ANATOMY

Evaluation of a 3-Dimensional Voxel-Based Neuronavigation System with Perspective Image Rendering for Keyhole Approaches to the Skull Base: An Anatomical Study

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Key words
- 3D neuronavigation
- Keyhole approach
- Neuroendoscopy
- Skull base

Abbreviations and Acronyms
3D: Three-dimensional
CCT: Cranial computer tomography
EC: Endocameleon
IGS: Image guidance systems
MRI: Magnetic resonance imaging
TS: Target structures

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■ BACKGROUND: **Keeping track of the endoscope tip in 3 planes (axial, coronal, and sagittal) while performing skull base surgeries can be difficult because the surgeon is focused most on the live video images of the endoscope. For that reason, it was the aim of this anatomical cadaver study to evaluate the usefulness of a voxel-based neuronavigation system with 3-dimensional (3D) perspective image rendering for endoscopic procedures through keyhole approaches to the skull base.**

■ METHODS: **On 5 whole-body fixed cadavers, frontolateral and retrosigmoid approaches were performed bilaterally using a neuronavigation system with 3D perspective image rendering (Cbyon, Med-Surgical Services Inc., Sunnyvale, California). Target points defined on the selected target structures were approached with the navigated ∅ 4-mm 0° endoscope (Storz, Tuttlingen, Germany). Using an Endocameleon 4-mm rigid endoscope capable of changing its angle of view while remaining stationary, the surgical field was checked for injuries before and after insertion of the navigated 0° endoscope.**

■ RESULTS: **The median neuronavigation registration error was 0.95 mm (range 0.6 to 1.2 mm). Evaluation showed that 100% of the defined targets were reached and visualized. Neither a target structure nor neurovascular structures or surrounding brain tissue were injured by the navigated 0° endoscope.**

■ CONCLUSIONS: **A neuronavigation system with 3D voxel-based perspective image rendering could potentially improve safety during complex skull base surgeries, and possibly also help to improve surgical results. Such a system, however, cannot replace a neurosurgeon's experience nor surgical skill or anatomical knowledge. It is an excellent teaching tool for young neurosurgeons, but it also has some limitations. Therefore, clinical studies will be necessary to further evaluate the benefits of this type of neuronavigation system in a clinical setting.**

INTRODUCTION

The highly complex anatomy of the base of the skull makes surgery in this area very challenging. Neurovascular structures are located within a small area and are subject to interindividual variations. With tumors such as skull base meningiomas displacing anatomical landmarks, orientation becomes more difficult, requiring a thorough preoperative analysis of the images. Modern imaging techniques with high-resolution computer tomography scans and magnetic resonance imaging (MRI) provide the skull base surgeons with valuable information, showing in 1-mm slices or less the details of the modified anatomy in patients with skull base lesions. To increase the safety of these types of procedures, image guidance systems (IGS) are frequently used. However, if the IGS provides the surgeon only with the typical triaxial images, then the surgeon must create a 3-dimensional (3D) model of the anatomy of each individual case in his or her mind.

In the late 1990s, there was a change of strategy with respect to the approaches to skull base lesions, from extensive approaches with large craniotomies and maximal exposures for a better overview (1, 10, 11, 21, 22) to smaller, less traumatic keyhole approaches (19, 24). Since the introduction of the endoscope to the field of neurosurgery, pioneers such as Pernetzky et al. (9, 14) have demonstrated that even for complex skull base procedures, minimally invasive approaches are possible when using an endoscope. This marked the beginning of a new era in skull base surgery. It has been shown that due to the small neurosurgical approaches and therefore significantly reduced surgical trauma compared to the classical approaches to the skull base from the 1970s, a better overall outcome can be achieved (2). One of the main advantages of using an endoscope, especially when operating through keyhole approaches, is that the light in the surgical field is not reduced due to the small craniotomy allowing optimal illumination of the surgical field in the depth of the skull. Furthermore, neurovascular structures can be better visualized because the endoscope allows a close-up view of the lesion and the surrounding neurovascular structures, and also, by rotation, different perspectives of the surgical field. However, this advantage also bears a risk because when freely inserting and maneuvering an endoscope through a small craniotomy, there is a danger of injuring the brain or neurovascular structures. For that reason the endoscope is frequently used in combination with an IGS (5, 12). Commonly used neuronavigation systems offer a tracking feature of the endoscope tip on triaxial images and usually only limited or no 3D capabilities. However, keeping track of the endoscope tip in the 3 planes (axial, coronal, and sagittal) while performing a complex procedure can be difficult because the surgeon is focused most of the time only on the live video images of the endoscope camera. Therefore, it was the aim of this anatomical cadaver study to evaluate the usefulness of a voxel-based IGS with 3D perspective image rendering for endoscopic procedures through keyhole approaches to the skull base.

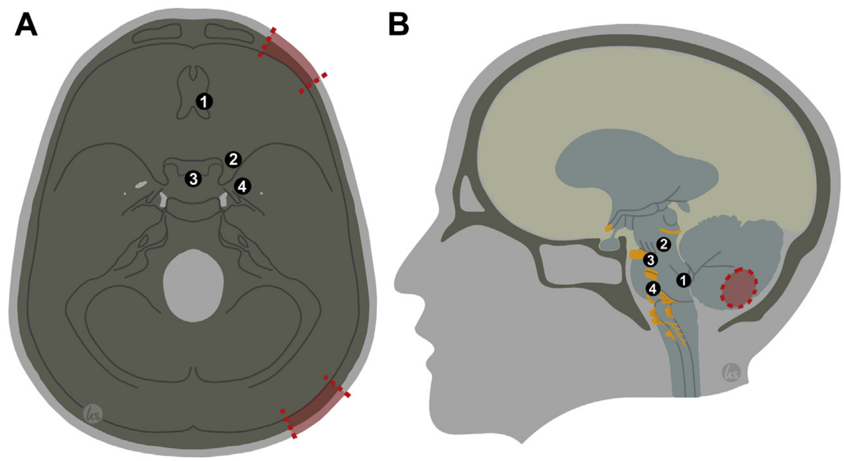

Figure 1. (**A**) Target structures approached through the frontolateral approaches: 1, the lamina cribrosa; 2, the anterior clinoid process; 3, the sella turcica; 4, the oculomotor nerve. (**B**) Target structures approached through the retrosigmoid approach are at the level of 1, the internal auditory canal; 2, the plane between tentorium and trigeminal nerve; 3, the plane between trigeminal nerve and facial/vestibulocochlear nerve; 4, the plane between facial/vestibulocochlear nerve and caudal cranial nerves.

MATERIALS AND METHODS

Specimens and Imaging

Five cadavers that were whole-body fixed by injecting a 4% formaldehyde solution in the femoral artery were used as specimens. A high-resolution cranial computer tomography (CCT) scan with 1-mm slices to visualize the bony skull base and T1-weighted MRI scans with 1-mm slices were acquired from each specimen. The digital image data were transferred via a USB flash drive to the neuronavigation system (Cbyon, Med-Surgical Services Inc., Sunnyvale, California). The specimens were registered in the IGS with anatomical landmarks using the CCT data sets. Images acquired for evaluation were recorded with the number of the specimen, type and side of approach, number of target structures (TS), endoscope position, and viewing direction.

Endoscopes

A Storz HD system (including a 300-W light source Xenon 300; HD module Image 1 hub, AIDA control II, and AIDA compact II) was used with 2 rigid endoscopes. A ∅ 4-mm 0° endoscope was used for the navigated approaches to the defined TSs on the skull base (Figure 1). An Endocameleon (EC) 4-mm rigid endoscope capable of changing its angle of view while remaining stationary and shape-invariant was used to inspect the surgical field for injuries before and after insertion of the navigated 0° endoscope. The EC provided in 1 plane a viewing range of approximately −10° to +120°, and therefore allows also viewing backward (8).

Neuronavigation

A voxel-based optical IGS (Cbyon) with 2D and 3D real-time perspective image rendering was used to navigate the ∅ 4-mm 0° endoscope. The IGS consists of a central processing unit, a tool interface unit connected to the infrared camera, a touch-screen monitor with a pen for manual segmentation, and the navigation software Cbyon Suite 2.8. The system volumetrically reconstructs a 3D image of the scanned anatomy, and it combines segmented volumes from the MRI and CCT scan in one 3D image. Furthermore, the system offers an image-enhanced endoscopy feature (23). This feature not only allows registering the tip of the endoscope and tracking it on the triaxial images as conventional systems do, but also shows the live image of the endoscope simultaneously next to the virtual 3D voxel-based endoscopic image from the same view as the endoscope camera (4). The virtual 3D voxel-based endoscopic images are based on preoperative MRI or CCT images. By changing the zoom of the endoscope camera, an offset between the virtual and the live endoscopic images can be created. This allows the surgeon to see more of the area surrounding the endoscopic tip on the virtual endoscopic images. Modulation of the tissue transparency in the virtual endoscopic image also allows the surgeon to see beyond the live video image during surgery. Whenever required, the defined target point from the virtual image also can be projected on the live video image of the endoscope for better orientation.

After transferring the image data to the planning station of the IGS, the CCT and MRI images were co-registered. The TSs were manually segmented in the MRI datasets. To optimize the view of the TSs, the surrounding tissue layers were gradually rendered translucent until the surrounding brain tissue allowed a good view of the TSs and related anatomical landmarks from the perspective of the planned surgical approach. In the augmented reality environment that is created by the IGS software, all approaches to the TSs were planned and simulated using the 3D fly-through mode.