent deficiencies, which limited their value in the management of complicated and revision sinus surgical procedures. Now with the introduction of computer-aided image guidance in 1993, the endoscopic view and the CT view have been united to provide a three-dimensional, triplanar perspective to the surgical anatomy. Studies have confirmed that the accuracy of localization in these computer systems is 2 mm or better (Fried et al., 1997; Anon, 1998; Olson et al., 2000). Although CAIGESS should never be a substitute for a thorough understanding of paranasal-sinus and nasal anatomy (Roth et al., 1995), it provides a confirmation and correlation to anatomy that otherwise could be rendered abnormal by scarring, inflammation or disease process. Further, it can be invaluable in crucial anatomic regions such as the sphenoid sinus, which is bordered by sensitive neurovascular structures.

The sphenoid sinus, by virtue of its recessed position in the skull base and by the host of vital neurologic structures that surround it, may be amenable to image-guided surgery in both primary and revision surgical cases. Laterally, the sphenoid sinus is flanked by the cavernous sinus, which houses the oculomotor nerve (Cranial Nerve [C.N.] III), the trochlear nerve (C.N. IV), the ophthalmic division of C.N. V, the maxillary division of C.N. V, the abducens nerve (C.N. VI) and the internal carotid artery (Figure 1). The internal carotid artery often forms an indentation in the postero-lateral wall of the sinus, with bony dehiscence not uncommonly present. The optic canals may project deeply into the sinus in a reported 7% of cadaveric specimens and further may have a similar absence of

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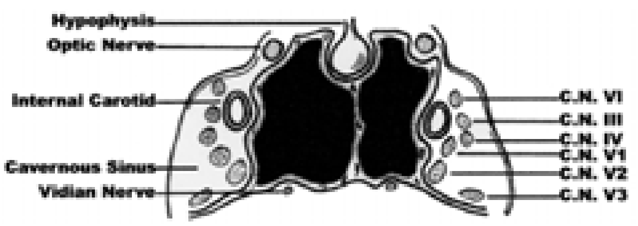

Figure 1. Neurovascular structures bordering the sphenoid sinus.

any bony covering. The maxillary division of C.N. V may also indent into the lateral wall of the sphenoid sinus. Van Alyea reported that the nerve of the pterygoid canal (Vidian nerve) could make a pronounced impression in the floor of the sinus in 36% and a slight indentation in 12% of specimens reviewed. Above, the middle cranial fossa borders the sphenoid sinus. Also superiorly, the hypophysis rests in the sella turcica, which can be particularly thin, and may project to variable degrees into the sphenoid depending on the extent of pneumatization of the sinus. The sinus walls usually average 0.5 mm, except the posterior wall and floor that may reach 1 cm, but may also be entirely dehiscent. Posterior-ethmoid cells may intrude into the sphenoid sinus and contain the optic nerves, known as the Onodi cells. All these vital structures and the variability of the anatomy make image-guided sphenoid surgery an important adjunct to safety (Hollinshead et al., 1982).

Generally, the sphenoid sinus may be accessed by two principal methods: bicoronal craniotomy or transnasal entry. The former approach is obviously fraught with many inherent risks and expected sequelae: CSF leak; an extended, visible, external incision; alopecia; scalp parasthesias; protracted operative time; brain retraction and possibly permanent anosmia. Transnasally, the sphenoid can be approached either directly through the nasal vault, via a complete ethmoidectomy or via a transeptal approach (such as the one used in hypophysectomy). The literature has recorded early success with computer-aided image guidance in transphenoidal hypophysectomies, which offers a superior surgical view of the sphenoid sinus, than the traditional C-arm fluoroscopy (Burkey et al., 1998; Moses et al., 1999; Elias et al., 1999).

We present 6 cases of unusual sphenoid disease, which have critically relied on the features of computer assistance in guiding our surgical procedures. We review 2 cases of varied sphenoid anatomy that posed problems to prior surgeons and could have resulted in serious ocular complications without the aid of image guidance. Further, we present 2 cases of meningoencephaloceles with CSF leak that benefited from wide exposure of the anterior face of the sphenoid achieved safely with CAIGESS in order to reduce the encephalocele and close the leak. Finally, we investigate 2 cases, an inverting papilloma and a mucocele after prior surgery, that required an intimate knowledge of all the dimensions of the sphenoid sinus to achieve complete eradication of disease.

METHODS

Instrumentation

The InstaTrak (Visualization Technology, Inc., Boston, MA) is an armless, frameless surgical navigation system that relies on electromagnetic signaling (Figure 2). The device runs on a Sun SPARC computer using a Solaris operating system (Sun Microsystems, Palo Alto, CA). Two electromagnetic sensors serve to provide three-dimensional positioning information: one is situated on the suction tip and the other, on the patient's headset. The headset is worn both preoperatively during CT imaging and intraoperatively and functions as a means to correlate position of the suction tip in the surgical field with the CT display in triplanar views: coronal, sagittal and axial.

Figure 2. The InstaTrak workstation.

Procedure

All patients underwent preoperative CT scans recorded at 2.5 mm intervals with 2.5 mm thickness in the coronal and axial planes, with axial reconstruction to a bone algorithm at 1.25 mm interval and thickness. These images are then digitally reconstructed at 1 mm for triplanar (axial, coronal, sagittal) presentation. Informed consent for the use of the InstaTrak system was obtained in all patients. Initial intraoperative calibration was performed with the suction-tip sensor in 4 directions according to the InstaTrak protocol. Calibration was verified with three standard anatomic landmarks: anterior heads of the inferior and middle turbinates and the caudal border of the nasal septum. All surgeries were performed by the senior author (VKA) under general anesthesia with 4-mm, 0- and 30-degree, rigid endoscopes. No intraoperative complications occurred.

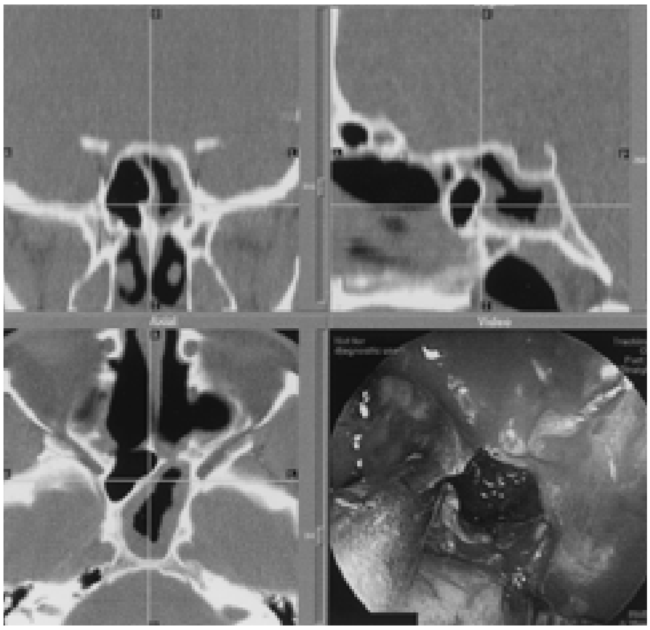

Figure 3. Case 1: Obliquely oriented intersinus septum of the sphenoid sinus.

CASES

Case 1: *Oblique Intersinus Septum & Failure to Enter the Correct Sinus*

L.S. is a 41-year-old man with a past history significant for Crohn's disease which had been treated with high-dose steroids in the past leaving him with adrenal insufficiency for which he now takes prednisone. He presents with a 5-year history of refractory sinusitis for which he underwent ESS at an outside institution 7 and 9 months prior to presentation. The patient however had persistent sinusitis despite these surgical interventions.

After the above 2 procedures, CT scan demonstrated postoperative changes as well as persistent mucosal thickening of the left sphenoid sinus. CAIGESS was undertaken which demonstrated that the right sphenoid-sinus ostium was partially opened but that the left ostium had not been explored. It appeared that the oblique orientation of the intersinus septum had misled the prior surgeons to believe that they were in the contralateral sinus (Figure 3). The intersinus septum was resected, with surgical position accurately confirmed by the computer probe, and further the left ostium was identified and widely enlarged. The patient has been symptom free since the surgical procedure.

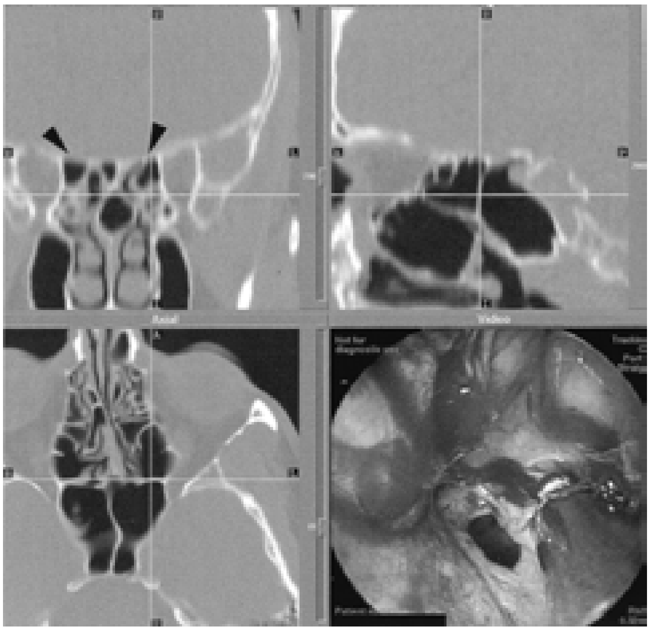

Figure 4. Case 2: Bilateral Onodi cells (arrows).

Case 2: *Avoidance of Onodi Cell*

A.G. is a 53-year-old man otherwise healthy who presents with chronic sinusitis and new-onset diplopia secondary to extension of sphenoid sinusitis to the left abducens cranial nerve. The patient received a total of a 3-week course of intravenous antibiotic therapy with ticarcillin/clavulanate but failed to improve. Curiously, the CT scan demonstrated polypoid mucosal thickening in only the contralateral sphenoid sinus. The CT scan also showed bilateral Onodi cells through which the optic nerves traversed (Figure 4).

The patient was taken to the operating room and underwent CAIGESS. Intraoperatively, the sphenoid sinus and posterior-ethmoid cells were noted to be hyperostotic. The Onodi cells were carefully marsupialized, and the anterior face of the sphenoid was opened using image guidance. The patient was noted to have a large Aspergillolith, which was confirmed by culture, with extensive mucopulurent secretions. He received 3 additional weeks of intravenous ticarcillin/clavulanate and cefipime and 3 months of sporanox p.o. His diplopia resolved, and he has been symptom free now since the operation.

Case 3: *Meningoencephalocele with CSF Leak*

M.M. is a 56-year-old man otherwise healthy who presents with left-sided nasal congestion and left-sided clear rhinorrhea for several months that has disturbed his sleep. His rhinorrhea was refractory to any medical management, and the patient was further evaluated with imaging studies. MRI revealed a postero-lateral herniation of middle-cranial-fossa contents into the left sphenoid sinus with surrounding fluid. CT scan confirmed a 6 mm x 4 mm bony dehiscence anterior to the carotid canal with bilaterally dehiscent optic nerves. The patient recalls blunt trauma when a door slammed against his forehead shortly before the onset of symptoms. However, we believe that this is an unlikely cause of his CSF rhinorrhea. Beta-2-transferrin confirmed the CSF nature of the rhinorrhea.

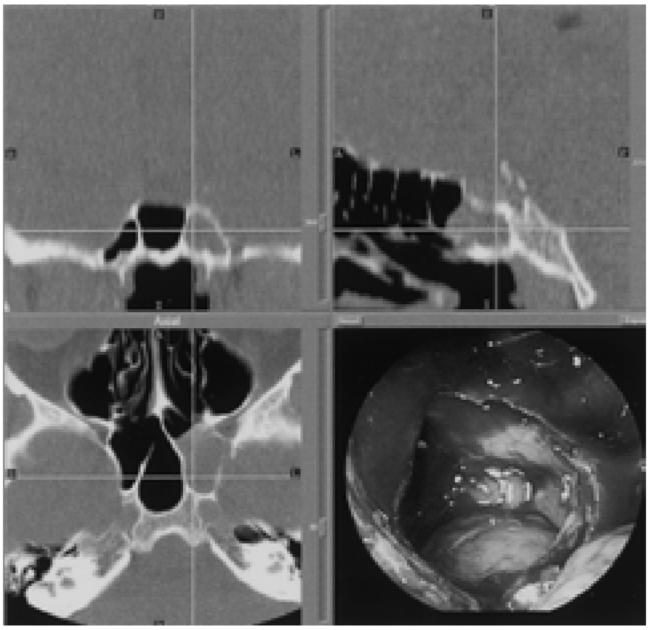

Figure 5. Case 3: Meningoencephalocele & CSF leak..

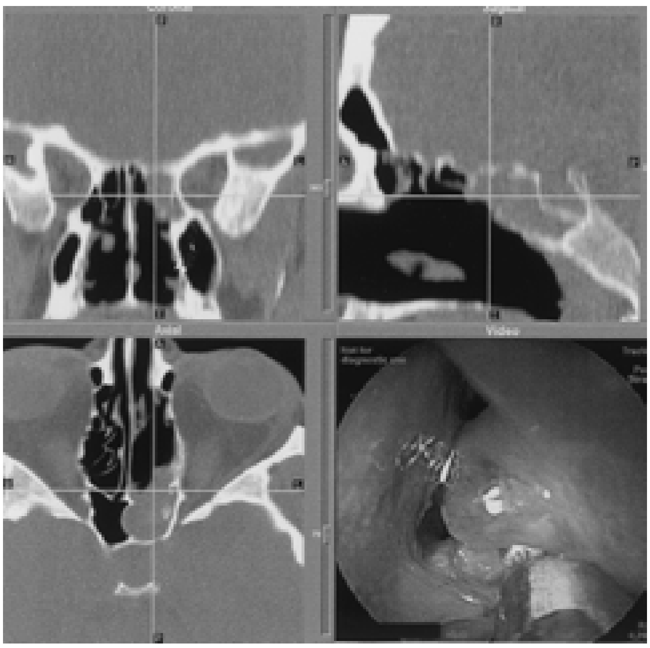

Figure 6. Case 4: Meningoencephalocele & CSF leak.

The site and extent of the meningoencephalocele was confirmed by the computer probe (Figure 5). The patient underwent a transethmoidal sphenoidotomy with closure of the CSF leak using conchal cartilage, temporalis-fascia graft, fibrin glue and gelfoam after reduction of the meningoencephalocele. Image guidance allowed safely opening the anterior face of the sphenoid widely to gain access to the meningoencephalocele and CSF leak.

Case 4: *Meningoencephalocele with CSF Leak*

Y.K. is a 39-year-old obese woman with past history significant for hypertension who presents with a reported 10-year history of clear, left-sided rhinorrhea without history of antecedent trauma. However, patient does report having had a history of nasal surgery of uncertain nature in Russia during her childhood. The suspected CSF leak was confirmed by beta-2-transferrin assay. Preoperative CT and MRI scans demonstrated a meningoencephalocele emanating from the left middle cranial fossa into the sphenoid sinus laterally. She underwent CAIGESS with reduction of the meningoencephalocele and closure of the CSF leak using conchal cartilage, temporalis fascia, fibrin glue and gelfoam. Computer probe accurately identified lateral sphenoid landmarks and facilitated wide sphenoidotomy for access to the meningoencephalocele (Figure 6).

The patient however had persistent CSF rhinorrhea confirmed by beta-2-transferrin assay and required revision surgery to close the leak. Two months after initial surgery, the patient underwent CAIGESS a second time. The computer probe permitted recognition of distorted postsurgical landmarks, which enabled effective closure of the CSF leak with temporalis fascia. Of note, the meningoencephalocele appeared to have remained fully reduced at the time of the second operation. The patient has not complained of further CSF rhinorrhea.

Case 5: *Inverting Papilloma of the Sphenoid Sinus*

P.F. is a 38-year-old man otherwise healthy who presents with a 7-year history of chronic rhinosinusitis for which he had undergone 2 ESS procedures 2 years prior to presentation. The pathology at that time was consistent with inverting papilloma, but the patient had not sought follow-up since the initial surgeries. He complains of left-sided nasal obstruction and mucoid discharge and was noted to have a left nasal mass emanating from the sphenoid region. Biopsy confirmed the presence of inverting papilloma.

Preoperative CT scan demonstrated a large polypoid mass in the postero-superior nasal cavity extending into the left sphenoid sinus with erosion of the anterior wall of the sphenoid. The patient underwent CAIGESS. The nasal portion of the mass was initially amputated. Then under direct image guidance, the anterior face of the sphenoid sinus was resected to facilitate removal of the mass that extended along the roof and lateral wall of the sphenoid sinus (Figure 7). The patient has

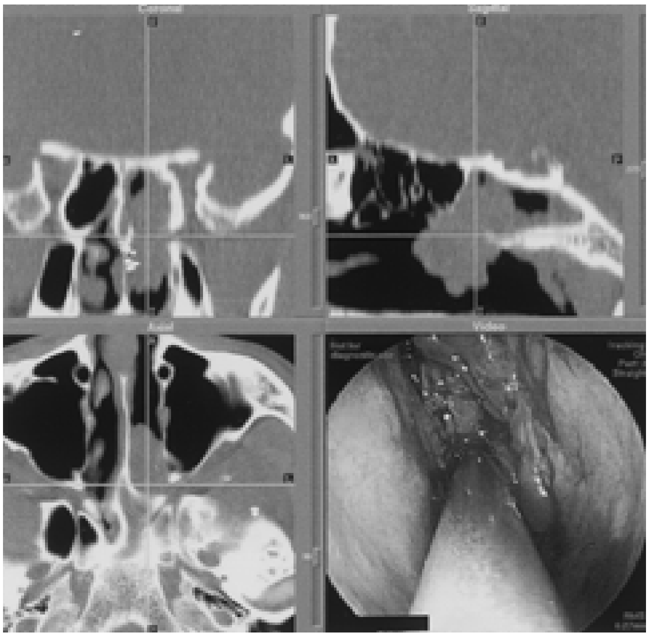

Figure 7. Case 5: Inverting papilloma of the sphenoid sinus.

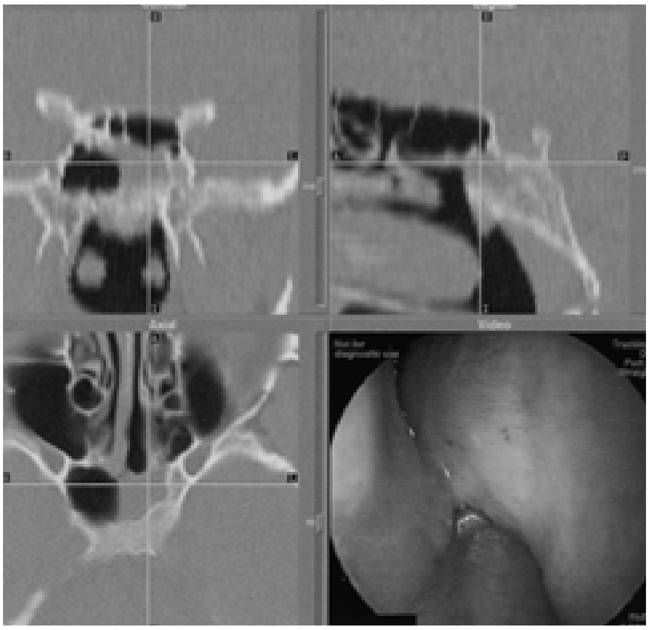

Figure 8. Case 6: Mucocele of the sphenoid sinus.

remained symptom free and without recurrence since the procedure.

Case 6: *Sphenoid Mucocele after Pituitary and Endoscopic Sinus Surgery*
J.M. is a 30-year-old woman who is status-post transphenoidal resection of a pituitary adenoma 3 years prior to presentation. Patient had symptoms of head pressure and pain postoperatively and was found to have sphenoid sinusitis for which she underwent 2 sphenoidotomies with ESS. She now complains of a return of her symptoms, which include head pressure, pain, and chronic fatigue. Preoperative CT scan demonstrated mucosal thickening and a mucocele that occupied the sphenoid sinus.

Patient underwent CAIGESS. The computer probe was essential in identifying the sphenoid-sinus ostia, which were bilaterally stenosed and hyperostotic. After drilling down the anterior face of the sphenoid sinus with image guidance, a mucocele filling the sphenoid sinus was encountered (Figure 8). The mucocele was decompressed and the mucosa removed. The patient has remained symptom free since the operation.

DISCUSSION
The earliest computerized navigation systems were stereotactic, framed devices secured to the patient's skull to immobilize the head and required mechanical articulated arms to maintain the probe in position. These cumbersome devices primarily catered to neurosurgical procedures and were of limited value to patients undergoing elective sinus surgeries. These computer systems moved into the otolaryngologic sphere when they evolved into more mobile units that were both frameless and free of articulated-arm restraints. Although many companies offer different products in the current competitive market, the image-guidance systems basically fall within two main types of tracking technologies: electromagnetic and optical, both of which have achieved commensurate success and accuracy (Goerss et al., 1993; Anon et al., 1998; Metson et al., 1998). The InstaTrak is a device that uses the former tracking method and represents the modus operandi in the cases reviewed for this paper.

Besides sphenoid surgery, computer-aided navigation systems may serve a variety of useful functions in sinus surgery. As already noted, computer assistance is particularly helpful when the anatomic landmarks are distorted by prior surgery. Further, significant tumor or polypoid disease, for example, can obscure surgical landmarks and render surgical exploration a difficult endeavor. As evident in 2 cases presented, CAIGESS affords precise localization mandated in cases of CSF-leak closure. This degree of precision is also useful for cases of optic-nerve decompression. With triplanar localization, especially with sagittal reconstruction, CAIGESS allows for safe and thorough exploration of the fronto-ethmoidal recess. It may serve a vital role in managing more advanced frontal-sinus disease that may require aggressive surgical intervention. The ethmoid sinuses may also present a challenge due to a low-lying, dehiscent or asymmetric cribriform, roof or lamina papyracea. Teaching programs, replete with neophyte endoscopic surgeons, have proven the unmistakable benefit of these computer systems in the prevention of irrevocable injuries (Casiano et al., 2000). The anatomy of the paranasal sinuses constitutes a complex, three-dimensional structure that deserves the accurate spatial representation afforded by CAIGESS to avoid surgical pitfalls.

Despite the distinct advantages that computer-aided surgery offers, there are also many shortcomings that pose a problem to the successful implementation of these devices. First, these image-guided machines are expensive, making them prohibitive to many hospitals especially in the current climate of cost containment. Further, preoperative CT scans require the technician to follow a prescribed algorithm to generate the required image sequences for computer interpretation. The bulky machines also demand valuable floor space in the operative suite and allocated storage space. Education of operating-room personnel is an essential ingredient to the success of these sophisticated systems, and familiarity with them promotes shorter preoperative time and enhanced skill in troubleshooting problems that may arise with the hardware or software. The surgeon must always calibrate and verify all anatomic landmarks and must ultimately rely on his own knowledge of the anatomy if there exists any inconsistencies or apparent inaccuracies displayed on the monitor. Signaling may also be a source of error: optical systems require a direct line of sight to function properly, whereas electromagnetic systems must operate in the absence of ferromagnetic interference. Although the surgeon can track his instruments in "real time" within the operative field, he must recognize that the displayed images are derived from a preoperative CT and do not represent live, intraoperative images that would otherwise reflect ongoing manipulations of the surgical bed. CAIGESS, conducted with the patient positioned in a live MRI suite, is only a nascent technology that has no real widespread clinical application as of yet (Fried et al., 1996). A preliminary report of intraoperative CT scan imaging with CAIGESS found little support for its clinical application (Cartellieri et al., 2000). Some of these limitations will not doubt be overcome as the march of technologic progress advances.

CONCLUSIONS

Computer-aided endoscopic sinus surgery represents state-of-the-art technology for modern sinus surgery. When the surgical field has been distorted by prior surgery, inflammation or disease, CAIGESS becomes extremely helpful for safety. The sphenoid sinus, with its extensive neurovascular structures that encircle it, is benefited from this technology in primary and revision cases, as illustrated in the 6 cases presented.

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Vijay K. Anand, M.D.
205 E 64th Street, Suite 101
New York, NY 10021
U.S.A.

Tel: +1-212-832-3222
Fax: +1-212-832-3287
E-mail: vijayanandmd@aol.com