Stereotactic Neurosurgery Using 3-D Image Data from Computed Tomography

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During the last decade computer tomography (CT) scanners have provided images that show internal anatomy of unsurpassed resolution and that, since they are inherently digital, a format computer graphics software can easily process. By combining CT images, a specially designed head-mounted instrument, and the software to coordinate them, improved surgical accuracy can result for stereotactic surgery. Using the head-mounted frame and the interactive computer software described here, the entire stereotactic approach is transportable to computer systems of three major CT manufacturers. Neurosurgeons now have a tool that allows trajectory selection and probe placement entirely within the CT suite. Compared with conventional stereotaxis, the CT-aided approach offers increased accuracy, with a significant reduction in procedure time and patient risk due to both the elimination of cerebral spinal fluid contrast injection for finding reference points and the avoidance of important brain structures due to the direct visualization afforded with CT. Key interactive features are shown here that allow unrestricted views of anatomy in the area of surgical interest. For example, oblique views that are normal to the trajectory of neurosurgical instruments are extracted in real time during the surgical procedure. Standard sagittal (lateral) and coronal (frontal) image planes are also shown integrated with the interactive technique. The surgical procedure is outlined and details of the pattern recognition technique for image-to-frame registration are presented. Test, phantom, and patient results are given.

INTRODUCTION

Stereotactic techniques are well-accepted neurosurgical procedures. The term stereotaxy means “arrangement in space” and refers to any neurosurgical procedure that places a probe in a region of the brain or spinal cord without directly visualizing that region. The advantage of these procedures is the fact that a structure in the brain can be reached in order to take a biopsy, stimulate the area, or destroy it without having to make a large incision in the brain or use general anesthesia.

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By combining new forms of technology we hope to provide the basis for a series of advancements within a field where the original and still-classic experimental work dates back to the earliest years of the 20th century, shortly after the discovery of X rays.1-5 Recent computer-assisted stereotactic research used a vector display processor to show stereotactic surgery planning in a three-dimensional viewing context.6 This recent effort showed simple outlines for the skull and target tissue within a line drawing model of a stereotactic frame. With viewing angle, frame adjustment, motion, and depth cueing all user-controlled, a visually convincing approach to stereotactic surgery emerged. Integration of computer speed and accuracy with a stereotactic device was finally demonstrated. Yet to be shown, however, was a technique that could be easily transported to CT installations having only the standard complement of imaging devices.

Few CT scanning centers have vector display processors (or the $100,000–120,000 to buy one) for stereotactic techniques using 3-D viewers. An approach using only 2-D raster images was needed. Though aesthetically less attractive, an approach using only 2-D raster images delivers several benefits difficult to exceed by 3-D methods. First, anatomy is shown in the context and format already well understood by neuroradiologists. Second, no additional hardware is needed other than that already supplied by CT scanner manufacturers. Third, no data conversion is needed to change raster CT images to vector drawings of key anatomic structures. Using a 2-D approach, CT images are shown unchanged; images are not reduced to simple skull, ventricle, or tumor outlines. Finally, surgical probe paths can be superimposed on actual CT images and their alternative sagittal and coronal view formats for a more complete analysis of their impact on neighboring tissue.

This paper briefly introduces the surgical procedure for CT-aided stereotactic localization, then examines in more detail the pattern recognition process and geometric transforms needed to orient CT images to the frame coordinate system.

THE FRAME AND SURGICAL PROCEDURE

The all-plastic frame, Figure 1, and software to plan stereotactic surgery is integrated with multiplanar display (MPD) imaging capabilities outlined in references 7 and 8. As an MPD option, a stereotactic operation can be planned and executed all within the CT suite.

The frame is made of gas-sterilizable delrin, which is sufficiently hard to resist deflection under operating conditions yet easily machined to ± .001 inch tolerance. The result is a head-mounted device (see Figure 2) that is lightweight (8.0 lbs.) and causes no image artifacts when CT-scanned.

The stereotactic operation begins by taking a series of parallel CT images of the patient's skull within the frame attached. (Though stereotactic software described here does not require parallel axial slices, sagittal and coronal reconstructions are important benefits realized when parallel scans are taken.) Scans are taken to include target and entrance points for the surgical probe. Like any set of CT images, MPD options can be used to review the anatomy, but once stereotactic planning is chosen, CT scans are frame-registered (see following section) and additional review capabilities are enabled.