The Changing Face of Technologically Integrated Neurosurgery: Today's High-Tech Operating Room

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Over the last decade, surgical technology in planning, mapping, optics, robotics, devices, and minimally invasive techniques has changed the face of modern neurosurgery. We explore the current advances in clinical technology across all neurosurgical subspecialties, examine how clinical practice is being shaped by this technology, and suggest what the operating room of tomorrow may look like.

INTRODUCTION

The increase in robotics and high-precision instrumentation, and the ongoing development of minimally invasive procedures, are leaving the hospital environments of just 5 years ago increasingly far behind. In the last decade, the advancement of surgical tools and the availability of data have drastically increased, allowing the modern neurosurgeon to rely on many inputs before, during, and after surgery. These inputs have created a surgical armamentarium that heavily leverages the benefits of technology and have created the opportunity for a technologically integrated operating room (OR) that can reshape clinical practice.

There is an ongoing migration to less invasive and even noninvasive procedures. Minimally invasive surgery, image-guided procedures, robotic surgery, and telesurgery continue to replace traditional surgical procedures. This substantial transformation relies on improved patient data acquisition and processing, more accurate selection of surgical trajectories (Figure 1), improved visualization, enhanced surgical tools, more effective resection techniques, and better intraoperative diagnostic procedures. Improved OR design and more efficient ergonomics are being developed using a multidisciplinary approach with close collaboration between clinicians, engineers, scientists, and industry. Real-time work flow improvement initiatives are being implemented that combine parallel processing, novel information technology architecture, asset management, and patient tracking solutions. Advanced image-guided surgery and a growing array of interventional procedures require the development of advanced visualization technologies that include enhanced acquisition, registration, segmentation, and augmented-reality systems. The technology available to the modern neurosurgeon includes methods for incorporating preoperative data intraoperatively to identify and follow the best surgical approach, as well as automation of the procedure through robotics, and minimally invasive techniques that can be optimized with these tools. Imaging systems located bedside within the OR provide faster and more accurate three-dimensional (3D) imaging of the body.[1-6]

We explore these and other current advances in clinical technology across all neurosurgical subspecialties, examine how clinical practice is being shaped by these technologies, and look at what the OR of tomorrow may look like.

THE TECHNOLOGICALLY INTEGRATED NEUROSURGICAL OR

New technologies are being developed to improve user interface, data connectivity and display, fusion of different imaging modalities, and 3D representation of anatomy in real time, among others. A functional surgical suite should connect a wide variety of key surgical systems such as robotics, radiography, navigation, ultrasonography, and endoscopy. Therefore, it is important for the

Key words
- Imaging
- Operating room
- Robotics
- Surgery
- Technology

Abbreviations and Acronyms
3D: Three-dimensional
ALA: 5-aminolevulinic acid
CT: Computed tomography
FUS: Focused ultrasound surgery
MR: Magnetic resonance
MRI: Magnetic resonance imaging
OCT: Optical coherence tomography
OR: Operating room
PET: Positron emission tomography

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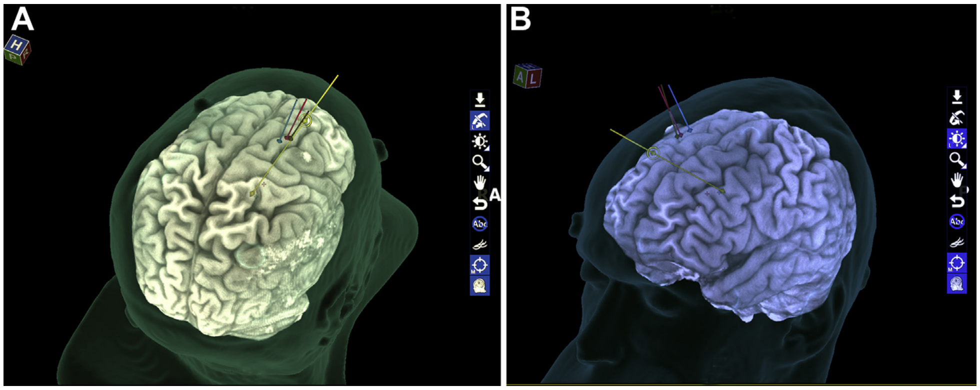

Figure 1. (**A**, **B**) Preoperative planning of patient-specific surgical trajectories can be used to plot an optimal trajectory to targets and avoid critical brain structures. Precise trajectory planning helps reduce the risk of hemorrhage and other complications.

design of a modern OR to not only consider current needs and systems but also to accommodate rapidly developing therapies and future needs. The modern operative theater steers away from the old and cumbersome space cluttered with equipment and medical machinery. Next-generation technologically integrated neurosurgical ORs requires a thoroughly planned environment that considers the space needed for imaging equipment and the integration of different components into one umbrella system.[1,2]

Large wall-integrated floor-to-ceiling digital displays to project imaging will play a crucial role in creating a fully immersive experience for the surgeon. New surgical suites use ceiling mounting that keeps the equipment off the floor but within reach. Large ceiling-mounted autostereoscopic displays and monitors integrating different imaging sources can be positioned on different sides of the patient to allow adequate visualization. 3D technology is an essential feature of future visualization because it holds the promise of restoring depth perception to the operative realm. State-of-the-art, robot-assisted, fixed C-arm systems allow for the most flexible setup with the highest hygiene standards needed for a crowed environment such as the OR. A flexible and versatile surgical table has to be a compromise between interventional and surgical functionality. Important aspects to consider in devising the proper surgical table include radiolucency (carbon fiber tabletop), compatibility, and integration of imaging devices and robots, adjustable table height, and horizontal mobility (floating), including vertical and lateral tilt.

Wireless technology in the OR prevents clutter and may reduce the risk of injury to both patient and staff.[1] In a wireless environment, it is easier to move throughout the room without having to disconnect and reconnect wired equipment. Wireless handheld controllers can easily position OR tables and transmit camera imaging to multiple surgical displays. The integration of an imaging system with an integrated surgical table allows imaging in sophisticated surgical positions without repositioning for acquisition. Instead of a keyboard and mouse (which take up space), gestures, touch, vision, and speech control are the optimal platform for user interface in a modern surgical suite. The advantage of a touchless sterile control is appealing in the OR environment. Eye tracking (including blinking) and speech recognition can be used to interface the surgeon with various technology modules.[2]

The Kinect hardware introduced by Microsoft in 2010 (Redmond, WA) laid the groundwork for Kinect-based research projects and products in different environments. Overall, gesture control will likely become the user interface of the future in the OR but limit the amount of gestures and shorten the time of interaction. Head-mounted displays such as Google Glass can provide data efficiently and in a sterile environment, enabling shared clinician perspectives and augmented reality, which can also be used for training and teaching. Voice control technology (Hermes system, computer motion, Stryker endoscopy) can serves as a centralized and simplified control interface, although speech recognition still poses the problem of ambiguity and robustness in a room with multiple persons.[2,3]

The future will likely see further integration and combination of these systems. Sensors will enable digital devices to see, hear, and feel. The goal will be to make these machines into helpful team members, but to achieve this vision, the machines will need to become more intelligent and anticipate the next step in the procedure, just like a good assistant. Digital technology will provide additional senses or memory, enriching reality with additional information.

IMAGING: DIAGNOSIS TO SURGICAL PLANNING TO NAVIGATION

The modern OR should provide a seamless transition between preoperative diagnostic imaging, preoperative planning data, and intraoperative stereotactic or navigable guidance.

Diagnostic Imaging

Traditionally, surgeons have mentally reconstructed the anatomic structures of interest from a set of two-dimensional images before surgery, a task that has varying degrees of difficulty depending on the imaging modality being used and the individual capability of volumetric reconstruction. 3D image reconstructions, widely available on