Minimally Invasive Navigated Procedures on the Skull Base

Omid Majdani, M.D.

Over the past 20 years, image-guided technologies and approaches have significantly helped to enhance minimally invasive surgical procedures. Today, navigation technologies are well established in many intraoperative fields, particularly in the area of skull base surgery.

Navigation technology has played a dominant role in computer-assisted surgery (CAS) and has established itself in many fields as an intraoperative diagnostic instrument, in particular, in head and neck surgery. The introduction of patient images enabled by the navigation system into the surgical microscope facilitates instantaneous visualization of the surgical site and the spatial location of surgical instrumentation. The depth of the surgical approach can also be visualized with the navigation system by determining the focusing distance of the microscope. This is especially helpful in demonstrating the position of adjacent anatomical structures by use of the navigation system. Using navigational technology, a prospective planned approach to critical structures is possible, minimizing procedural complication rates typically experienced in the absence of this technology.

Today's navigation systems can detect objects in space via a non-contact technique. Optoelectronic systems locate points in space by firm placement of two or more cameras and space determination by triangulation. Points are marked by reference objects which contain infrared diodes (active optoelectronic systems) or reflector elements (passive systems).[1] The basic principle of electromagnetic navigation systems is the temporally and locally changing of magnetic fields. An electromagnetic transponder is fixed to the patient's head by adapting it to a headset, and a magnetic field sensor is attached to the distal part of the instruments.

The development of intraoperative navigation systems in the last 20 years has not solely concentrated on incremental technological achievements, but also on the increasing realization of ergonomic design, user operability, surgical efficiency, microscope system integration and its financial feasibility.

Anterior skull base procedures

The main application area for navigation systems is the surgery of the frontal skull base such as sinus surgery procedures. Critical structures such as the carotid arteries, the optical nerves and the orbits,

Fig. 1: The integration of navigational systems into the surgical workflow is a precondition for the routinely use of the systems.

the skull base and the hypophysis can be segmented preoperatively. During surgery, the position of the instrument and its distance to the highlighted critical structures can be demonstrated on the navigation screen. Similarly, in hypophysis surgery, the navigation systems represent a genuine alternative to the intraoperative fluoroscopy to ensure proper identification of this critical anatomical structure.

The injection of microscope videos into the navigation screen enables the illustration of the definite position of the instrument (microscope video) and the virtual position of the instrument calculated by the navigation system on the same screen. This kind of representation can be very useful for intraoperative documentation.

Surgery on midface fractures can also be optimized using intraoperative navigation systems. These cases present tripoid or orbital fractures, which are mostly unilateral in nature. Navigation assistance can be very helpful in the process of reconstructing the facial symmetry and ensuring the desired patient outcome. This procedure first involves a relatively complex preoperative segmentation of the non-fractured side. The anatomy of the unaffected side can then be mirrored to the contralateral fractured side. The symmetry planes can be computed on the basis of classical anatomical landmarks (sella turcica, supraorbital notch, porion, nasion and the anterior nasal spine).[2] During the surgery, the desired position of the fractured elements can be controlled by navigating their endpoint position and compared to the preoperatively calculated position.

Lateral skull base procedures

Procedures of the lateral skull base region such as acoustic neurinoma or infratemporal approaches to the skull base place make special demands on navigation systems and surgeons. Before the completion of preoperative images, special fiducial markers for registration need to be affixed to the patient. These markers are identified as artificial landmarks for the registration procedure at the beginning of the

Fig. 2: Navigational systems may be very useful teaching instruments, since the learners have biomedical information about the actual position of the instrument during the surgery.

surgery. By fixing a reference adapter to the skull, maximum navigation accuracy can be achieved. For tumor removal surgery, the overlay of CT scans and MRI images is reasonable in order to get both an optimal representation of the expansion of soft tissue, for example, tumor borders and sufficient imaging of bony erosions. Graphic data fusion can be accomplished, however, with arbitrary imaging modalities (CT scan and ultrasound, MRI and PET, etc.). If the tumor is very deep with difficult accessibility (e.g., biopsies at the skull base), it can be helpful to plan the trajectory preoperatively. The navigation system indicates during the surgery the planned direction, any deviations from the intended course, and the distance to the goal.

Soft tissue navigation

Due to the instability of soft tissue and its unpredictable position after the initial surgical approach, intraoperative navigation is not possible at this phase of the procedure. Baseline images for navigation must be updated intraoperatively to enable the surgeon to successfully complete the procedure. In order to capture the actual position of the soft tissue after trepanation of the intraoperative CT scan, a MRI or ultrasonics can be helpful. In future operating theaters, intraoperative imaging will be integrated more and more into all surgical systems. Since the complexity of the whole system continues to grow, ergonomic aspects in the workflow are becoming more and more important. The control of the different intraoperative diagnostic and therapeutic tools should be centralized to a common console which is easily attainable by the surgeon. As in head and neck surgery, most cases are done with a microscope, using it as a control panel for the operating room, and instruments seem to be a meaningful and feasible idea.

Robotic applications

New CT scan technologies based on flat panel detector volume computer tomography (fpVCT) could enhance the detail resolution capability of the image. It could be shown that by using fpVCT data for navigation, the localization accuracy of navigation systems can be improved.[3] This allows performing highly precise navigated procedures at the skull base. One possible procedure is the minimally invasive freehand or robot assisted cochlear implant surgery. A pilot

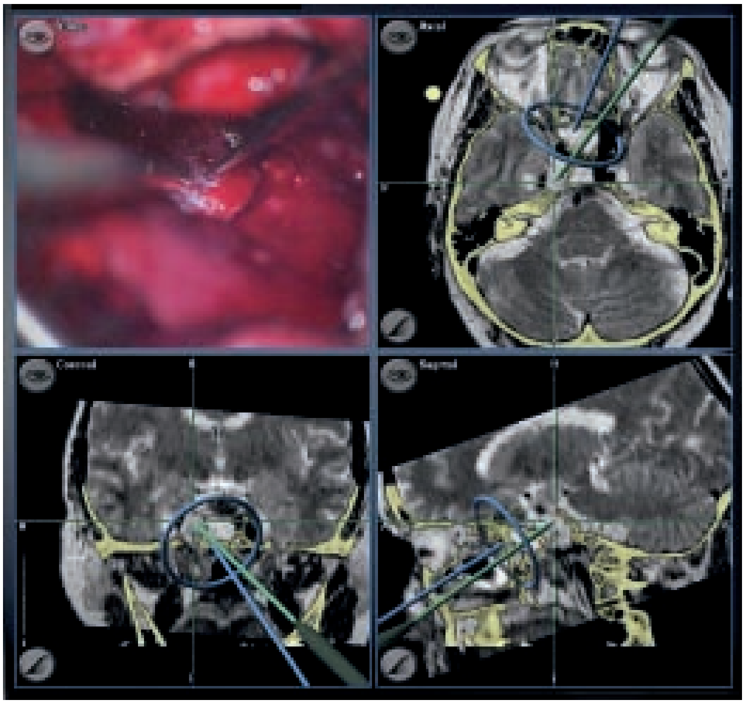

Fig. 3: The virtual position of the instruments calculated by the navigational system and the distance to the critical structures are demonstrated on the navigational screen. The injection of microscope videos into the same screen enables the illustration of the definite position of the instruments.

study was done on human cadaver temporal bones. The fpVCT image acquisition was done after 5 miniosteosynthesis screws were placed for registration procedure. The scan data was transferred to the planning computer. An approach trajectory was planed from the mastoid surface to the round window membrane niche without touching the critical anatomical structures (facial nerve, chorda tympani, sigmoid sinus, semicircular ducts and the cochlea). The data was transferred to the control unit of the robotic device. A medical drill was attached to the end effector. The robot was activated to move along the planed trajectory. For evaluating the result of the drill work, we performed postoperative CT scans, followed by a conventional surgical mastoidectomy on the temporal bones. With both methods, we were able to see that the critical structures were not damaged and the cochlea was opened at the planed target point.

The evolution of navigation technology has not slowed down despite the introduction of highly developed durable and multifunctional systems. Within this framework, a renaissance of robotics in medicine, this time based on small robots, seems to be becoming a reality.

Image courtesy:

Fig. 1 and Fig. 3: Omid Majdani, M.D., Department of Otolaryngology, Medical University of Hanover, Germany

References:

1. Majdani O, Leinung M, Lenarz T, Heermann R (2003): Navigation-supported surgery in the head and neck region. Laryngorhinootologie 82:632-644

2. Gellrich NC, Schramm A, Hammer B, Rojas S, Cufi D, Lagreze W, Schmelzeisen R (2002): Computer-assisted secondary reconstruction of unilateral posttraumatic orbital deformity. Plast Reconstr Surg 110:1417-1429

3. Bartling S, Leinung M, Rodt T, Dullin C, Becker H, Lenarz T, Stöver T, Majdani O (2006): Increase of accuracy in intraoperative navigation through high resolution flat-panel Volume-CT: Experimental comparison to multi-slice-CT based navigation. Otol Neurotol. 28: 129-134

contact

Omid Majdani, M.D.
Senior Physician
Department of Otolaryngology
Medical University of Hanover
Carl-Neuberg-Str. 1
30625 Hanover
Germany
www.mhh-hno.de