Frameless Optical Computer-Aided Tracking of a Microscope for Otorhinology and Skull Base Surgery

Guoyan Zheng, PhD; Marco Caversaccio, MD; Richard Bächler, PhD; Frank Langlotz, PhD; Lutz-Peter Nolte, PhD; Rudolf Häusler, MD

Objectives: To integrate a digitally controlled operating microscope without a laser autofocus system into a frameless optical computer-aided surgery system and to test the accuracy and usability of this system in otorhinological surgery.

Design: Experimental study and case series.

Setting: Department of Oto-Rhino-Laryngology, Head and Neck Surgery, Inselspital, and the Maurice E. Müller Institute for Biomechanics, University of Bern, Bern, Switzerland.

Patients: Eight computer-aided microscopic surgical procedures were performed between January and October 2000 on patients with various diseases of the anterior and lateral skull base.

Results: The practical accuracy of the navigated microscope on the lateral side of a cadaver skull was 2.27±0.25 mm and on the anterior side of the same skull was 2.07±0.35 mm. In all 8 cases of computer-aided microscopic surgery, no complications occurred. Clinical inaccuracy was 2 to 3 mm.

Conclusion: Integration of a low-cost, non–laser autofocus microscope into our computer-aided surgery system was successfully performed and offers surgeons the ability to combine the precise optics of the operating microscope with the localization power of a computer-aided system.


The technology for computer-aided surgery (CAS) and indications for its use in otorhinolaryngologic (ORL) practice have emerged in the past 10 years.1,3 Ultrasonic, electromechanical, electromagnetic, and optoelectronic guiding systems have been proposed to support the surgeon’s 3-dimensional intraoperative orientation and to prevent complications. These systems allow the surgeon to reach targets without direct visual control. Combined with anatomical information obtained from magnetic resonance imaging, computed tomography (CT), and angiography, CAS offers a safe and minimally invasive approach to the treatment of skull base lesions. In general, 3 major components are common to CAS systems. (1) The real object is that part of the anatomy to be approached surgically. In the case of ORL surgery, this is the skull. (2) A virtual object is any kind of image representing the real object and allowing for better insight into its interior. Computed tomographic scans are commonly used for this purpose in ORL surgery, but magnetic resonance images and angiography may serve as the virtual object as well. (3) The navigator is an aiming device that guides the surgeon to a point in the real object that was defined in the virtual object.

Today, most of the demanding procedures in ORL surgery require the aid of the operating microscope. In microsurgery, in which use of a specially designed operating microscope allows for the performance of controlled tissue removal under improved lighting and magnification, there is a great need for online information about patient anatomy and the orientation and position of a surgical tool. However, the microscope and handheld navigation instruments cannot be used at the same time.1 Because of the size of the microscope and its sterile cover, the space between the instruments and the optoelectronic digitizer is shadowed. To measure without removing the microscope from the surgical field, it must be used as a localizing instrument itself.4

In this article, we propose an effective method for integrating a digitally controlled microscope into a frameless opti-
PATIENTS, MATERIALS, AND METHODS

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

OPTICAL CAS SYSTEM

The CAS system (SurgiGATE ORL; Medivision, Synthes-Stratec Medical, Oberdorf, Switzerland), developed by a research group in Bern, Switzerland, is based on CT scans. The images are saved in a digital archiving system by means of a network or are directly transferred to the computer in the operating room (Sun Workstation [Unix]; Sun Microsystems, Mountain View, Calif). The frameless optical tracking system used in the operating room included an optoelectronic space digitizer (OPTOTRAK 3020; Northern Digital Inc, Waterloo, Ontario) as the passive navigation device. The precalibrated system can track up to 256 pulsed infrared LEDs with an accuracy of 0.1 mm. Three or more LEDs can be defined to represent a rigid body to be followed globally with respect to the camera's frame of reference or locally with respect to any other rigid body. Each surgical instrument carries a shield with 4 LEDs to form a rigid body that defines the tracked instrument's pose (position and orientation) and its graphical representation through points of interest (eg, the tool tip and the tool axis). This optical tracking system allows the surgeon to get online spatial and geometrical information about any surgical instrument in use.

MATCHING STRATEGIES

Matching, or registration, is defined as the transformation between the real and virtual objects and is a critical aspect in most CAS applications. Two different methods were developed and evaluated by our group: (1) a paired point-matching algorithm, which determines the relation between both objects by a number of discrete points given in both worlds, and (2) a surface-matching algorithm that does not use any fiducial markers. This registration method uses 15 to 18 points captured by the surgeon with a space pointer and its graphical representation through points of interest (eg, the tool tip and the tool axis). This optical tracking system allows the surgeon to get online spatial and geometrical information about any surgical instrument in use.

OPERATING MICROSCOPE

The operating microscope used in this work consists of a digitally controlled operating microscope and a floor stand (models VM900 and FS3013, respectively; Möller-Wedel GmbH, Wedel, Germany). It provides a communication interface for navigational systems to read or send commands and variables about all movements of the operating microscope, such as the moving distance of the focal point and the zooming scale. A camera is used to capture the video image. The video output of the camera is connected to a television monitor and to a standard frame grabber (MultiMedia Access Corporation, Cary, NC) installed in the workstation.

To integrate the digitally controlled operating microscope into a CAS system, the following specifications have been established:
1. Conforms to the cleanliness and sterilization standards for equipment in the operating room.
2. Does not interfere with normal operative procedures or limit the surgeon's access to the operative field.
3. Does not interfere with the surgeon's use of the CAS system with all other existing CAS tools.
4. As a new CAS tool, should require minimum alteration of the existing CAS system and should be compatible with other CAS tools.
5. Requires minimum alterations in the operating microscope and its floor stand, none of which should void the microscope's warranty.

To achieve these objectives, we developed a special bracket that is mounted on the operating microscope frame and that holds a shield with 4 LEDs (Figure 1). In designing this device, care was taken so that the operating microscope was attached as rigidly as possible. At the same time, the shield must not be occluded by any part of the operating microscope and the floor stand so that the 4 LEDs can always be seen by the optical tracking system. These LEDs establish a local coordinate system for the microscope that defines the operating microscope as a traceable rigid body. This computer-aided microscopic system can be guided by a virtual keyboard.7

CALIBRATION OF THE MICROSCOPE

At a particular zooming scale, the focal point in any position is rigidly fixed to the frame of the operating microscope. Therefore, after rigidly attaching a shield with 4 LEDs on the frame of the microscope to establish a local coordinate system for the microscope, it is possible, through a calibration procedure, to find the position of the focal point in this coordinate system. Later, with the help of the optical tracking system, we can transform this position to the coordinate system defined by the dynamic reference base and finally to the image space with a matching transformation.

A special tool has been designed to calibrate the operating microscope (Figure 2). The basic principle is to solve a linear equation between the steps that the focal point has moved and the coordinate of this focal point in the local coordinate system of the microscope. Later, no matter where the focal point is and based on the steps that the focal point has moved, we can calculate its corresponding spatial coordinate in this local coordinate system based on the linear equation.

During calibration, in nonspecified varied distances between the microscope and the calibration tool, we focus the microscope on the center of the bottom crosshair of the calibration tool through the center of the top crosshair. The position of the bottom center in the local coordinate system of calibration is known before calibration. We retrieve the steps each time that the focal point has moved from the microscope itself and the coordinates of the bottom center in the microscope's local coordinate system from the optical tracking system. Based on these data, we can calculate the coefficients that define the linear relationship.

MEASUREMENT

Accuracy measurements were performed on a cadaver skull model and in 8 patients undergoing ORL microsurgery for a variety of diseases. The euclidean distance was used. Microsoft Excel 97 (Microsoft Corp, Redmond, Wash) was used for evaluation of the data.

Cadaver Skull

A needle pointer with a tip diameter of 0.5 mm was used. The calibration unit defines the point of interest (eg, the tool tip, axis, and orientation) accurately and checks the tool geometry by a simple point comparison. We used this pointer and the calibrated microscope to digitize the same landmark point on the skull model. System accuracy was assessed by measuring the deviations between the digitized results, where one is the output from the needle pointer and the other is based on the microscope. Two sets of points were chosen as measuring points from different anatomical areas of the skull (Figure 3 and Figure 4) that correspond to areas that commonly undergo ORL surgery. One is on the anterior skull side and the other is on the lateral skull side.

Patients

In our preliminary clinical evaluation, 8 patients were treated on the anterior and lateral skull base (for recurrent polyposis nasi [n=3], frontal recess stenosis [n=2], osteoma of the frontal recess [n=1], or ear malformation [n=2]) with our computer-aided microscopic surgery system based on paired and surface matching. During surgical planning, either an axial CT scan of the skull (sectional thickness, 1.5 mm; spacing, 1.5 mm) or a helical scan was performed. Reliable anatomical paired points were then marked on the CT scan, such as in the case of the anterior skull base, the frontozygomatic sutures, the nasion, and the anterior nasal spine. Neither fixation of the head with frames nor insertion of invasive markers is needed. In addition, possible surgical trajectories (paths to the target and goals) can be identified.

During microsurgery, after focusing the microscope on an anatomical area, the needle pointer was used to point to the same position. The positions of the microscope's focal point and the needle pointer tip were transformed to image space, and the deviation between the 2 points in image space was calculated. The deviation was then measured in multiples of the pixel size of the CT images.

Downloaded From: https://jamanetwork.com/ on 06/08/2022
PATIENTS

In all 8 patients who underwent computer-aided microscopic surgery, no complications occurred. However, a problem remains, ie, the focal level in the case of bleeding, in which the deviation error is higher (>3.0 mm).

COMMENT

Several methods have been proposed previously for integrating the operating microscope into the CAS system. Different technical approaches have been used clinically, such as passive mechanical arms, active robotic arms, and ultrasonic, electromagnetic, and optical digitizing systems. Currently, 3-dimensional digitizers based on optical sensor technology are supposed to be the most accurate systems because they are less affected by disturbing environmental factors than are the others. Furthermore, in contrast to mechanical arms, they allow an unobstructed view of the surgical site and a straightforward surgical procedure in the operative field.

Our proposed method is somewhat similar to that used by Hauser and colleagues in that we both used an optical digitizing system to track the microscope. However, the main difference between the system used by Hauser and colleagues and ours is that a stereotactic frame is required in their system as a patient registration and reference system, which is often disadvantageous for ORL surgery. In their system, the frame is mounted transitorily 1 day before surgery for CT acquisition. On the day of surgery, the frame is repositioned on the patient’s head. Our system is frameless. We use software technology to solve the registration problem. In addition, in their system, the shield holding the LEDs is mounted to the housing of the microscope, and an object distance-measuring unit is attached in front of the objective lens. In our system,

Figure 1. A, A bracket with a simple shield of infrared diodes. B, The operating microscope equipped with the bracket holding a shield of 4 infrared diodes that must be detected by the optical tracking system.

Figure 2. Operating microscope focal point calibration tool, which is also equipped with a simple shield of 4 infrared diodes that are detected by the optical tracking system. Of 2 mechanically aligned crosshairs, the center of the bottom crosshair is selected as the calibration point. Each time, the operating microscope focuses on this point through the center of the top crosshair so that in the microscope view, the center of the top crosshair is superimposed onto that of the bottom crosshair.

Figure 3. The 11 landmarks on the anterior skull base that are used for measuring system accuracy.
the shield holding the LEDs is mounted to the frame of
the microscope, and no other unit is required. The
moving distance of the focal point is retrieved from the
microscope itself.

Compared with other surgical instruments, the
non–laser autofocus microscope is less accurate. In
our previous study, the practical accuracy for other
surgical instruments on the cadaver skull was 0.5 to
1.2 mm, whereas the mean±SD error for the micro-
scope was 2.07±0.35 mm on the anterior skull and
2.27±0.25 mm on the lateral skull. These larger spa-
tial errors can probably be attributed to the following
factors: (1) The instrument’s trajectory is defined by
its origin and tip as the rigid end of the longitudinal
axis. In contrast to the geometrically predefined tip of
the instrument, the microscope’s focal point and asso-
ciated optical trajectory must be localized by surgeons
because an operating microscope without a laser auto-
focus system is used. Different surgeons will have
different focal levels. The large range of individual
visual adaptation of the surgeons makes it difficult
to determine the exact focal point of the microscope.
(2) Errors can be introduced directly by the micro-
scope and are referred to as errors caused by the optical
properties of the microscope, such as the method
of focal point adjustment, focal length, and magnifi-
cation of the lens. (3) Errors can be introduced indi-
rectly by the microscope and are referred to as errors
caid by tracking properties of the microscope, such
as the tracking distance, the number of the reference
infrared diodes, and the area covered by these infrared
diodes. (4) The condition when intraoperatively track-
ing the microscope can be different from the condition
when calibrating the microscope, such as microscope
orientation, tilt, or rotation. (5) The anatomical struc-
tures in the microscopic surgical site can affect accu-
rracy, in that the more spatially sparse the distribution
of the anatomical structures in the surgical site, the
less accurate the microscope.

Clinically, we found that a problem remains. The inaccuracy of the focal level is greater than 3 mm in
the case of bleeding. Because of the well-vascularized
mucosa of the nose, it is common to find such a situa-
tion. On the lateral skull base, the soft tissue is not as
thick as in the nose, except in chronic inflammation.

In addition, the bleeding is usually less than in the
nose, except for in well-vascularized tumors. This
means that microscopic navigation on the bone of the
lateral skull base with an exact navigation level of the
focal point can be more accurate in clinical practice.

The handling of the navigation microscope with only a
shield of infrared diodes (Figure 1) is not impaired.

In conclusion, a new method has been proposed
to successfully integrate a low-cost non–laser autofo-
cus operating microscope into a CAS system without
interfering with the surgical procedure and changing
any existing CAS tools. It offers surgeons the ability to
combine the precise optics of the operating micro-
scope with the localization power of the CAS.
Accepted for publication June 27, 2001.

Corresponding author and reprints: Marco Caversaccio, MD, Department of Oto-Rhino-Laryngology, Head and Neck Surgery, University Hospital, Freiburgstrasse, CH-3010 Bern, Switzerland (e-mail: marco.caversaccio@insel.ch).

REFERENCES