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Main Article

Computer-assisted surgery of the paranasal sinuses: technical and clinical experience with 368 patients, using the Vector Vision Compact® system

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Abstract

Introduction: This paper presents our experience with a navigation system for functional endoscopic sinus surgery. In this study, we took particular note of the surgical indications and risks and the measurement precision and preparation time required, and we present one brief case report as an example.

Materials and methods: Between 2000 and 2004, we performed functional endoscopic sinus surgery on 368 patients at the Ludwig Maximilians University, Munich, Germany. We used the Vector Vision Compact® system (BrainLAB) with laser registration. The indications for surgery ranged from severe nasal polyps and chronic sinusitis to malignant tumours of the paranasal sinuses and skull base.

Results: The time needed for data preparation was less than five minutes. The time required for preparation and patient registration depended on the method used and the experience of the user. In the later cases, it took 11 minutes on average, using Z-Touch® registration. The clinical plausibility test produced an average deviation of 1.3 mm. The complications of system use comprised one intra-operative re-registration (18 per cent) and one complete failure (5 per cent). Despite the assistance of an accurate working computer, the anterior ethmoidal artery was incised in one case. However, in all 368 cases, we experienced no cerebrospinal fluid leaks, optic nerve lesions, retrobulbar haematomas or intracerebral bleeding. There were no deaths.

Discussion: From our experience with computer-guided surgical procedures, we conclude that computer-guided navigational systems are so accurate that the risk of misleading the surgeon is minimal. In the future, their use in certain specialized procedures will be not only sensible but mandatory. We recommend their use not only in difficult surgical situations but also in routine procedures and for surgical training.

Key words: Paranasal Sinuses; Surgery; Endoscopes; Surgical Instruments; Surgical Equipment; Image Processing, Computer-Assisted

Introduction

Computer-assisted guidance systems have already been used to a considerable degree in many medical disciplines (e.g. neurosurgery, radiotherapy, orthopaedics, and maxillofacial surgery). Their use in the head and neck area was first described by Schlöndorff *et al.* in the mid-1980s; since then, various working groups have established the clinical relevance of computer-guided surgery, primarily for the paranasal sinuses but also for the lateral skull base.[1–21]

In the last two decades, ENT surgery has gained much greater significance within due (amongst other factors) to the increasing incidence of chronic inflammation of the paranasal sinuses and the development of new surgical instruments and surgical techniques. With the introduction in the 1980s of endoscopic and microscopic paranasal sinus procedures, the incidence of associated complications initially increased.[2,14] Numerous publications in the late 1980s and early 1990s bore witness to the range and significance of these new procedures.[5–7,11–13,18–20,22–26] Appropriately, early modifications attempted to decrease the rate of such complications. In addition to the introduction of new surgical instruments,[7,23] the introduction of computer-guided surgery had special relevance in this respect.

Computer-guided systems establish an real time connection between pre-operative imaging data collected under conventional conditions (using computed tomography (CT) and magnetic resonance imaging (MRI)) and the surgical field. Using a computer-guided system, the surgeon can obtain information on the current position of the surgical instruments, either continuously or on demand. The patient's imaging data can be input directly into the navigation system computer, using an appropriate

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network (i.e. a picture archiving communication system), or via digital media (e.g. digital audio tape, read-only compact disc (CD-ROM) or magneto-optical disk (MOD)).

Previously, identifying markers were affixed to the patient before the CT or MRI examination, and these markers would then be correlated to the radiological images via the navigation system during the operation. The position of the markers, which were firmly attached to the head, was correlated by the appropriate program to the relevant radiological image. This allowed an exact assessment of the marked surgical instruments in the operative field via the coronal, sagittal and axial CT sectional images. A three-dimensional reconstruction was also possible on screen.

Surface Registration of the patient enabled an improvement in clinical precision and a reduction in time wasted both during registration of the imaging data and during pre- and intra-operative registration. The used navigation system offered laser surface registration, which made the preoperative implementation of affixed markers unnecessary.

In this paper, we present our experience with the Vector Vision Compact® system (BrainLAB, Heimstetten near Munich, Germany), taking particular account of the indications for surgery, operative procedure, measurement precision and time duration.

Material and method

The functional endoscopic sinus surgery (FESS) procedures were carried out between September 2000 and September 2004 in the otorhinolaryngology department of the Ludwigs Maximilians University, Munich, Germany.

Seventy-two per cent of the patients included had already undergone several previous operations and were therefore at higher risk of complications (Table I).

We began using the Vector Vision Compact system with Z-Touch® registration (BrainLAB) at the beginning of the study period. We operated on 368 patients with the aid of the navigation system: 169 women and 199 men. The average patient age was 53 years, ranging from 14 to 89 years. The patients' indications for surgery ranged from severe nasal polyps and chronic sinusitis to malignant tumours in the paranasal sinuses and skull base (see Table I).

TABLE I

PATIENT DIAGNOSES

Diagnosis	Procedure			Total
	1st	2nd	Multiple	
Chronic sinusitis	42	28	0	70
Nasal polyps	9	53	38	100
Mucocele	1	76	11	88
Sphenoid sinus	16	2	0	18
Carcinoma	55	20	0	75
Clivus tumour	2	0	0	2
CSF otorrhoea	0	2	0	2
Liquor leak	2	6	2	10
Atresia	2	0	0	2

CSF = cerebrospinal fluid

Pre-operative imaging

Each patient's imaging data were produced on a Siemens Somatron plus 4 Spiral-CT (Siemens, Erlangen, Germany) and included 90 to 115 axial images (2 mm table incrementation, 3 mm focus, 1 mm reconstruction interval, 140 kV, 100–150 mAS).

Of the 368 patients, the first 35 were examined using a 'head-set localizer' and the remaining 333 were scanned without previous marking. Data were transferred to a MOD and then to a CD-ROM, to be input later into a workstation.

This meant that the data record could be checked before the operation for completeness (for FESS, an anterior–posterior scan must be taken from the tip of the nose both tragi- and craniocaudally from the frontal sinuses to the lower margin of the incisors).[21] It also meant that extra information about the patient's individual pathology could be obtained using the zoom function and various contrast adjustments. In addition, the surgeon could plan the procedure pre-operatively.

The data record was modified if necessary and transferred to a zip disk, which was then loaded into the navigation system.

High quality image data were essential for safe and precise navigation during the operation. Any patient facial changes (e.g. shaving of a patient's beard between scanning and operation) and movement artefacts had to be excluded. In the first phase of routine use of the navigation system, the CTs of the paranasal sinuses were prepared the day before the operation. However, it was subsequently shown that the time window between CT examination and operation could be extended by up to four weeks. This made the planning of operations using navigation easier.

Patient positioning and registration

All patients were positioned conventionally, on their backs with a slightly raised head (inclined approximately 30°), without invasive (e.g. Mayfield clip) head fixation. Before registration of the patient, a head-set localizer with a marker star or a headband localizer was attached, to enable the head to be moved freely during surgery. Navigational precision was not negatively influenced by movement of the head, provided that all three localizers were visible to the cameras.

The Vector Vision Compact system is a two camera system which works passively; that is, infrared light is emitted by transmitters installed near the receiving cameras and is reflected by suitable objects (localizers or markers). These reflections are detected and used by the computer to establish both the positional coordinates of the patient's head and also the position of surgical instruments.

After the navigation system was suitably positioned (next to the monitor displaying the endoscopic view), surface registration of the patient was carried out using Z-Touch (class 1 laser) registration. The laser beam was moved over the face of the patient and reflections from the surface of the patient's face were detected by the cameras.[6] A virtual model of the patient's facial surfaces was then created, which

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correlated with the facial surface provided by the imaging data, i.e. the patient was matched with the three-dimensional data record. After this matching process was completed, the navigation system gave an estimated value of approximation of the computer generated point and the real actual point measured on the patient, i.e. the root mean square error value.

To check the clinical precision of the system, we carried out a standardized plausibility test on all patients. Anatomical landmarks on the patient's face were located by a specially marked pointer instrument (i.e. lateral and medial orbital edge, tip of the nose, columella, nasion, head of the middle nasal concha, and anterior wall of the sphenoid sinus) and compared with the corresponding position provided by the navigation system. Any deviations were measured in millimetres, in all three axes, and documented. If deviations were more than 2.5 mm, another patient registration was carried out. Registration could be performed on the patient either before anaesthesia (after they had been fully prepared for the operation, i.e. washed and covered) or directly after intubation. After successful registrations, the navigation system guided procedure was conducted by a single surgeon, without other technical assistance for navigation. The time duration of the registration and operation and the frequency of registration, along with any other relevant details, were also documented.

Besides use of the pointer, the system also offered the possibility of registering other instruments. Thus, we registered various straight and curved aspirators, Weil Blakesley forceps, and a Xomed Shaver (Xomed Medtronic, Germering, Germany).

Results

After establishing a standardized pre-operative routine for imaging and transferring data to a CD-ROM, data preparation at the work station took less than 10 minutes in all cases (average, 5.2 minutes) and was carried out by the surgeon themselves. For the first 35 patients, the CT examination was carried out with a head-set localizer; patient explanation and fitting took an extra 10 to 30 minutes (average, 20.2 min) in these cases.

Because of technical problems with the CT examination (i.e. insufficient sections were taken or important anatomical structures were too faint), nine patients needed to be scanned again.

The time spent on system preparation and patient registration depended greatly on the experience of the users. Initially, the navigation system was used too infrequently to gain sufficient handling experience; however, with increasing use, the system preparation time shrank (for later cases) to 10.8 min. Patient registration was a time-consuming but important

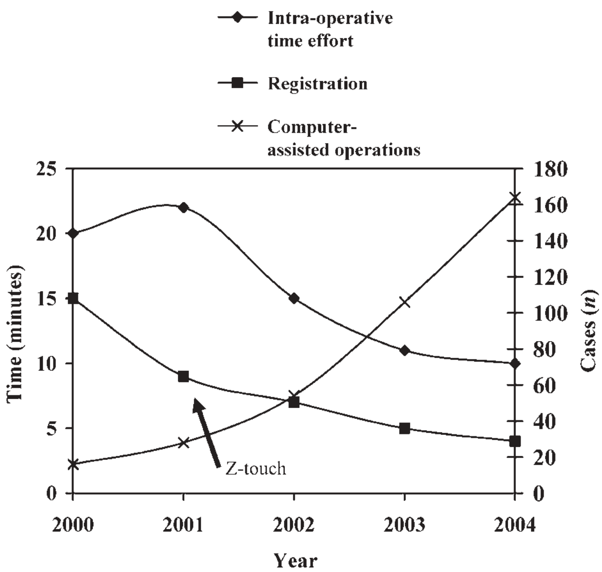

FIG. 1

Number of cases and time duration for system set-up, boot, data transfer and registration for computer-guided operations. As the number of cases increased, the time duration decreased.

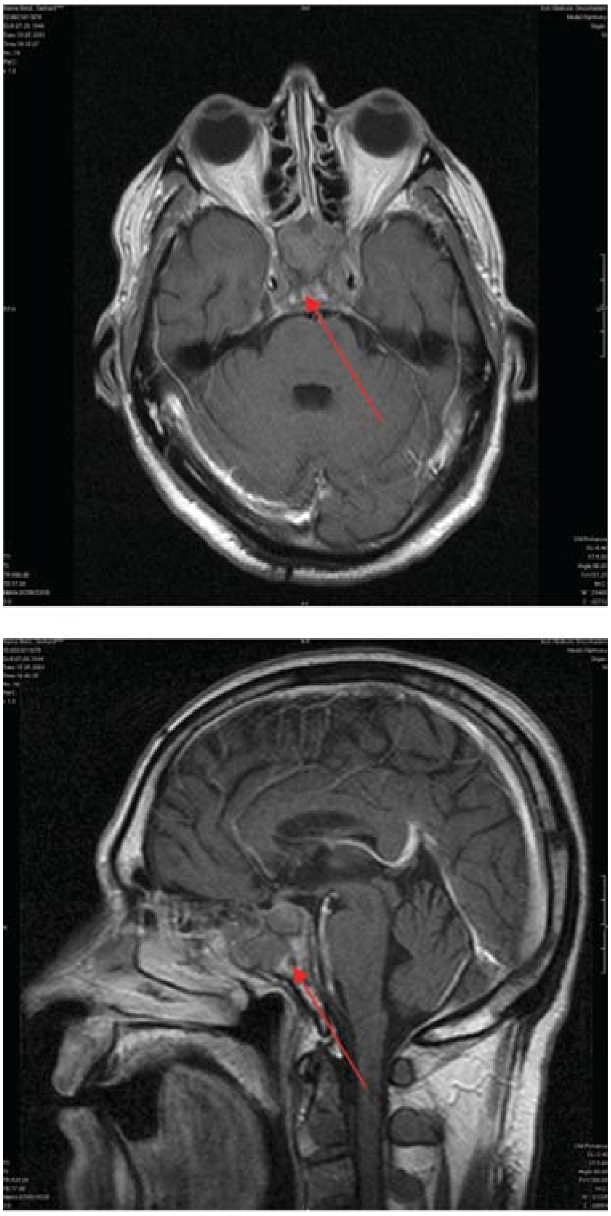

FIG. 2

Magnetic resonance imaging scan showing hyperintense tumour of the clivus.

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procedure. After 2001, all cases were registered with the aid of Z-Touch; at the end of the study (2004), registration required an average of five minutes (range, 2–16 minutes; see Figure 1) using this method.

The root mean square error value (a theoretical value of the maximum deviation, calculated internally by all opto-electric navigation systems) was 1.2 mm on average, ranging from 0.7 to 2.5 mm. Patients with a deviation of more than 2.5 mm were re-registered. For 202 patients (55 per cent), a single registration produced the required clinical precision. One hundred and thirty-five patients (37 per cent) needed to undergo laser registration twice, and the remaining 31 patients (8 per cent) needed to be registered several times. Despite repeated registration in 11 cases (3 per cent), the accuracy was so poor that navigation was impossible. In five cases (1.4 per cent), the navigation system could not be used at all because of a technical failure during the boot sequence. In four cases (1 per cent), the CT dataset was insufficient because of artefacts (i.e. metal prostheses and teeth).

The clinical plausibility test produced an average deviation in the *x* and *y* axes of 1.3 mm and in the *z* axis of 1.4 mm. In the clinical accuracy test, the deviation between the real pointer position and the navigated position was measured. Identifying the real pointer position depended on good anatomical landmarks and the ability to place the pointer precisely on these fixed landmarks. Re-registration during the procedure was necessary in 67 cases (18 per cent). However, our proficiency with registration

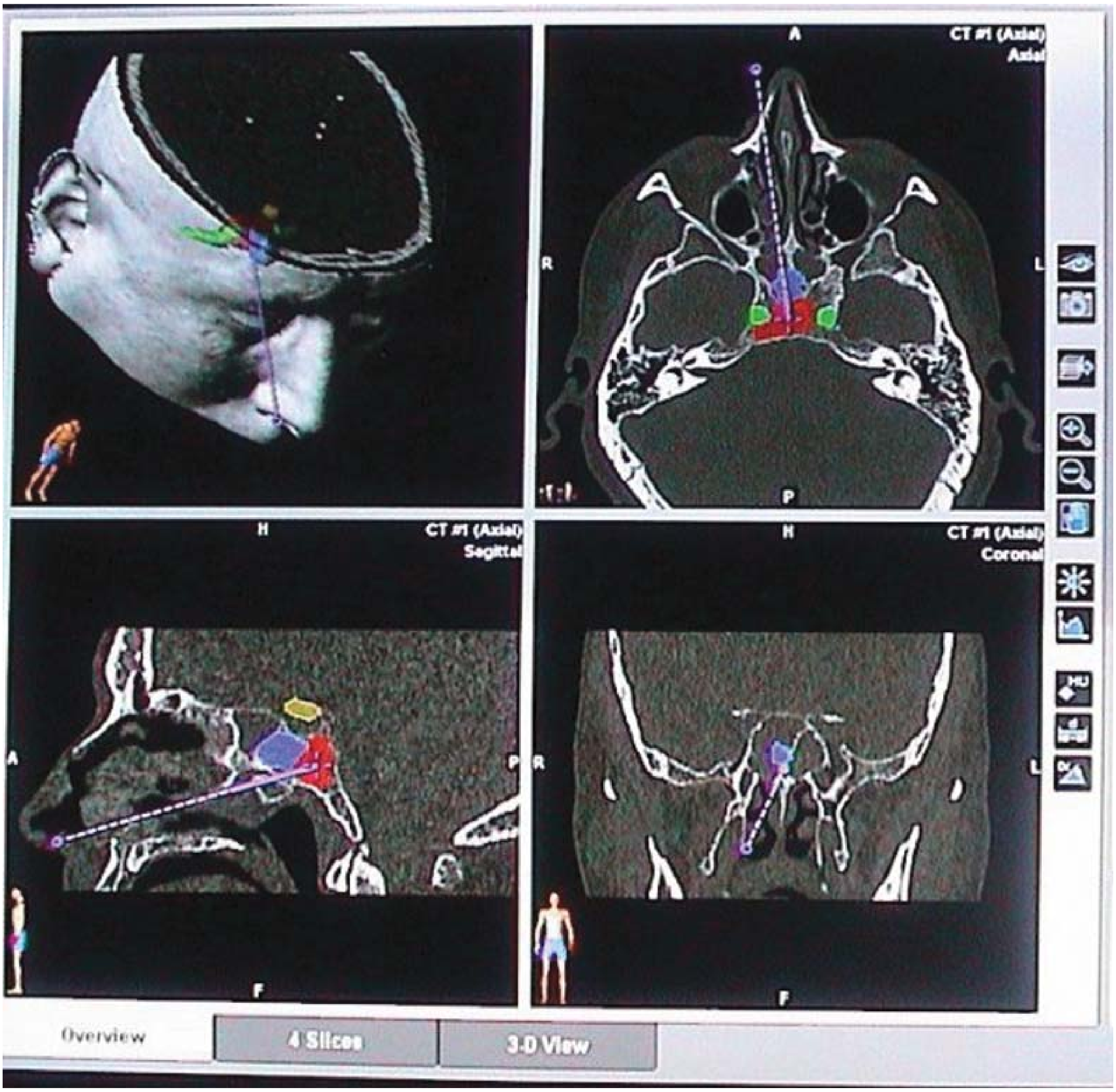

FIG. 3

Pre-operative three-dimensional planning of surgical treatment, using I-plan software (BrainLAB). The carotid arteries are marked in green, the tumour in red and the sphenoidal sinus in blue.

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improved dramatically with the aid of Z-Touch, headband fixation and increased experience. Of the 164 cases (45 per cent) we performed in the final year of the study, only 11 (3 per cent) required re-registration during the operation.

Major complications

Major complications were seen in 22 patients (5.9 per cent) and included bleeding of soft tissue and mucosa. In one case, the anterior ethmoidal artery was incised, requiring ligation. However, in the 368 cases, we encountered no cerebrospinal fluid leaks, optic nerve lesions, retrobulbar haematomas, intracerebral bleeding or deaths. There were minor post-operative complications (i.e. bleeding from nasal arteries) in nine patients (2.4 per cent), which required surgical treatment under general anaesthesia.

Case report

An example of the utility of the system is provided by the case of a 58-year-old man who presented to the neurologist with increasing headache and paresis of the left cranial nerves (I, III, IV and V_1).

The CT examination showed only minimal pathologies of the sphenoid sinus. The MRI, however, revealed a hyperintense tumour of the left clivus, adjacent to the intracranial carotid artery (Figure 2).

The goal of the operation was to obtain a biopsy of the tumour via an endoscopic approach. Pre-operatively, we merged the MRI and CT images on a workstation (I-plan 1.0, BrainLAB) and simulated the surgical treatment and its navigation points on the computer screen (Figure 3).

The pre-operatively set navigation points were then searched out intra-operatively via computer-guided navigation and six biopsies were secured (Figure 4). Histological analysis showed a plasmocytoma.

Discussion

In light of both the increasing use of intranasal surgical techniques for diseases of the paranasal sinuses[22,25,26] and the possibility of potentially life-threatening complications, there is a need to improve both the techniques and conditions for this type of surgery. In particular, alteration of

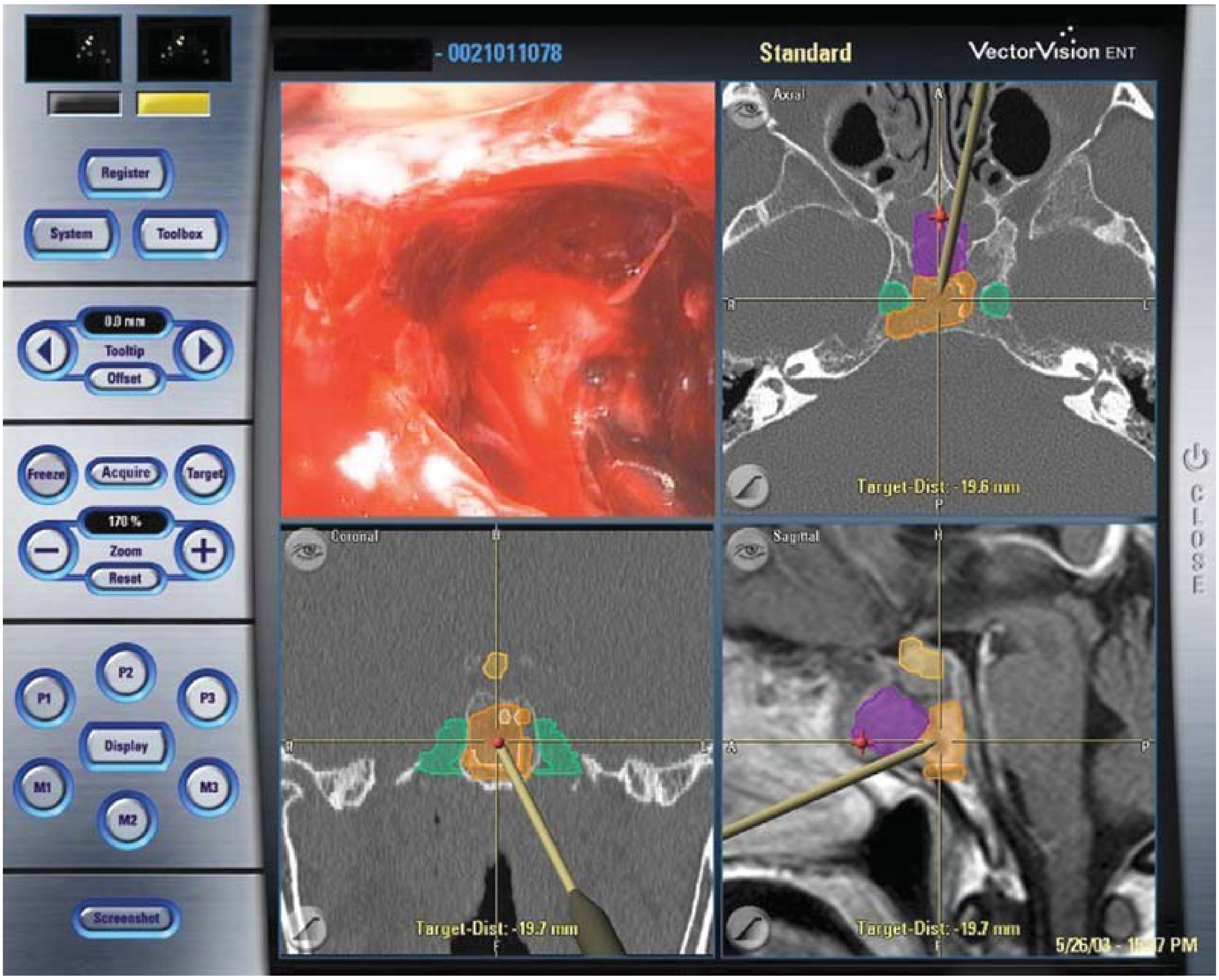

FIG. 4

Screenshot during operation, with view of the tumour behind the sphenoidal sinus and between the intracranial carotid arteries. Use of navigated instruments enabled risk-free biopsies.

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anatomical landmarks following previous surgery requires optimum surgical orientation in order to avoid serious injury to neighbouring structures.

One response to this situation has been the refinement of existing surgical instruments and the development of additional ones.[7,23] However, independently of this, various groups have also concerned themselves with the possibility of developing computer-guided navigational systems for surgery of the paranasal sinuses.[1–14,22,27] Since 1996, we have used one electromagnetic system (InstaTrak®, General Electric Healthcare, Munich, Germany) and two opto-electric systems (Surgigate®, Medivision/STRATEC Medical, Oberdorf, Suisse and Vector Vision®, Brainlab, Munich, Germany) for procedures (with a variety of surgical indications) on the anterior skull base. The clinical accuracies of these commercial systems are quite similar.[4]

An important new feature of modern opto-electric navigation systems is laser surface registration. With the aid of laser-guided surface detection, it is possible to avoid use of the head-set localizer during pre-operative CT scanning. Most up-to-date systems have similar surface matching technology available. Therefore, we were able to use CT scans obtained by other clinics or radiologists as key navigational data. Thus, the possible applications of the navigational system are extended.

In our experience, the biggest problems with computer-assisted surgery are the financial aspects and the initial loss of time. Regarding the former, manufacturers are currently designing lighter and cheaper navigation systems (i.e. the Kolibri®, BrainLAB; the I-Nav elemENT®, Medtronic, Dusseldorf, Germany; and the EasyGuide®, Philips, Best, Holland). The initial preparation time is heavily dependent upon the chosen method and experience of the user. Figure 1 shows that, with increasing numbers of cases and a familiar method, the unproductive time in the operating room decreases and the system can be used more effectively. The learning curve for surgeons and assistants can be very long, especially if the navigation system is used very infrequently. This problem should not be underestimated; it can be a source of considerable frustration and may even result in the replacement of an expensive system.

- **This paper demonstrates (as have other studies) the utility of a commercially available computer-guided navigation system in assisting endoscopic sinus surgery**
- **The authors conclude that such systems are now so accurate that the risk of misleading the surgeon is very small**
- **In their opinion, computer assistance is sensible and necessary for quality assurance and training**
- **As an example, they describe excision of a plasmocytoma in proximity to the carotid artery**

Therefore, the use of computer-guided navigational systems should be encouraged, not only for experienced surgeons in difficult surgical situations but also within the framework of routine procedures and for surgical training. During apparently routine paranasal sinus procedures, every nasal surgeon has at some stage found themself in an unexpected but critical situation in which it would have been helpful to have a 'virtual' view of the other side of the bone structure before proceeding through it. Another important aspect of training and mental preparation is the facility for conceptualization of the anatomy and pre-operative planning on a workstation. All navigation systems have this specialist software available.[4]

In conclusion, the commercially available computer-guided navigation systems are now so accurate that the risk of misleading the surgeon is very small. In our opinion, in difficult procedures involving the anterior skull base, computer assistance is not only sensible but necessary. As illustrated in the case described, the risk of serious complications would be unacceptable without a navigation system. The issues of quality assurance and surgical training make it especially important that we not refrain from future use of these systems. However, it is still the duty of the surgeon to know the anatomy and to check the clinical accuracy before every important use of the navigation system. Accuracy and effectiveness depend on the experience of the user. Occasionally, a total failure of the navigation system is possible in even well established systems, and this must be remembered at all times.

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