A Three-Dimensional Computer-Based Perspective of the Skull Base

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Key words
- 3D computer model
- Dextroscope
- Endoscopic endonasal surgery
- Skull base
- Surgical anatomy

Abbreviations and Acronyms
3D: Three-dimensional
CT: Computed tomography
VRS: Virtual reality system

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■ OBJECTIVE: **To describe our designed protocol for the reconstruction of three-dimensional (3D) models applied to various endoscopic endonasal approaches that allows performing a 3D virtual dissection of the desired approach and analyzing and quantifying critical surgical landmarks.**

■ METHODS: **All human cadaveric heads were dissected at the Laboratory of Surgical Neuroanatomy of the University of Barcelona. The dissection anatomic protocol was designed as follows: 1) virtual surgery simulation systems, 2) navigated cadaver dissection, and 3) postdissection analysis and quantification of data.**

■ RESULTS: **The virtual dissection of the selected approach, the preliminary exploration of each specimen, the real dissection laboratory experience, and the analysis of data retrieved during the dissection step provide a complete method to improve general knowledge of the main endoscopic endonasal approaches to the skull base, at the same time allowing the development of new surgical techniques.**

■ CONCLUSIONS: **The methodology for surgical training in the anatomic laboratory described in this article has proven to be very effective, producing a depiction of anatomic landmarks as well as 3D visual feedback that improves the study, design, and execution in various neurosurgical approaches. The Dextroscope as a virtual surgery simulation system can be used as a preoperative planning tool that can allow the neurosurgeon to perceive, practice reasoning, and manipulate 3D representations using the transsphenoidal perspective acquiring specifically visual information for endoscopic endonasal approaches to the skull base. The Dextroscope also can be used as an advanced tool for analytic purposes to perform different types of measurements between surgical landmarks before, during, and after dissection.**

INTRODUCTION

The skull baserepresents the floor of the cranial cavity on which the undersurface of the brain rests. Neurovascular structures that are crucial to the function and integrity of the entire central nervous system are contained and travel within the skull base. A precise working knowledge of the surgical anatomy is essential for effective treatment of diseases in such a complex region. In recent decades, as minimally invasive neurosurgery has progressed, there has been an increase in the depth and complexity of required anatomic knowledge for the delivery of adequate treatment. The acquisition of new surgical techniques and skills taught at hospital residency training programs has also grown more complex in a parallel fashion.

Despite restrictions for residents on maximum work hours per week, a limited number of instructors, and legal and ethical concerns, laboratory dissection, hands-on experience, and observerships still remain the "gold standard." This situation is especially true in the field of endoscopic endonasal skull base surgery, in which factors such as the transition from microscopic techniques, visualization, and instruments to endoscopic ones restrict training to a few specialized centers and out-residency workshops all over the world.

Surgical laboratories remain the optimal choice for acquiring both the skills and the anatomic knowledge through anatomic dissection (3). Such laboratories still represent the best strategy to make surgery as realistic as possible compared with a surgical scenario. Over the years, hands-on anatomic dissection has allowed surgeons to learn in a low-stress environment where mistakes are permissible and procedures can be repeated multiple times. However, such a process is not without limitations. Surgical laboratories are subject to shortage of cadaveric specimens, partially secondary to legislative restrictions in Europe, and appropriate surgical instrumentation is not as easily available as in the operating room.

A potential new field in neurosurgical training arises as rapid advances in medical image data processing extend the use of computed tomography (CT) and magnetic resonance imaging beyond their purely diagnostic use. Computerized three-dimensional (3D) models of cadaveric specimens obtained through CT and magnetic resonance imaging before dissection and the use of advanced virtual reality systems (VRS) coupled with neuronavigation provide reliable tools for the analysis of approaches from both a quantitative and a qualitative perspective. Quantitatively, these tools allow precise measurements of simple data, such as linear and angular distances, as well as calculation of more complex variables (i.e., the area exposed during a selected approach, the volume of the drilled bone while performing the surgical pathway, and the surgical freedom) (5, 9, 10). Qualitatively, 3D models serve as a highly effective means for the comprehension of anatomic structures and their relationships, whereas VRS enhance this process through dynamic manipulation. Neuronavigation and VRS have proven highly effective for the planning of surgery and better surgical outcomes (1, 2, 6, 20), and they have been effectively exploited for research and educational purposes (11, 12, 19).

Our team has designed a protocol for the reconstruction of 3D models of dissected specimens for analytic and anatomic purposes. Its application and results have been described elsewhere (8). In this article, we discuss the addition of a VRS to our laboratory and describe our newly developed techniques of 3D visualization, predissection planning, and quantitative analysis applied to the main endoscopic endonasal approaches to the skull base. We also discuss this device and the experience we gained through the processing of medical data obtained preoperatively and postoperatively.

MATERIALS AND METHODS

During cadaveric dissections, all procedures (30 specimens) were performed emulating surgical approaches in the operating room to enhance the learning process and obtain as much useful data as possible.

Preparation of Specimens

Each specimen was fixed with an industrially manufactured embalming mixture composed of different percentages of phenol, ethanol, formaldehyde, and glycerin. The arterial system was injected with red latex. One cadaveric head was injected with a mixture of red latex with barium sulfate at 0.015% to assess the feasibility of performing cadaveric CT angiography.

Acquisition of Data

Preoperative CT Scan. Before the dissections, CT scans were performed on each cadaver head. A multislice helical acquisition protocol (slice thickness 0.6 mm, gantry angle 0 degrees) was adopted; heads were precisely positioned in the scanner (SOMATOM Sensation 64; Siemens AG, Erlangen, Germany) to obtain a projection perpendicular to the palate. The images achieved were stored in a picture archiving and communication system that streamlined the "postproduction" management.

Virtual 3D Model: Dextroscope. We added the Dextroscope (Volume Interactions Pte. Ltd., Singapore, Singapore), a dedicated VRS, to our laboratory (16). This device was used for specific surgical approaches using CT Digital Imaging and Communications in Medicine images of the specimens for which predissection planning was considered appropriate, mainly for the execution of complex endoscopic endonasal skull base approaches.

With the Dextroscope, the user works with both hands inside a stereoscopic virtual workspace; this is achieved by reflecting a computer-generated 3D via a mirror into the user's eye (Figure 1). Wearing liquid display shutter glasses synchronized with the time split display, the user reaches with both hands behind the mirror into the 3D data. Electromagnetic sensors in both hands convey the interaction and allow manipulation of the 3D data in real time. The user holds an ergonomically shaped handle to move the 3D data freely as if it were an object held in real space. The other hand holds a pen-shaped instrument that appears inside the virtual reality workspace as a computer-generated instrument that can be used to perform specific data manipulation. The Dextroscope software supports multimodality imaging, allowing the visualization (visual fusion) of several imaging modalities and complementary graphic objects sharing the same virtual space. To work on these imaging modalities, it provides a range of virtual tools that allow manual and semiautomatic segmentation; image coregistration; curved, linear, angular, and volumetric measurements; and removal of virtual tissue (which can be used to simulate bone drilling or soft tissue resection). These tools are complemented by reporting tools such as screen captures and video making.

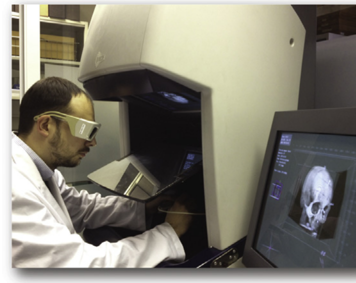

Figure 1. The Dextroscope bimanual neurosurgical planning and simulation system.

Image-Guided Dissection. All dissections were performed in the Laboratory of Surgical Neuroanatomy, at the University of Barcelona, Barcelona, Spain. Various endoscopic endonasal transsphenoidal approaches to the midline skull base, to the cavernous sinus, and to the orbit were performed using rigid 0- and 45-degree endoscopes, 18 cm in length and 4 mm in diameter (KARL STORZ GmbH & Co., Tuttlingen, Germany), as the sole visualizing instruments. Each dissection was aided with the use of a neuronavigation system (StealthStation AxiEM; Medtronic). During this step, coordinates of relevant landmarks were retrieved to measure postoperatively the area exposed by the selected approach (Figure 2).

Postoperative CT and 3D Model. After each dissection, a second, postoperative CT scan with the same characteristics as the

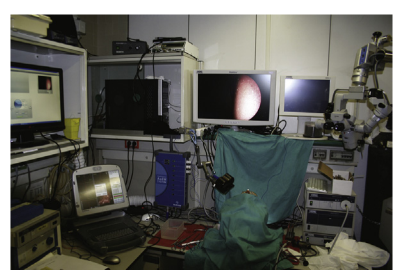

Figure 2. Laboratory of Surgical NeuroAnatomy of Barcelona (Spain): anatomical dissection step with the aid of the neuronavigation system.