REVIEW

Rhinology, 40, 1–9, 2002

Image guided surgery of paranasal sinuses and anterior skull base - Five years experience with the InstaTrak®-System*

Wolfgang Koele[1], Heinz Stammberger[1], Andreas Lackner[1], Pia Reittner[2]

[1]ENT Department, University Medical School, Graz, Austria
[2]Department of Radiology, University Medical School, Graz, Austria

SUMMARY

We report on our experience with navigational tools in paranasal sinus and anterior skull base surgery, especially with electromagnetic guidance systems. During the last five years we operated over 80 selected cases with the InstaTrak® system from VTI (Lawrence, MS, USA). Applicability and user friendliness were explored.
The InstaTrak® 3500 employs a Sun® Workstation and is a frameless and free-arm and navigation system. Two different suction devices, used as sensors (receivers), and one transmitter are interconnected to this workstation. The position of the tip of the aspirator is displayed as a pair of crosshairs on the screen in axial, coronal and sagittal planes of the patient's CT-scan on the computerscreen online.
Our results showed high accuracy-level, usually better than one millimeter and a setup-time less than ten minutes, on average. No additional personnel is required in the OR. We believe that the system enhances efficacy in selected cases like revision surgery, tumor surgery or difficult anterior skull base surgery. However, one should consider that medicolegal responsibility stays always with the surgeon and not with any navigation system.

Key words: computer assisted surgery, image guided surgery, functional endoscopic sinus surgery, FESS, ESS

INTRODUCTION

Since the 1970s functional endoscopic sinus surgery (FESS) is the method of choice for surgical treatment of sinus problems. This method was developed at the University ENT-Department at Graz, Austria and became widely spread and is now one of the most frequently performed operations in ENT worldwide (Stammberger, 1991). Unfortunately, this operation also can be accounted responsible for several, partially serious complications worldwide. Even though statistically the rate of severe complications after FESS is much lower when compared to external approaches, the absolute numbers climbed due to the increased popularity of endoscopic sinus surgery. It is true however, that there have been severe complications following FESS and surgeons have to be aware that they are operating in an anatomically complex and delicate area (Maniglia, 1991; Kainz et al., 1993; Kennedy et al., 1994).

In order to improve safety of this operation attempts have been made in implementing computer aided image guidance systems, as they are already in clinical use for neurosurgical procedures (Mösges et al, 1993; Roth et al., 1995; Fried et al., 1996). In recent years we collaborated with different companies and became involved in development and testing of such devices for applications in sinus and anterior skull base (Luxenberger et al., 1999).

The basic idea of such systems is to provide a real time control of orientation for the surgeon while operating in a complex anatomical field - in this case the paranasal sinuses. These systems are able to calculate motion of a sensor in relation to the patient in a three-dimensional field and display the current position of this sensor on the patient's CT scans on a monitor. This allows surgeons to evaluate their assessment of the patient's individual surgical anatomy (Fernandez et al., 1997; Javer et al., 2000).

Major drawbacks of such devices are considered their cost intensity, complicated setup in the OR as well as circumstantial scanning of the patient. Some systems also require fixation of the patient's head (Freysinger et al., 1997). Other problems include lack of reliability and accuracy of these systems (Fried et al., 1997; Cartellieri et al., 2001).

* Received for publication: February 6, 2002; accepted: February 10, 2002

MATERIAL AND METHODS

Since the mid-1980s the authors have used and tested most of the early computer-assisted navigational devices during many FESS courses and workshops worldwide. Despite significant progress in design, handling and accuracy of several electromechanical or optical systems the development of electromagnetic technologies have finally allowed for a breakthrough of intraoperative navigation in the paranasal sinus and anterior skull base regions. Today however, the optical guidance systems are widely spread as well.

In January 1997 we started to test the InstaTrak® system of VTI (Visual Technology, Inc., Lawrence, MS, USA). Eighty patients have been operated by now using InstaTrak®. Though in the beginning we were skeptical whether this technology already was advanced enough for clinical routine, we have to admit that our overall experience with the InstaTrak® system was very positive. It was not anymore this indeed promising, but still rather circumstantial and not always reliable technique we were used to. Operating the system is easy and does not require a software specialist or extra PhD in the OR. We were surprised by the accuracy of the system, when we tested it in our first 80 patients (Luxenberger et al., 1999).

The VTI InstaTrak® System is the first system that compensates for or avoids several disadvantages of other systems. The patient's head can be moved during a surgical intervention without the need for recalibration. The system is frameless, so no rigid fixation in a frame or to the operating table is required. Neither are fiducial markers, which might lead to inaccuracy when reattachment becomes necessary. As rigid head frame or fiducials are not required, one can operate on the patient a few hours but as well weeks after the CT scanning. Once trained, the operating room team is able to run the system with high accuracy, and no additional technician is required in the operating room.

The system consists of a headset that fits securely over the nasion and into the patient's external ear canals. An electromagnetic transmitter is connected to the headset. The electromagnetic receiver is integrated into the handle of a surgical aspirator. Transmitter and receiver are interconnected via the system's computer, a Sun® Ultra10, employing an UltraSPARC IIi processor at 440 MHz, 1024 MB RAM and a 21 GB harddisk. The resolution of the 17" LCD touch screen is 1280 x 1024 (Figure 1). First, an axial CT scan of the patient is performed using the algorithms listed in Table 1. The patient must wear the headset during the CT scan. The headset has integrated fiducial markers, which must be included in the scan. Their position remains constant in relation to the patient's anatomy within a margin of fractions of a millimeter, despite the relative elasticity of the headset itself. The position of the fiducials is automatically identified via an image-processing algorithm. The CT data are transferred either via a direct network ("Ethernet") or magneto optical disks and loaded into the InstaTrak® computer in the operating room.

Table 1. Parameters of the CT sanners we use.

	Toshiba Aquilion	**GE LightSpeed QX/i**
Gantry Angle:	0°	0°
Table Swivel:	---	---
Matrix:	512 x 512	512 x 512
Scan Mode:	Helical	Helical
Scanning plane:	Axial	Axial
Slice thickness:	1mm	2.5mm
Reconstructed		
Table Increment:	1mm	0.8mm
Algorithm / Filter:	FC30	Bone
KV:	120	120
mAS:	200	150
SFOV:	Head /240mm	250mm
Reconstructed		
Diameter:	209mm, Dependant on the anatomy; has to be re-done each time.	200mm, Dependant on the anatomy; has to be re-done each time.
Duration of Scan	1 Minute	1 Minute
Radiation Dose	2-4 RAD	2-4 RAD

Figure 1. OR-setup of the system.

Figure 2. System's monitor: splitscreen in four quadrants, the original axial view and the reconstructed coronal and sagittal views. In the right inferior quadrant is the reconstructed 3-dimensional image. The patient is an 11-year old boy with a bullet in his left orbit, stuck between the medial and inferior rectus muscles and the optic nerve. Both bullet fragments were safely removed via an endonasal route and vision recovered completely.

Here, the axial, coronal and sagittal sections are reconstructed and a triplanar CT display is generated (Figure 2).
Movements of the electromagnetic receiver with attached VTI aspirator in the electromagnetic field are registered and tracked in relation to the position of the transmitter. The system's software calculates online the position of the tip of the aspirator-receiver. This position is displayed on the monitor (represented by the center of a crosshair) in all three planes (sagittal, axial and coronal). Thus the surgeon can identify the position of the instrument in space intraoperatively on the CT scan in all three planes, and correlate this with the direct endoscopic/microscopic view. The InstaTrak® System and the ConneCTstat workstation support the DICOM® 3.0 (Digital Imaging and Communications in Medicine), standard in most modern CT scanners.

During the operation the patient has to wear again the very same headset used for the CT scan. One of the first problems we ran into at Graz resulted from not all seven fiducials of the headset being included in the CT scan, which led to problems with auto registration. Therefore, the radiologist must identify and include all of the headset's seven fiducials on their scan. For proper data acquisition, therefore a very close relationship between the radiology department and ENT-surgeons is mandatory.
During the surgical procedure, dense and heavy metallic objects may interfere with the electromagnetic field and cause distortion, if for example a metal operating table is used, a 4-inch (10 cm) foam pad must be placed between the table and the patient to avoid interference and distortion of the electromagnetic field. A metal detector integrated into the VTI System informs the surgeon of potential magnetic distortion by flashing a special warning on the monitor screen.
We were pleasantly surprised at how little time the system needs for preoperative setup. A few minutes usually suffices. On average in all our cases we stayed under 10 minutes of total setup time in the operating room. This included adjusting, calibrating and verification of the system, positioning the headset and draping.

RESULTS

Advantages and Limitations of the InstaTrak® System

Until recently, some of the major disadvantages of most navigational systems have been the almost unacceptable amounts of expensive technology, bulky hardware, time consuming setup and, most of all, the need for additional operating room personnel (Freysinger et al., 1997; Cartellieri et al., 2001). We believe this problem has been solved, by and large, with the InstaTrak® technology.

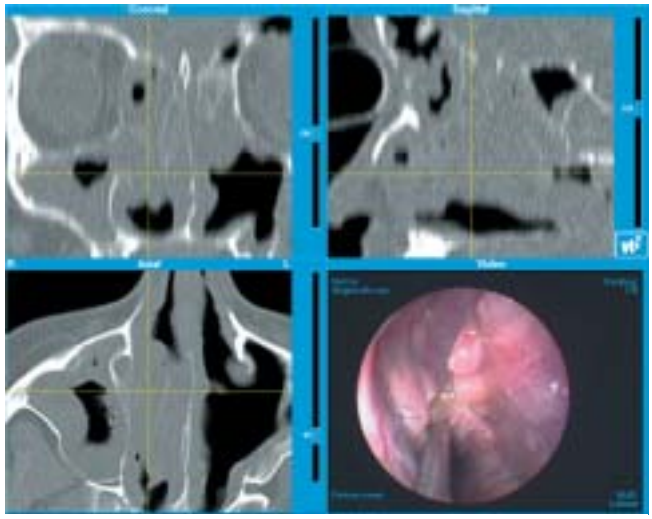

Figure 3. Picture – in – Picture (PIP) on the screen: If the navigation instrument is within the surgical volume, and a camera is attached to the system, the right inferior quadrant of the splitscreen shows the endoscopic image, in this case a recurrence of massive polyposis, lacking of known anatomical landmarks.

According to our experience, the major advantages of the InstaTrak® System include:
- High practicability and user-friendliness in clinical application.
- Setup time of less than 10 minutes.
- No specialized personnel (i.e. "expensive" additional technicians) required.
- Days to weeks interval possible between scan and surgery.
- Full motility of the patient's head intraoperatively, no need for recalibration after or during movement, no fixation to a frame or the surgical table required.
- No problem with covering LED's (like in optical systems) by surgeon's hand, arms or body.
- Highly reproducible accuracy, in our cases better than one millimeter on average (Fried et al., 1997; Luxenberger et al.,

1999; Cartellieri et al., 2001).
- Availability of a "picture-in-picture" system. All relevant information is presented on one monitor screen: the triplanar CT display plus the corresponding actual endoscopic picture. All information required to obtain accuracy and orientation can be seen on a single monitor.

(We are proud to have been involved in the development and installation of this "PIP" system: The first video clips of surgical procedures with synchronous display of triplanar VTI-CT-reconstruction and endoscopic pictures world-wide originated from our department at the Graz University Hospital (Figure 4).)

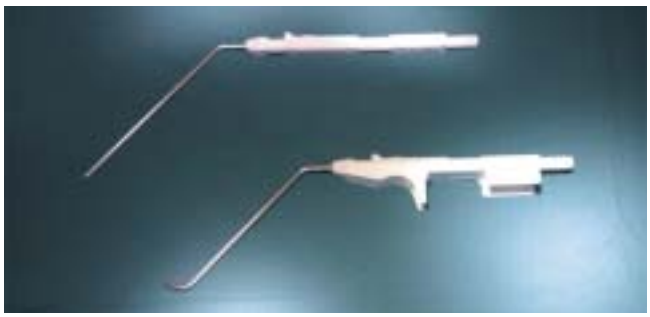

Figure 4. We use two different types of aspirator-localizers: straight and 45°.

The "hardware" consists of one single tower and is easily transportable. The entire device can be rolled from one operating room into another, even "over the street" to other departments. There is no need for any devices to be mounted to the ceiling or for a special type of operating table.
The aspirator is used as a localizer (Figure 4). This avoids the disadvantage of using a pointer and saves frequent change of instruments. Other instruments that can be used as localizers are under construction.
Should the endoscopic picture become blurred due to blood or debris topographical information does not get lost (Figure 5).

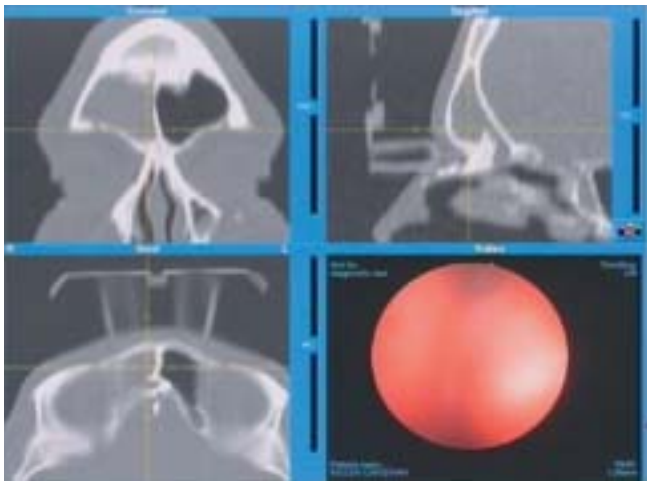

Figure 5. The aspirator tip is clearly in position inside the right frontal sinus, despite not visible in the direct endoscopic image, which is blurred by debris.

To fully appreciate the possibilities of the system and to avoid navigational problems, surgeons must understand its working principle and consider the following:
- Due to its flexibility, relatively minor pressure on the headset by direct or indirect force (leaning on it, pulling the cable, pressure on the draping, etc.) may distort the headset slightly and temporarily decrease accuracy.
- If the VTI aspirator is used as an instrument, i.e. if pressure is put on it, distortion of several millimeters may occur due to the flexibility of the steel shaft (Figure 6).
- As with all navigational systems relying on preoperatively acquired imaging data, only the localization of the tip of the navigational instrument is indicated in the triplanar display. The system cannot give the surgeon information on the amount of tissue, which was or is removed during the procedure.

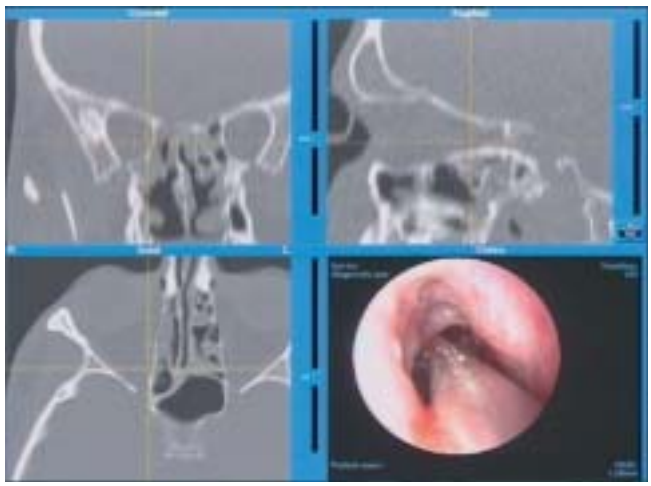

Figure 6. Example of deviation: The VTI aspirator is flexed by the surgeon (incorrect handling) resulting in erratic display of crosshairs intraorbitally. Endoscopically the instrument is clearly not inside the orbit but in the posterior ethmoid.
This is the favorable one of two possible erratic situations: it is worse if the cross-hairs indicate a safe position but if the instrument has actually gone astray already (for instance) intracranially, intraorbitally, or dangerously close to the optic nerve or carotid artery. This however, is not the system's fault. Medico-legally the surgeon must realize such a potentially dangerous situation and correct it.

The headset can be placed in a wrong position: During scanning or when reapplying the headset preoperatively, the tragus of one or both sides may be "trapped". This may lead to a slight inaccuracy that would not be identified during verification of the system. Only the direct correlation of the visual information through the endoscope and identification of known landmarks there and on the triplanar reconstruction can precisely confirm the actual position.
In our department, in one case, the headset was misplaced a full 180 degrees by a radiology assistant. This mistake, however, led to extended possibilities: by placing the headset in this way, considerable areas of the infratemporal fossa adjacent

to the retro- and parapharyngeal space could be scanned and navigation applied to this region. With this technique we were able to place devices used for brachytherapy with extremely high precision absolutely parallel into tumors of the skull base. This enabled our radiotherapists to precisely deliver the best radioisodoses possible for the individual case (Figure 7).
The distance between the front of the headset where the fiducial markers are located and the forehead is rather large. Therefore significant "empty space" has to be scanned between the fiducials and the areas of interest, which adds to the radiation dose.

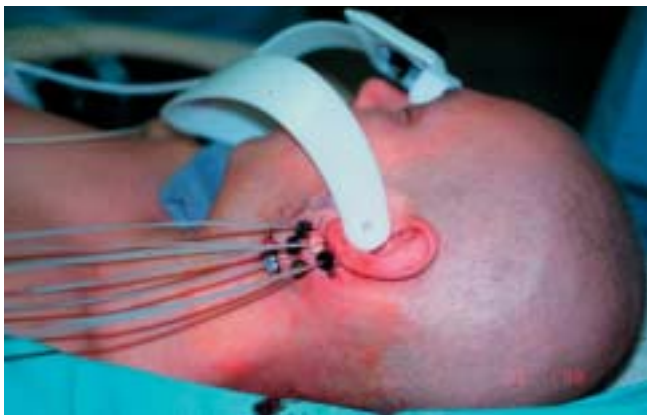

Figure 7. Inverted position of the headset: Areas of the infratemporal fossa adjacent to the retro- and parapharyngeal space could be scanned and navigation applied to this region. With this technique we were able to place devices used for brachytherapy with extremely high precision absolutely parallel into tumors of the skull base.

The handle of the receiver (aspirator) is still rather bulky, not all "corners" of the sinuses can be reached even with the curved navigational aspirators currently available. This can be of disadvantage especially in the frontal sinus region.
Like in all electromagnetic systems, interference may occur if massive metallic instruments (like the shaft and handle of the endoscope) are too close to the receiver in the handle of the suction device. This, however, is clearly indicated as a warning on the screen of the VTI System.
There is a relative contraindication to use electromagnetic systems in patients supported by implanted electronic devices such as cochlear implants or cardiac pacemakers as the electromagnetic fields may cause interference.
A cranial pin for lateral skull base or cranial approaches is available. The pin is screwed into the patient's skull; the transmitter is attached to the pin. This of course requires placement of fiducial markers prior to the CT-scan. These markers cannot be moved or replaced after the scan until the end of surgical procedure. Cranial pin and fiducial markers are replacing the headset.
Instead of the CT-scan a MRI can be used, if necessary. Image fusion is not possible by now.

Intraoperatively
After the patient has been intubated for endoscopic surgery and the face been prepared, the headset is put in place by the surgeon, who is responsible for the correct positioning of the device. The nurse then completes the draping and both nurse and surgeon put in place the clear sterile drape to cover the headset. Then, decongestant-soaked swabs are placed into the nose and after this, the instruments are calibrated and verification performed. While waiting for the decongestant to act (~ 5 - 8 minutes), the triplanar scans are studied again, special anatomical features pointed out and danger areas highlighted. We considered the possibility of scrolling through the triplanar anatomy (and pathology) one of the most valuable features of the system as it enables the surgeon to build a triplanar/3-dimensional conception in his/her mind of the patient's anatomy and individual pathology. If necessary, magnification, contrast and brightness are modified to parameters considered best for the individual case (depending on the CT scanning machine).
Then we acquire the video signal from the endoscope's digital camera, which is connected with the VTI System. The VTI System allows either a BNC or an Y/C (Super-VHS) input, the latter providing the better quality.
After pledgets have been removed, the all-important "system vs. reality-check" takes place. Under direct endoscopic vision, anatomical landmarks are visually identified and touched with the electromagnetic receiver with attached VTI aspirator. "Real" anatomy and virtual triplanar display must match precisely ("optical cross-matching"). Various points – pathology permitting – along each axis are cross-matched in this fashion, all with clear bony or non-shiftable soft tissue substrate. Commonly used landmarks are septal spurs, spines or crests, anterior tip of middle turbinate, insertion of the middle turbinate or any characteristic structure in revision surgery (Figure 8).

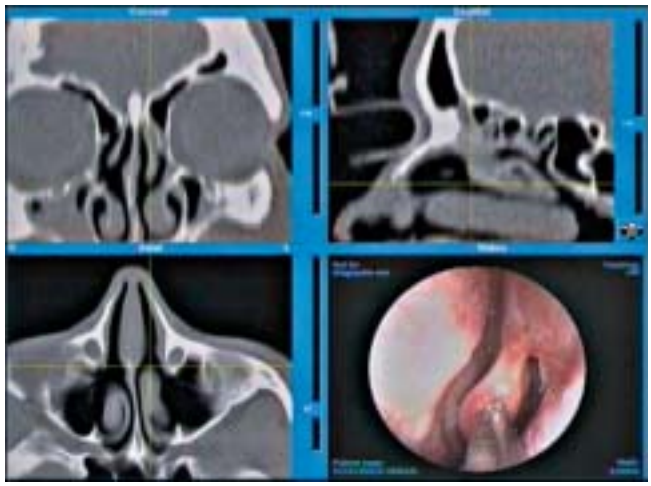

Figure 8. Optical cross-matching: Under direct endoscopic vision, anatomical landmarks are identified and touched with the electromagnetic receiver with attached VTI aspirator. "Real" anatomy and virtual triplanar display must match precisely, like here at the anterior tip of the middle turbinate.

With RMS values (Root-Mean-Square deviation, a mathematical function indicating deviation between points in the CT-volume and the "real" patient) usually better than 1.0 mm, following a comprehensive "cross-matching" procedure, a high degree of certainty and accuracy are confirmed for the surgeon, thus enhancing the confidence in the system's displays.

Clinical application examples

Patient 1: (Figure 9) A 70-year old female with an expansion originating from the apex of the right pyramid.

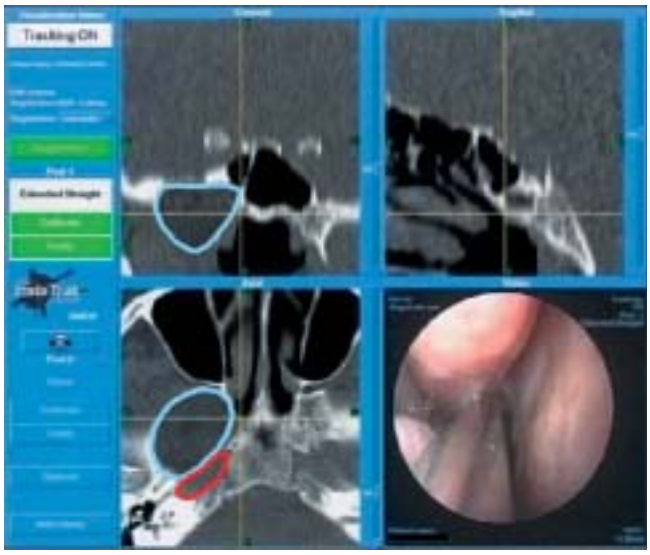

Figure 9.

This lesion turned out to be a dermoid cyst. The triplanar display demonstrates best accessibility from the choanal region just behind the posterior end of the middle turbinate and above the tubal lip. This information could not be generated with the same accuracy from the standard CT Scan and the endoscopic findings alone.

Figure 10.

During surgery, the sphenopalatine artery (crosshair on axial scan) and the pterygopalatine fossa can precisely be located and bleeding thus avoided (see axial and coronal displays (Figure 10).

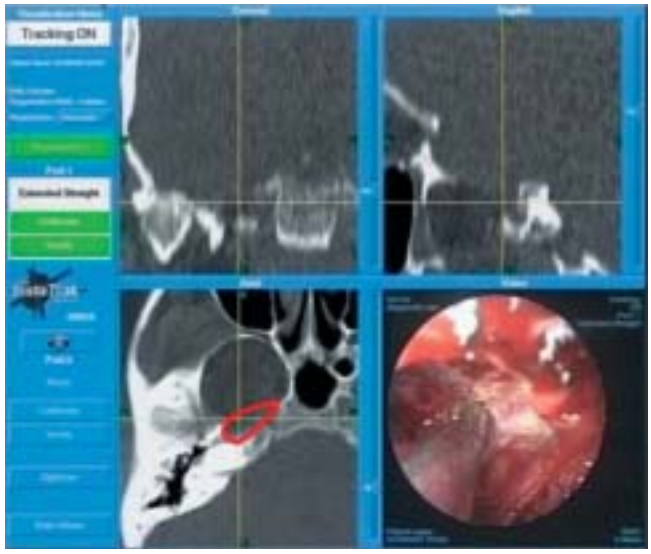

Figure 11.

The cyst contained cholesterol masses; hairs and other components have been evacuated (Figure 11). The tip of the probe sits on the horizontal course of the internal carotid artery, the wall of which is slightly indented by the probe (see endoscopic image). The artery was without any bony cover for two centimeters in the cavity during its course through the floor of the middle cranial fossa. A large communication was created towards the nasopharynx and toward the maxillary sinus (not visible here). There were no problems post-operatively. The patient is free of symptoms without any recurrence after 4 years.

Case 2: (Figure 12) A 73-year old female with recurrence of adenoid cystic carcinoma on the right side, 13 years after the primary surgery on the left side.

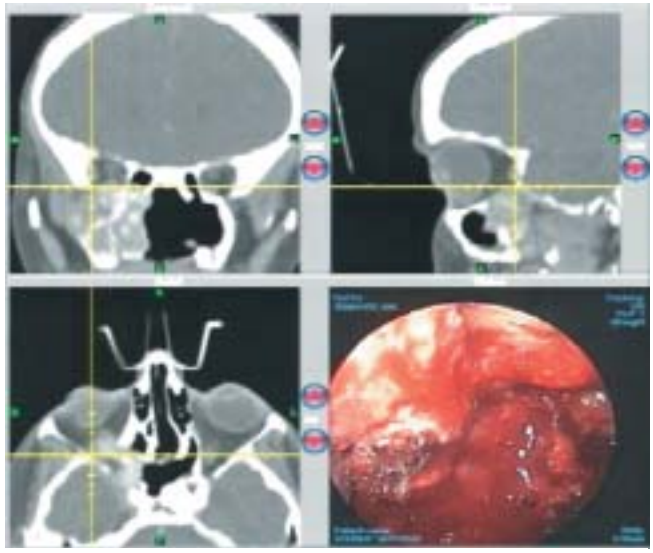

Figure 12.

Endoscopic approach: crosshairs indicating arrival at lateral orbital wall.

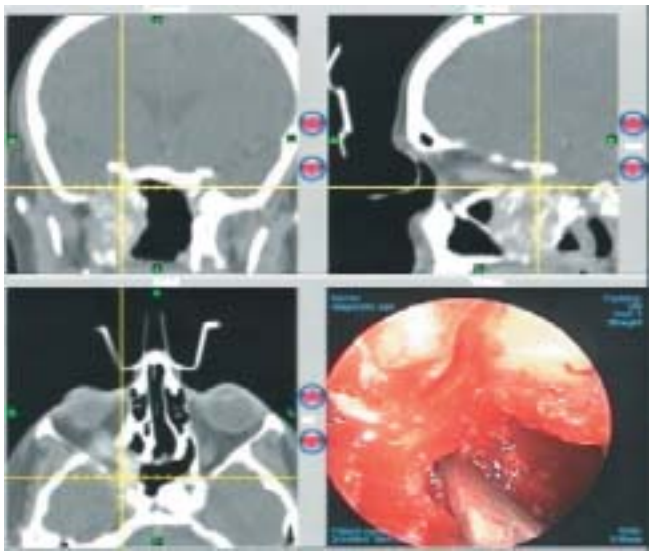

Figure 13. Behind the pterygoid process, which has completely resected endoscopically, and beyond the orbital apex.

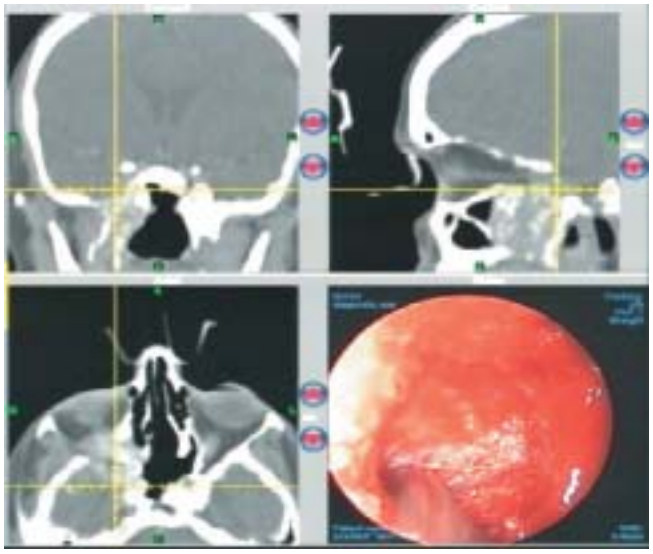

Figure 14. Identification and exenteration of the cavernous sinus on the right and arriving at middle cranial fossa at temporal lobe dura.

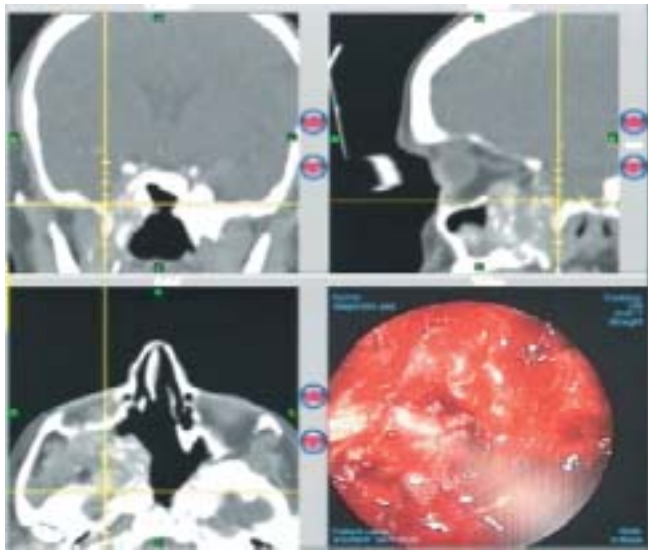

Figure 15. Skeletonizing the trigeminal ganglion.

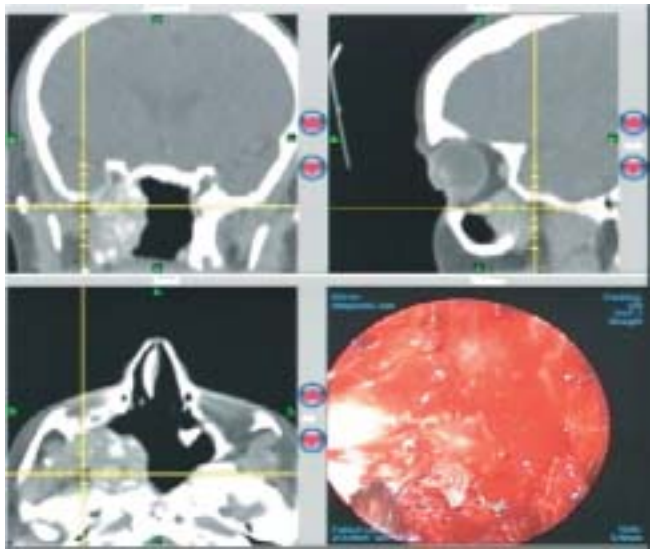

Figure 16. Approaching the infratemporal fossa lateral to the tumor margin.

CONCLUSIONS

Despite our initial skepticism, our experiences in the first selective difficult cases over the first few months have been extremely positive. Today, after five years of VTI-use, we see very good applications for special indications, for example in very difficult anatomical relationships after previous operations, especially in revision surgery of the frontal recess/sinus, in the vicinity of critical structures of the anterior skull base, the medial wall and apex of the orbit, the sphenoid, and especially when operating on tumors. Here, the limits of possibilities are clearly extended in the hands of experienced surgeons and operating time can be reduced (Figure 17).

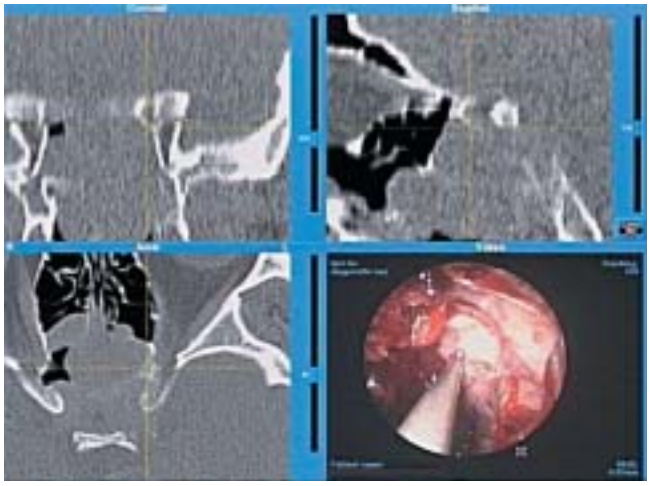

Figure 17. In a T3 adeno carcinoma of sphenoid and posterior ethmoidal sinuses the optic nerve is identified on the left side. Following endoscopic surgery and radiation (Gamma knife and conventional) the patient is free of disease for more than three years now.

We have operated on more than 40 cases of tumors with complete destruction of all anatomical landmarks, especially surrounding the internal carotid arteries and the optic nerves, with a radicality, precision and relative safety that would not have been possible without the navigational system. The InstaTrak® System enhances the degree of confidence of the surgeon, once the accuracy has been verified in the individual case. There are good applications for teaching and training, as the system "forces" the resident to deal with and perfectly master CT as well as endoscopic anatomy.

However, it remains to be seen whether and to which degree navigational devices make sense in everyday routine cases (we did not use the system for those), and whether lesser-experienced surgeons will improve their quality of surgery when using these devices. Under no circumstances must surgeons forget that "opacifications" displayed in CT and/or MRI do not automatically relate to pathological structures that should be removed. Only in this way can routine radical operations and surgical "overkill" be avoided.

There is a (slight) theoretical possibility that under the impression of additional security, surgeons might be encouraged to approach cases upon which, based on their experience and abilities, they probably should not attempt to operate.

The single most important criterion when using this intraoperative navigational device is the direct visual control of the surgical field. Only in this way can reality be correlated to the triplanar reconstructions with a high degree of certainty.

Misguidance can occur, but rarely is it the system's fault. Inexact placing of the headset leads to different positions of the fiducials in the CT-scan and on the "real" patient. Only the surgeon can detect this error by optical cross-matching. Another possibility of misguidance not automatically detected by the system is forced pressure either on the navigation aspirator, so that it will bend and give wrong information about the actual position, or pressure on the flexible headset by assisting staff or wrong draping during the procedure.

From this it becomes evident that the final responsibility is always with the surgeon. He or she must understand the working principles of their system and readily identify potential interferences or deviations.

Based on our experience, the VTI InstaTrak® System is the most user-friendly and reliable of all systems we tested for use in very difficult cases in the paranasal sinus and anterior skull base regions. Despite the high number of very complex cases performed, no complications occurred in our series.

Intraoperative computer-assisted navigation is a very helpful technology in selective cases, providing high accuracy and reliability. The surgeon must be familiar with anatomical structures of the surgical field, however, no system can take away that responsibility. Navigational systems provide intraoperative help, but surgeons will remain responsible for all of their decisions.

There is no answer yet as of today whether routine use of navigational systems will decrease the number of complications of endoscopic or other sinus surgery, nor whether such systems will improve any surgeon's dexterity, talent or results. We have become convinced however, of the increased efficacy of the surgical treatment in selected, difficult cases, when the confidence of the surgeon is significantly enhanced when working in topographically delicate areas.

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Wolfgang Koele, M.D.
ENT Department
University Medical School Graz
A-8036 Graz
Auenbruggerplatz 26-28
Austria

tel: +43 316 385 7979
fax: +43 316 385 3425
e-mail: wolfgang.koele@uni-graz.at

SOCIETY NEWS

CALL FOR PAPERS

RESEARCH PRIZES 2002 of the EUROPEAN RHINOLOGIC SOCIETY

The European Rhinologic Society biennial awards two Research Prizes; one prize is awarded for original basic research, and the second for an original clinical research in the field of Rhinology. In 2002 again, these prizes will be awarded, and therefore ENT Residents and Fellows are kindly requested to apply. Entries will have to meet the following conditions:

- Entries are to be submitted in the form of a scientific paper. Papers that have been accepted for publication by an international scientific journal will also be considered. Scientific papers – as well as supplements and Ph.D.-theses – that have already been published are excluded from competition.
- The research paper submitted is either the result of individual research activities or resulting from a team effort. In the latter case the first author will be considered as the nominee.
- Each applicant is allowed one entry. The author indicates whether the paper is a basic research or a clinical study. (We define clinical research as studies that deal with patients or normal subjects in a clinical set-up, whereas basic research refers to studies performed with either animals or tissues taken from patients or normal subjects).
- Only candidates below the age of 40 years can apply.
- The executive Committee of the European Rhinologic Society, supported by a number of invited expert referees, will act as the jury and will select both prize winners.
- The prizes, each of which amounts to € 1,500.- will be awarded during the Opening Ceremony of the forthcoming ERS Congress at Ulm (Germany), June 15- June 21, 2002. The prize winners will be invited to attend the congress, free of charge. The prize-winning entries will be given priority when submitted to the Journal Rhinology.

Applications together with five copies of the submitted papers, should be directed before April 15, 2002, to the Editor-in-Chief of the Journal Rhinology, Prof.Dr. E.H. Huizing at the following address: Department of Otorhinolaryngology, University Medical Center Utrecht, Heidelberglaan 100, NL-3584 CX Utrecht, Room G05.127, The Netherlands.