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Main Article

Real-time computed tomography image update for endoscopic skull base surgery

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Abstract

Introduction: The development of computer-aided systems for endoscopic sinus surgery has enabled surgical navigation through diseased or surgically altered sinus anatomy with increased confidence. However, conventional computer-aided systems do not provide intra-operative updated computed tomography imaging. We describe the technical aspects of the xCAT™, a new intra-operative mobile volume computed tomography scanner.

Technical report: A patient with a malignant melanoma unwittingly removed at another hospital underwent surgery for removal of the lateral nasal wall and directed biopsies, in an attempt to identify the site of tumour origin. The procedure was performed with the GE InstaTrak 3500 Plus™ computer-aided system, updated with intra-operative computed tomography images. Intra-operative, updated images were integrated successfully into the InstaTrak system, and these images were consistent with the observed endoscopic anatomy.

Conclusion: The xCAT intra-operative mobile volume computed tomography scanner is a technological advancement that can assist the endoscopic sinus surgeon when performing complex rhinological and skull base procedures.

Key words: Paranasal Sinuses; Otorhinolaryngologic Surgical Procedures; Endoscopy; Computed Tomography Scanners

Introduction

Over the last decade, the development of new technologies for endoscopic sinus surgery has increased the surgeon's ability to manoeuvre safely through diseased or surgically altered sinus anatomy. In particular, the development of image-guided or computer-aided systems has enabled sinus surgeons to monitor surgical instruments, relative to a pre-operative computed tomography (CT) scan, and to navigate the skull base and orbital walls with more precision. These computer systems provide continuous information in the coronal, axial and sagittal planes. This technology does not eliminate potential intracranial or orbital complications, and is no substitute for expert anatomical knowledge and sound surgical training. However, it does provide additional information for intra-operative decision making.

Recent updates to this technology include the integration of CT angiography and of CT and magnetic resonance imaging (MRI) fusion techniques into computer-aided systems. Because CT scans do not provide detailed anatomy of the intracranial vasculature, the incorporation of CT angiograms represents a substantial improvement in imaging technology for skull base surgery. Computed tomography–MRI fusion facilitates delineation of soft tissue tumours, while providing the necessary bony anatomical boundaries and landmarks for intra-operative navigation.

Despite these advancements, conventional computer-aided systems do not provide true, real-time, updated imaging while the patient is on the operating table. Once data have been acquired for these navigation systems, they do not provide the opportunity for any modification of the data sets themselves.

One attempt to remedy this problem is through the application of Eraser™ software (BrainLab, Munich, Germany). Eraser software enables digital erasure of tumour or sinus disease from the pre-operative CT scan, based upon intra-operative tracking of the surgical instruments. This technology is very useful if the tumour or disease is confined by

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the bony anatomy of the sinuses and skull base, and if the surgeon can obtain a virtual image update of the actual surgical progress. However, the utility of this software decreases dramatically when surgery extends beyond the bony boundaries of the sinuses into soft tissue (e.g. pituitary surgery). Soft tissue collapse and anatomical shift effectively limits this technology. A method of updating CT images using an actual intra-operative CT scanner could limit these shortcomings.

Intra-operative image acquisition with computer-assistance is not a new concept. As early as 1980, intra-operative CT imaging was being performed, using a CT-dependent frame with diagonal rods that served as fiducial markers for the computer during neurosurgical procedures.[1] Stereotactic ability was conveyed by the CT scanner itself, so that repeat scans could be obtained during surgery to confirm the position of the probe tip. Because of the impractical nature of using large CT scanners in the operating room, and the resulting large doses of radiation to patients, intra-operative imaging was abandoned in favour of a single, pre-operative imaging sequence that could be applied to a CT-dependent frame, and subsequently frameless, stereotactical navigational systems. Because neurosurgical procedures ultimately involve soft tissue, anatomical shift decreases the utility of this technology for neurosurgical purposes. However, in endoscopic sinus surgery the limits of dissection are the bony boundaries of the skull base and orbit – stable structures with no anatomical shift. Therefore, computer-aided systems were well suited for this type of surgery. As the field of rhinology has evolved, the boundaries of endoscopic surgery indications have broadened. Now, rhinologists resect skull base tumours and other lesions with intracranial involvement; in such procedures, the limitations of these systems again become apparent with regards to anatomical shift.

A compact, portable CT scanner named the xCAT™ (Xoran Technologies, Ann Arbor, Michigan, USA) has been developed, which provides real-time intra-operative CT scans of the sinuses and skull base (Figure 1). This new technology allows updated intra-operative registration of computer-aided navigational systems.

Previously, Cartellieri and Vorbeck[2] had published their report of six patients who underwent intra-operative conventional CT scanning during endoscopic sinus surgery, in order to provide an update to their computer-aided system. Unfortunately, this study required additional staff to operate the CT, the operation to be performed on a CT table, and a complete CT data set to enable updating of the three-dimensional navigation system. This resulted in prolongation of anaesthesia, ranging from 20 to 60 minutes.

In contrast, the xCAT system is a cone-beam CT scanner that contains an X-ray source and detector mounted on a rotating scanning arm, a personal computer with an integrated wide screen monitor, and an image-processing unit. During one rotation of the scanning arm, the detector collects the flux of X-rays that have passed through the patient.

FIG. 1

The Xoran xCAT™ system is a cone-beam computed tomography scanner that contains an X-ray source and detector mounted on a rotating scanning arm. The personal computer and wide screen monitor are integrated into the system.

Cone-beam CT scanners utilise a two-dimensional multi-row detector, which allows for a single rotation of the gantry to generate a scan of the entire head, as compared to conventional, full body 'fan-beam' CT scanners, the multiple 'slices' of which must be stacked to obtain a complete image. Thus, the xCAT system displays scans on its integrated monitor in less than three minutes. Cone-beam technology utilises X-rays much more efficiently, requires far less electrical energy, and allows for the use of more compact X-ray components than fan-beam technology.[1,3,4] This system creates CT images with an isotropic spatial resolution of 0.4 mm, and its customised field of view is optimised for scanning the sinuses and skull base. The effective radiation dose to the patient is as low as 0.25 mSV, while the radiation dose from a full-body CT scanner is on average 10 times greater.[5,6] With this new intra-operative CT scanning ability, this technology can provide real-time up-to-date registrations for image guidance systems, enabling assistance in complex sinus and skull base procedures. Furthermore, this technology can be applied to endoscopic sinus or skull base surgery without limiting the operative field or interfering with the procedure, because of the speed of image acquisition.

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- **Computer-aided systems for endoscopic sinus and skull base surgery have increased surgeon confidence when operating on distorted anatomy**
- **Conventional computer-aided systems do not provide real time updated imaging during surgery**
- **A new intra-operative mobile volume computed tomography scanner allows intra-operative updates for computer-aided surgical navigation**
- **This is a technological advancement which can assist with complex rhinological and skull base procedures**

Technical report

A 56-year-old man underwent unilateral nasal polypectomy at another hospital. The permanent pathology report was positive for malignant melanoma. The original surgeon did not report a discrete location for the origin of the tumour, nor was he able to recall the site post-operatively.

Therefore, the patient underwent repeat surgery to remove all structures of the lateral nasal wall as well as to take directed biopsies in an attempt to identify the site of tumour origin. Pre-operative imaging (Figure 2) was obtained and the procedure was performed with a computer-aided system and an intra-operative CT imaging update system.

We used the GE InstaTrak 3500 Plus™ computer-aided system (General Electric Medical Systems, Salt Lake City UT, USA) for this case. This system consisted of a headset frame with an electromagnetic transmitter that had three metal balls along each side and one ball placed off-centre and inferiorly embedded within the structure. The headset provided a constant coordinate reference for the patient and also a means of automatic registration. The headset was placed on the patient's head before the pre-operative axial CT scan was obtained. Thus, at the time of surgery, when the same headset was placed on the patient, the reproducible position allowed accurate registration of the system. Radiopaque fiducial markers were not required for this reason.

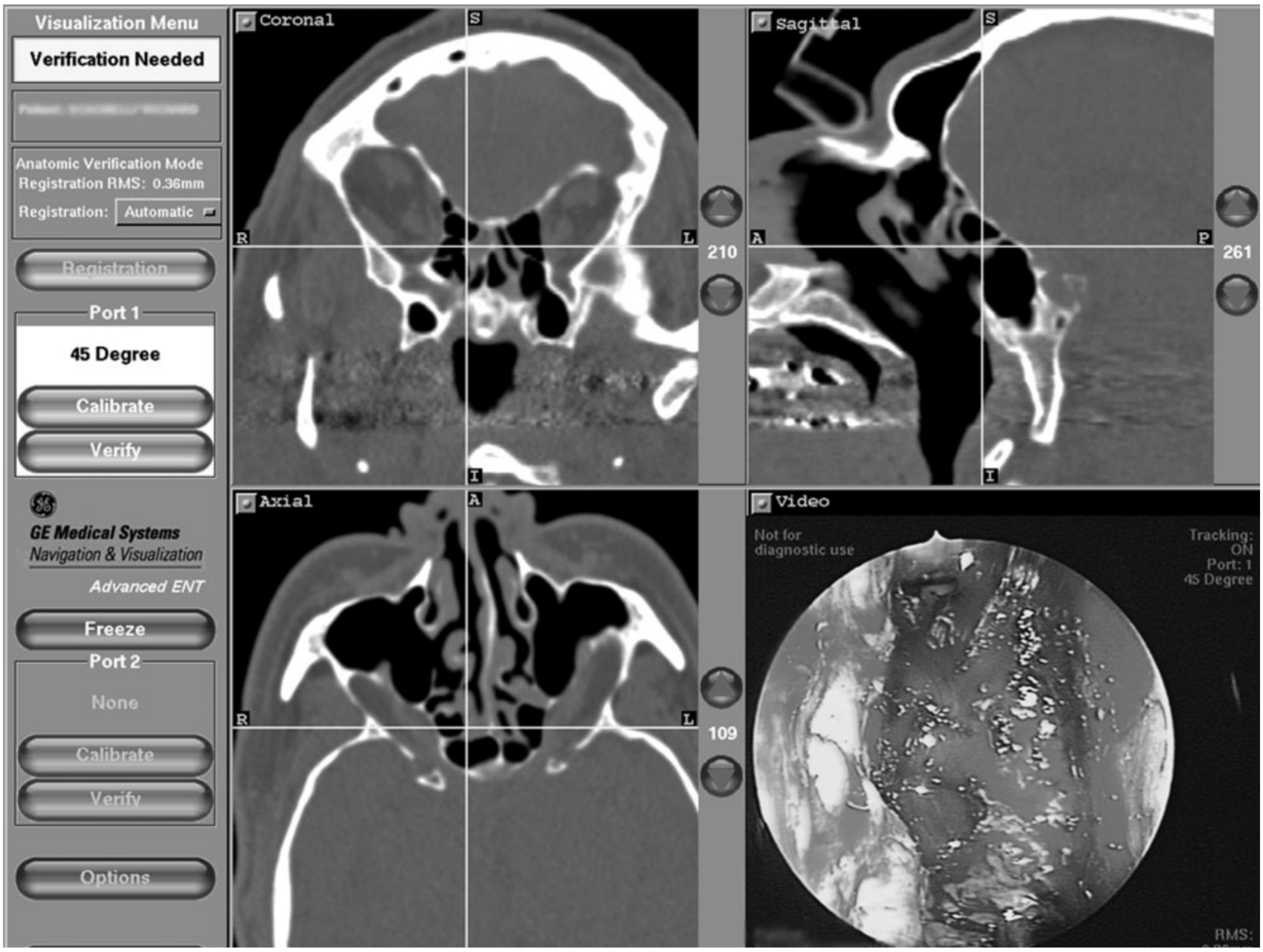

FIG. 2

Intra-operative navigation with an InstaTrak computer-aided system, showing triplanar computed tomography imaging. Despite resection of the middle turbinate and skeletonisation of the skull base to obtain directed biopsies, navigation continues based on pre-operative imaging. The middle turbinate and its basal lamellae, along with the posterior ethmoid sinus, are still present on imaging.

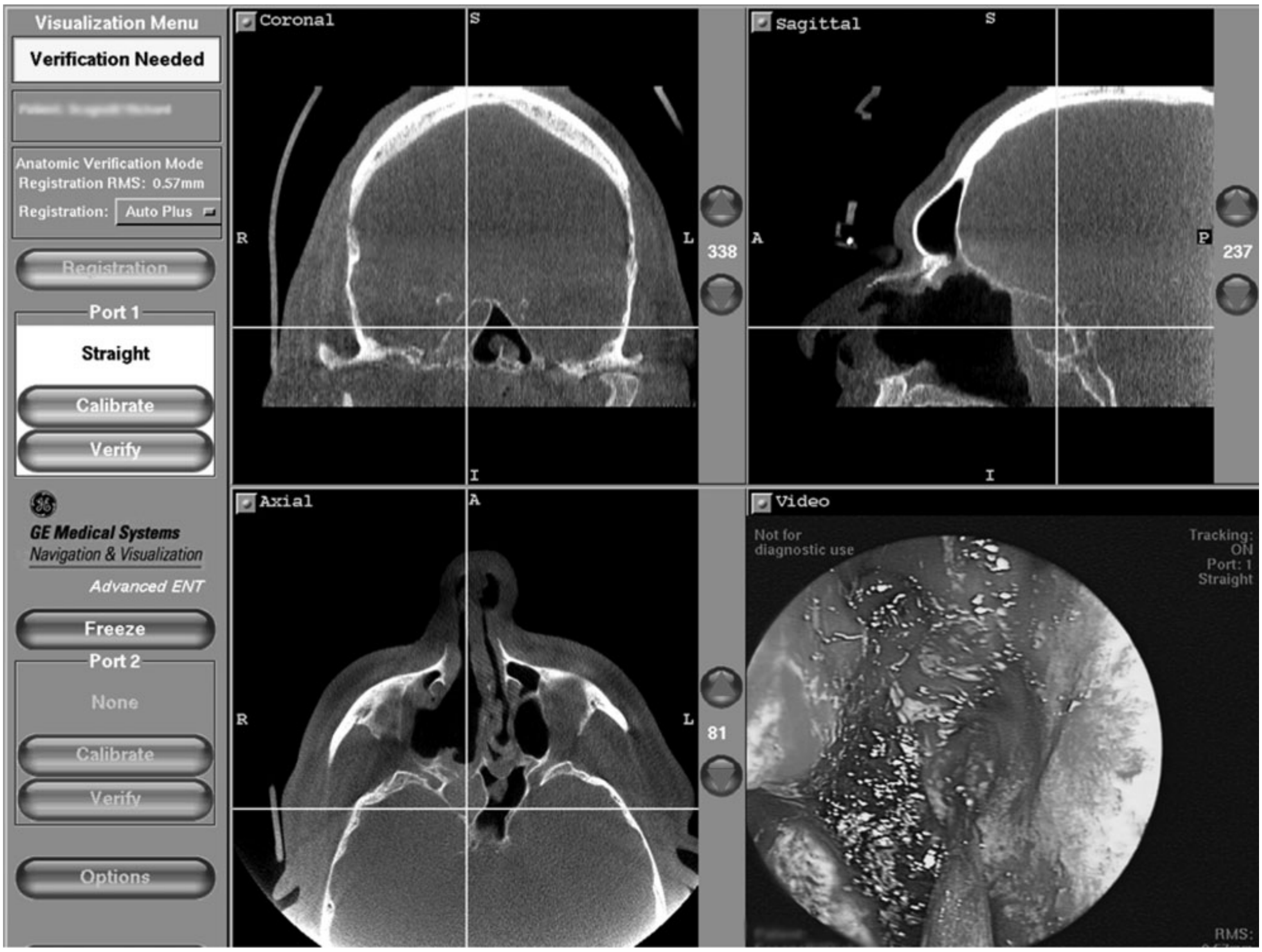

FIG. 3

The GE InstaTrak system shows a similar endoscopic view, but intra-operative images from the xCAT are now loaded into the system. On the updated image, the skeletonised skull base is readily apparent and the lateral nasal wall is absent.

Surgery was performed to remove the lateral nasal wall and to obtain directed biopsies. At that point, the xCAT system was properly positioned around the patient at the head of the bed in order to acquire updated CT images. The xCAT intra-operative scanning was performed so as to include the InstaTrak headset unit. The xCAT used alignment lights to indicate the centre of the imaging volume where they converged, depending on the desired anatomy to be imaged (brain, sinuses, inner ear, etc). Manual 180° rotation of the gantry was performed to check for obstruction and to avoid collision. With the scanner in position, the system began image acquisition. The data were then downloaded in digital imaging and communications in medicine (DICOM) format and transferred to the InstaTrak computer. The InstaTrak then conducted a post-processing procedure whereby DICOM data were translated into a volumetric data set in order to allow calibration and subsequent navigation. The new, updated images were then referenced during the remainder of the procedure, allowing navigation (Figure 3). These updated images were integrated successfully into the InstaTrak system. These images were consistent with the endoscopic view of the anatomy.

Conclusion

The advent of frameless, stereotactic computer-aided systems, over 10 years ago, has accelerated the field of rhinology by enabling enhanced real-time imaging. The xCAT intra-operative mobile volume CT scanner is a technological advancement which can assist the endoscopic sinus surgeon with complex rhinological and skull base cases, by providing up-to-date CT imaging integrated with the computer-aided system.

References

1 Perry JH, Rosenbaum AE, Lunsford LD, Swink CA, Zorub DS. Computed tomography/guided stereotactic surgery: conception and development of a new stereotactic methodology. *Neurosurgery* 1980;**7**:376–81

2 Cartellieri M, Vorbeck F. Endoscopic sinus surgery using intraoperative computed tomography imaging for updating a three-dimensional navigation system. *Laryngoscope* 2000; **110**:292–6

3 Siewerdsen JH, Jaffray DA. Cone-beam computed tomography with a flat-panel imager: magnitude and effects of x-ray scatter. *Med Phys* 2001;**28**:220–31

4 Sukovic P. Cone beam computed tomography in craniofacial imaging. *Orthod Craniofac Res* 2003;6(suppl 1):31–6, 179–82

5 Aldrich JE, Bilawich AM, Mayo JR. Radiation doses to patients receiving computed tomography examinations in British Columbia. *Can Assoc Radiol J* 2006;**57**:79–85

6 Cohnen M, Wittsack HJ, Assadi S, Muskalla K, Ringelstein A, Poll LW *et al.* Radiation exposure of patients in comprehensive computed tomography of the head in acute stroke. *AJNR Am J Neuroradiol* 2006;**27**:1741–5

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