Frameless computer-aided surgery system for revision endoscopic sinus surgery

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To increase the intraoperative safety factor and to acquire anatomic assistance during revision endoscopic sinus surgery (RESS), we used an optical computer-aided surgery (CAS) system that we developed collaboratively in Bern, Switzerland. During 1 year, 25 RESSs were performed with CAS: recurrent polyposis (n = 20), recurrent frontal recess stenosis (n = 3), and recurrent frontal recess stenosis with mucocele (n = 2). These patients were compared with a control group of 10 patients undergoing RESS without CAS. The same surgeon (M.C.) performed all operations, and there were no minor or major complications in either group. The clinical inaccuracy of our system is between 0.5 and 2 mm with paired-point and surface matching. The navigation system is an important aid to surgeons in identifying anatomic landmarks that are typically difficult to visualize in this type of surgery, thus reducing the stress placed on the surgeon. (Otolaryngol Head Neck Surg 2000;122:808-13.)

Modern-day imaging techniques, such as CT and MRI, permit detailed identification of very fine anatomic structures. Their primary clinical use traditionally has been for the topographic diagnosis of illness and injuries. However, an application that has begun to emerge in the last few years is the use of these imaging techniques for computer-aided surgery (CAS).[1] Different systems can be used to localize an instrument: electromechanical systems,[2] electromagnetic systems,[3] optical systems,[4] or ultrasonography.[5] Each system uses a different principle to locate the exact position of a marked surgical instrument that is followed online on the CT or MRI images during surgical intervention. These systems were first conceived for use during neurosurgical procedures in which the head was rigidly fixed.[6] Fixation of the head is not suitable for endoscopic paranasal sinus surgery because the head must often be moved to obtain access to deep-seated structures. Therefore a novel frameless CAS system has been developed at the Maurice-E. Müller Institute for Biomechanics in Bern, in collaboration with the University Clinic of ENT, Head and Neck Surgery at the Inselspital.[7] The system is now used routinely for anterior and lateral skull base surgery and has proven to be a success.[8] In this article we report the results we have obtained by using the Bernese CAS system for revision endoscopic sinus surgery (RESS) over a 1-year period.

Our goals were to evaluate how much time is necessary for this procedure and to determine whether the system is an aid in identifying anatomic structures in a complex area without important missing landmarks.

METHODS

Informed consent was obtained from patients, but the study was classified as exempt by the local institutional review board.

Characteristics of the Optical CAS System

The concept developed by the research group in Bern is based on CT scans. The images are saved in a digital archiving system by means of a network or directly transferred to the computer in the operating room (Sun WorkStation [Unix], Sun Microsystems). A frameless optical system is used in the operating room. Intraoperative digitization through an infrared system is based up the 3-dimensional motion analysis system (Optotrak 3020, Ontario, Canada; Fig 1). The camera bar contains 3 one-dimensional sensors, each of which uses a 2048 linear charge-coupled device array and a cylindrical lens. It can track up to 256 pulsed infrared light-emitting diode (LED) markers, with a maximum rate of about 3500

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Fig 1. Intervention with CAS for RESS. Visible is the infrared camera *(arrow)*, the workstation, and the position of the surgeon.

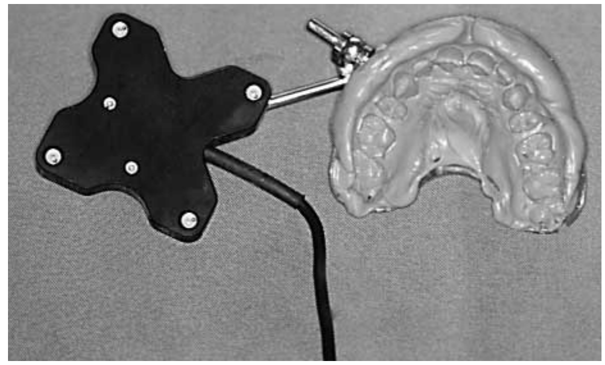

Fig 2. The upper jaw (maxilla) splint with tooth impression in the siloxane mass compound (after postoperative removal) serves as the dynamic reference base. The rod is used to affix the infrared LEDs.

markers per second. Within a field of view of 1.0 × 1.2 m at a distance of 2.0 m, the camera can locate each LED with an accuracy of 0.1 mm in the x and y axes and 0.15 mm in the z axis, with a resolution of better than 0.01 mm. By attaching at least 3 markers onto each rigid tool, the intraoperative localization and orientation in space can be calculated trigonometrically.

Operation Planning

If pathology in the sinuses must be surgically addressed, an axial CT scan of the skull is made, with a sectional thickness of 1.5 mm and a spacing of 1.5 mm or a helical scan. Reliable paired points are then marked on the CT scan, such as, in case of the anterior skull base, the frontozygomatic sutures, the nasion, and the nasal spine. Neither fixation of the head with frames nor insertion of invasive markers is needed. In addition, possible operation trajectories (paths to the target and goals) can be identified. These are especially relevant with regard to the anatomic structures that will be encountered and bypassed during the intervention.

Fig 3. The virtual keyboard, with its various functions, allows the surgeon to carry out commands by way of the computer workstation.

Operation

After the administration of the local anaesthetic, a dynamic reference base is positioned on the head of the intubated patient. It consists of an upper jaw (maxilla) splint equipped with a rod and is attached to the jaw by means of a siloxane impression material of medium consistency (Coltène, Altstätten, Switzerland; Fig 2). The rod is equipped with LEDs. If the patient is edentulous, the same splint with siloxane mass is needed. Additionally, we fix the splint with 1 to 2 miniscrews (diameter of 2.0 mm and length of 12-14 mm; Leibinger, Freiburg, Germany) on the hard palate. The miniscrews are left on until the end of the operation. This system allows free head movement during the intervention. The surgeon controls the various computer functions by using a specially developed virtual keyboard (Fig 3). To control variability in the study, all procedures were performed by the same surgeon (M.C.) and compared with a control group of 10 patients undergoing RESS without CAS.

CAS Instruments and Evaluation of Instrument Accuracy (Matching)

To use the tools with the CAS system, a calibration is mandatory. Each tool is checked preoperatively for its accuracy

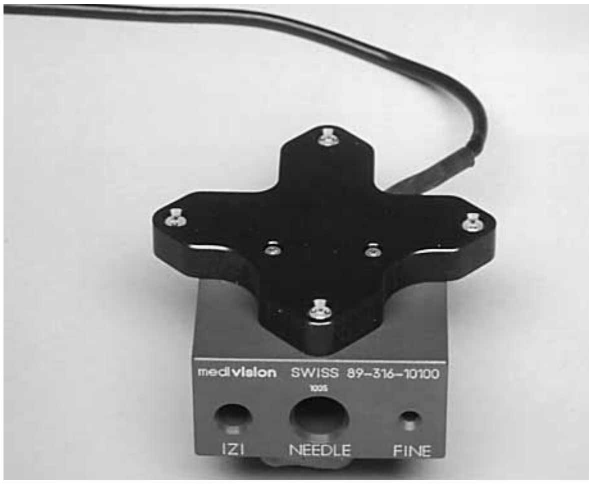

Fig 4. The calibration unit is equipped with an LED shield and with different holes for the tools (different sizes of shells are at the surgeon's disposal).

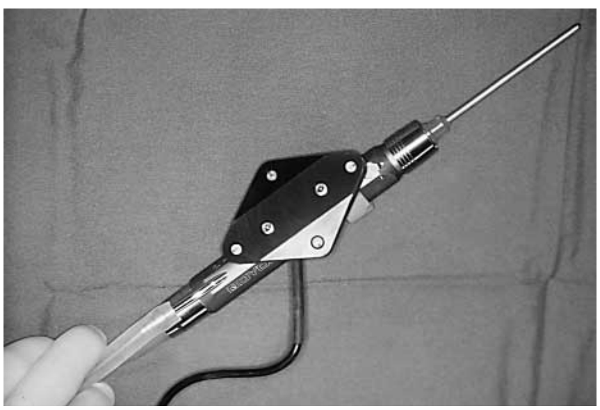

Fig 5. Microdebrider (Dyonics, Smith Nephew) equipped with LED.

in a calibration unit equipped with LEDs and different sizes of holes (Fig 4). The calibration remains valid as long as the marker probe is rigidly attached to the tool and no deformation of the tool has occurred. The single calibration unit used allows for fast and secure calibration of all tools.

The actual position of the skull is compared with the CT scan by using a needle pointer. For this purpose, the anatomic paired points (landmarks) established the previous day and, if necessary, points on the surface of the skull are used. By using a computer algorithm that was developed specifically for this system, these anatomic points are precisely correlated with the CT scan (matching).

Before the operation begins, an anatomic check is carried out in which known anatomic structures are evaluated online for positional accuracy and to estimate the target error. During the operation, the tips of the surgical instruments (eg, Rhinoforce [Storz, Tuttlingen, Germany] and Dyonics [Smith Nephew, Andover, MA]; Fig 5) and the endoscope (Hopkins-Optic, Storz, Tuttlingen, Germany) are followed online on the computer monitor.

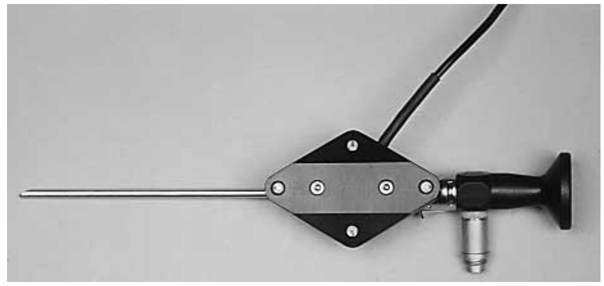

Fig 6. Hopkins-Optic 30° endoscope (Storz) equipped with a rotatable 360° LED shield (90° step).

A 4-mm diameter endoscope equipped with 4 LEDs and the possibility to turn 90º (Fig 6) is used for this purpose, which provides the position of the endoscope on the monitor.

During surgery, the operator faces the computer workstation monitor and observes the CT projections (axial, sagittal, and coronal) and the endoscopically navigated picture. The setup allows direct surgery by way of the monitor (Figs 1 and 7).

Patients

During 1 year, 25 RESSs were performed: recurrent polyposis (n = 20), recurrent frontal recess stenosis (n = 3), and recurrent frontal recess with mucocele (n = 2). The subjective advantages for the surgeon using the CAS were analyzed (Fig 8*A* and *B*). A control group (n = 10; n = 8 with recurrent polyposis nasi and n = 2 with recurrent frontal recess stenosis) operated on without CAS was compared with the group of 25 patients undergoing RESS with CAS.

RESULTS

We found clinically average inaccuracies at the anterior skull base and the lamina papyracea between 0.5 and 2 mm (average, <1 mm).

Although the operations were difficult in all cases, there were no minor or major complications. The splint was removed without any dental fracture, and in cases with edentulous patients (n = 3), no bleeding or infection in the hard palate occurred. There were also no complications in the control group of 10 patients (n = 8 for recurrent polyposis and n = 2 for recurrent frontal recess stenosis) undergoing RESS without CAS.

The supplementary installation time for CAS was always between 15 and 20 minutes in the 25 patients undergoing RESS with CAS.

The operation time (same surgeon) with CAS or without CAS depended on whether a radical or a functional endoscopic revision surgery in recurrent polyposis was made. In addition, the amount of time consumed depended on which technique was used in recurrent frontal recess stenosis (Type Draf I-III).[9] Because of the small number of patients and the large parameters, statistical determination of whether the time spent during the operation was less with CAS than in our control group of 10 patients could not be determined.

The CAS subjectively gives the surgeon more security and an anatomic aid during RESS in situations such as when fibrous or granulomatous scar tissue without anatomic landmarks is found (eg, uncinate process and bulla ethmoidalis). In addition, it allows preview and measurement of the distance to the bone border on the CT slices.

DISCUSSION

Interventions at the skull base during revision operations are often difficult because of the presence of complex anatomic structures that are difficult to identify. According to the literature, minor or major complications can occur (eg, loss of vision and intracerebral neurologic complications) as a result of surgical procedures in this location.[10] The use of computer-aided technology can represent an important safety factor for this area of surgery. The clinical accuracy achieved for our system, as determined for 25 patients who underwent surgery of the anterior skull base, was between 0.5 and 2 mm (average, <1 mm). The accuracy of other systems on the market lies between 0.5 and 3 mm.[11-13] It is worth noting that a scattering of the results (of the inaccuracies) can be present and that the systematic and repeatable reproducibility can be progressively improved up to 1 mm by pair-point matching and surface matching with our system.

A clear advantage of the system we developed is that it is frameless and allows unimpeded head movement. The first use of frameless noninvasive stereotactic intervention in neurosurgery with an upper jaw splint is credited to Carini et al in 1992.[14] The Bern research group wanted no additional preoperative marking, such as insertion of screws, *fiducial markers*, a headset, or a fixed splint.[3,11,15] Therefore our system uses only one anchored upper jaw splint during the operation. It is made of plastic with a metal rod and is attached to the jaw with a siloxane impression compound (Coltène). Additionally, in edentulous patient 1 or 2, miniscrews (Leibinger, Freiburg, Germany) are needed to hold the splint in place. This allows a dynamic reference base to be affixed to the skull precisely.

In ear, nose, and throat surgery the patient's CT scan is stored in an archiving system, such as an optical disk or a digital audiotape, or in a picture archiving system so that no additional exposure to radiation is necessary, and time used is reduced for the patient.

Fig 7. Endonasal intervention with LED-equipped Rhinoforce (Storz; *right hand*) and the endoscope *(left hand)* with CAS. An LED-equipped splint *(bottom right)* is fastened onto the patient's upper jaw, which allows an exact dynamic online display of the location of the tips of the instrument, while still allowing free head movement.

The time for the installation of the computer, the infrared camera, the upper jaw splint, the instrument calibration, and matching (comparison of the actual positions with the previously taken CT) processes takes 15 to 20 minutes. During this time, as is the usual practice with other such systems,[4,16] the local anaesthetic is administered in the operation field.

Operating times are initially longer because of the time needed to learn to work with a navigation system and video-controlled endoscopy; however, after the first few operations, the surgeon finds his rhythm, and surgery can progress at an even pace. In our study we did not find that CAS reduced the time needed for RESS when compared with a control group of 10 patients who underwent RESS without CAS.

The anatomic aid provided by the CAS system for RESS is very important for the surgeon. It provides more security and reduces stress, which makes the operation more efficient. In addition, it allows preview and measurement of the distance to the bone border on the

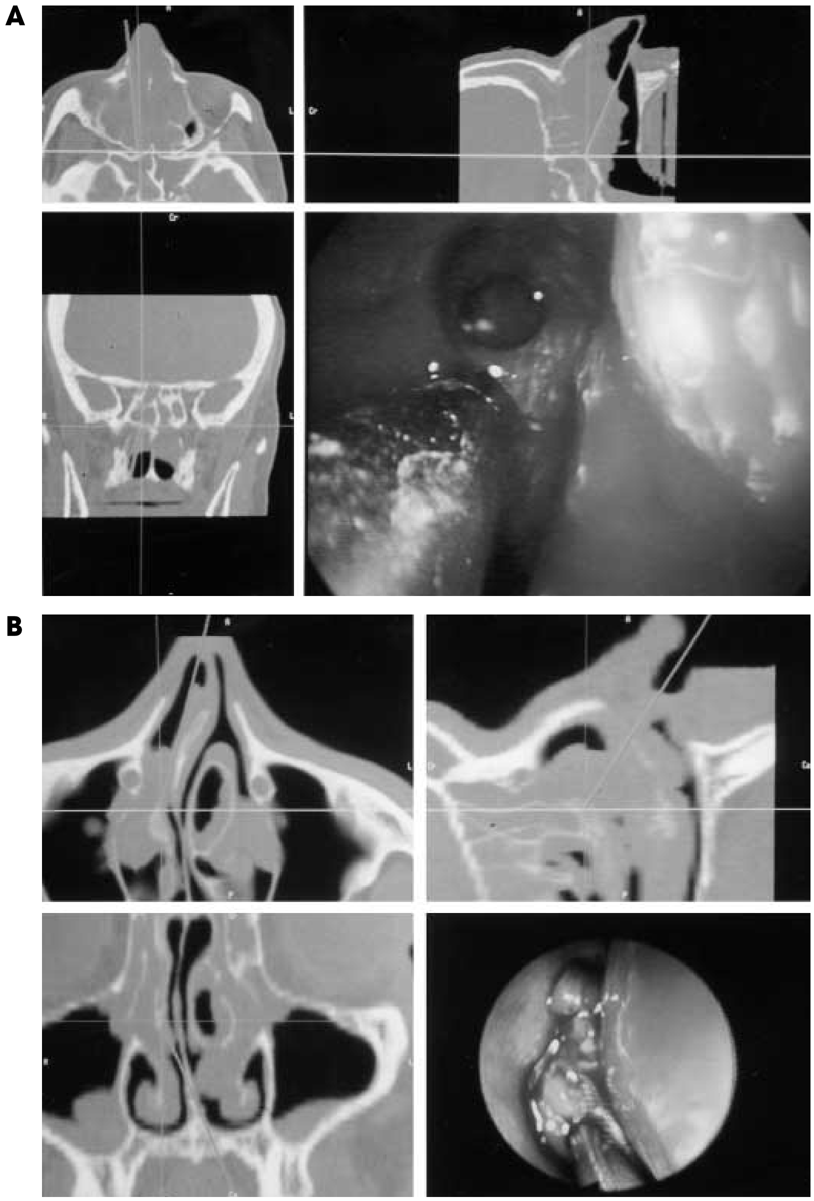

Fig 8. Intraoperative instrument tracking with CAS on the anterior skull base. **A,** CT of the paranasal sinuses in a patient operated on 2 times before (Samter syndrome) is shown on the monitor: axial, sagittal, and coronal views and 3-dimensional reconstruction (note the absence of the anatomic landmarks). The cross-hair corresponds online to the tip of the microdebrider at the sphenoid entry visible on the endoscopic picture. **B,** Monitor view (axial, sagittal, and coronal view) with endoscopic picture of a recurrent polyposis nasi and a concha bullosa on the left side.

CT slices, which gives the surgeon the possibility to be more radical. A prospective study will be necessary with a CT control after the healing phase (8 weeks) to conclude whether RESS with CAS is more radical or efficient than RESS without CAS.[17]

Our rhinoinstruments (Blakesely forceps, scraper, optics [Storz, Tuttlingen, Germany], and microdebrider [Dyonics, Smith-Nephew]) were equipped with LEDs and calibrated before the operation with a specially manufactured calibration unit. Subjectively, we found that the microdebrider equipped with LEDs gives more security than a normal forceps because the microdebrider cut away and did not drag the tissue. The accuracy on the lateral wall (lamina papyracea) with the bent forceps or the microdebrider equipped with LEDs (blade on the side) is the same, but the forceps (equipped with or without LEDs) seem better on the top (lamina cribrosa) because the opening is on the front of the tool.

The sterile touch pad or virtual keyboard that we have developed is equipped with LEDs and allows the surgeon to remain independent by inputting commands directly into the computer without the danger of disturbing the sterile field. Additional computer personnel are not needed.

A disadvantage of the optical or infrared camera system is that no obstacle can be tolerated between the tool, dynamic reference base, and infrared camera.

The cost of our system (Surgigate ORL, medivision; Stratec Medical, Oberdorf, Switzerland; CHF: 300,000 [US: $200,000]) is easily offset by its advantages. There are higher levels of safety, which means fewer potential medicolegal consequences in the future.

An additional advantage of a CAS system is its potential as a teaching tool for residents, both during an actual surgery and during the preoperative planning process.

In conclusion, the CAS system that we have developed in Bern is an aid to surgeons because it is convenient and provides anatomic orientation, which is not available otherwise. This raises the level of safety for interventions for RESS without increasing the time needed for the surgery. Future studies are necessary to demonstrate whether RESS with CAS is more efficient.

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