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Frameless stereotaxy for surgery of the epilepsies: preliminary experience

Technical note

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Frameless stereotactic techniques used in conjunction with three-dimensional images allow accurate planning and performance of a variety of neurosurgical procedures. The authors have used the frameless stereotactic Allegro Viewing Wand system to provide real-time correlation of the operating field and computerized images in 42 neurosurgical operations, including 31 epilepsy procedures. The system consists of an image-processing computer that creates three-dimensional and triplanar images; a mobile computer to display reformatted magnetic resonance images; and a hand-guided, articulated, position-sensing arm with a probe. At the start of the operation, the probe identifies the patient's facial and scalp features and correlates these with the computerized images. The position-sensing arm can then guide the operation and locate anatomical structures and lesions of interest. This system can be used to advantage in performing smaller craniotomies and intraoperatively locating anatomical structures and lesions to be removed. Postoperative magnetic resonance images demonstrate that this technique was accurate to within 3 mm in measuring the anteroposterior resection of fixed structures, such as hippocampus and corpus callosum. Disadvantages include longer preoperative preparation for data analysis and lack of both real-time computer analysis of tissue removal and angiographic data display. Preliminary experience suggests that the viewing wand system's advantages outweigh the disadvantages, and it is most helpful as an adjunctive navigational device in the microsurgical treatment of epilepsy.

KEY WORDS • **frameless stereotaxis** • **epilepsy** • **operative technique** • **instrumentation**

STEREOTACTIC techniques used in conjunction with three-dimensional image reconstruction allow accurate preoperative planning and can guide a variety of neurosurgical procedures;[4,5,9,13] however, the use of a stereotactic frame is cumbersome for the surgeon and uncomfortable for the patient, and in some centers its use is limited primarily to small or deep-seated lesions. Several image-guided, frameless intraoperative navigational devices that use various localization techniques have been recently developed (BL Guthrie, *et al.*, unpublished data).[2–4,12–14] These devices provide accurate intraoperative localization of structures of interest and can be easily moved away from the operating field when not in use, giving the surgeon a wide working space.

Description of System

The Allegro Viewing Wand system* consists of a computer workstation to create three-dimensional and triplanar images, and a position-sensing arm connected to a computer display system that provides real-time feedback between the operative field and the reformatted magnetic resonance (MR) images. Stereotactic coordinates are calculated from the patient's facial features, obviating the need for the implanted markers required with other systems (BL Guthrie, *et al.*, unpublished data).[6]

* Allegro Viewing Wand system supplied by ISG Technologies, Toronto, Ontario, Canada.

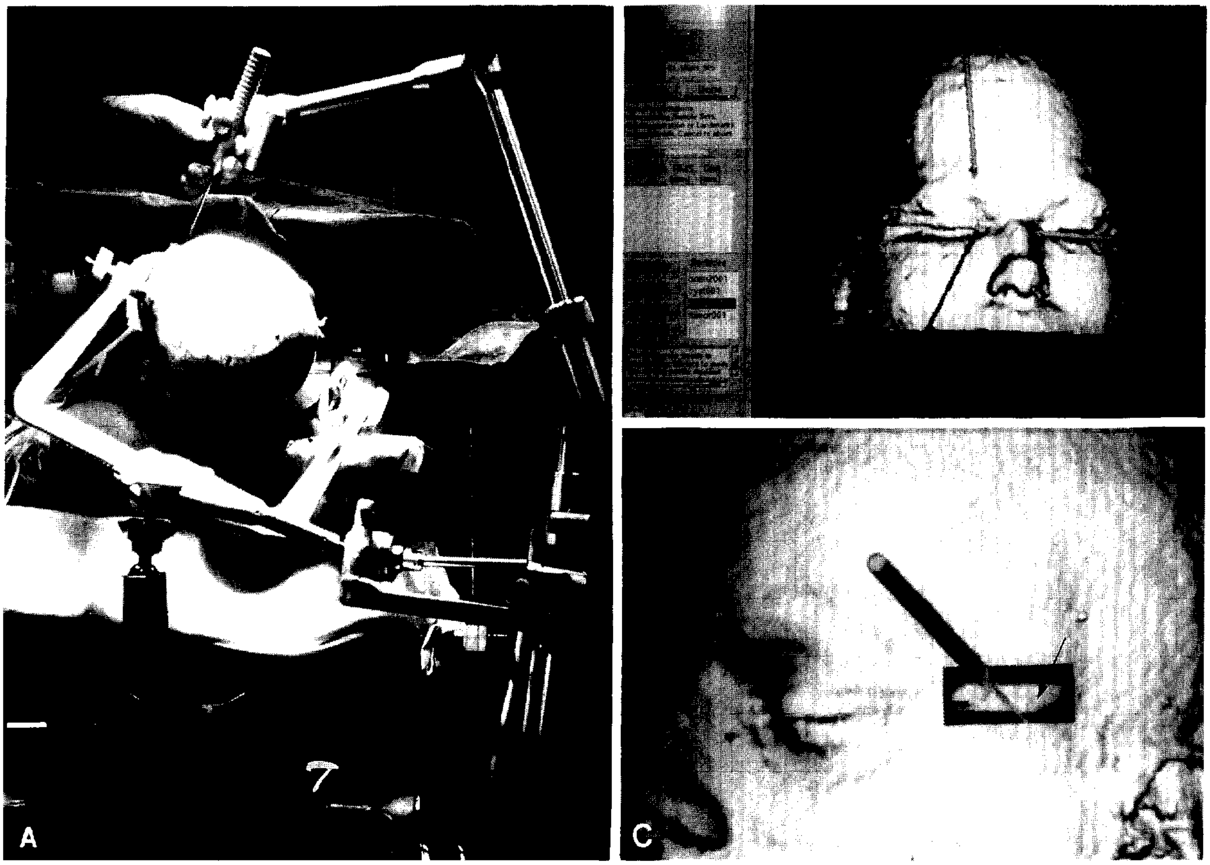


FIG. 1. Photographs showing the use of the Allegro Viewing Wand as a navigational device for a selective amygdalohippocampectomy. A: The viewing wand position-sensing arm is attached directly to the Mayfield head holder. A probe connected to the arm is used to identify five or more facial features and correlate them with the reconstructed three-dimensional image of the patient's face. B: Computer-generated three-dimensional reconstructed magnetic resonance image of the patient's face showing crossing of the lines, indicating the position of the probe on the patient's inner canthus during the registration. C: The real-time positioning of the probe on the patient's head is seen on the screen and used to plan the craniotomy window. The mesiotemporal structures are indicated by an *arrow*.

We have used this system to guide 42 neurosurgical procedures. This report describes the advantages and limitations of this system used as an adjunctive navigational device in the surgical treatment of 30 patients with epilepsy.

Between March, 1992, and December, 1992, 42 patients at the Montreal Neurological Institute underwent neurosurgical procedures guided by the frameless stereotactic viewing wand system; 31 procedures were for surgical treatment of epilepsy. All operations were performed by the same surgeon (A.O.).

Frameless Stereotactic Procedure

Preoperative Procedure

Preoperative MR images were obtained in all patients (64 axial images, TR 550 msec, TE 30 msec, FOV 250 slice, thickness 2.6 mm). The images were stored on magnetic tape and transferred to the Allegro workstation, where three-dimensional and triplanar images were derived with an interactive algorithm that incorporates threshold-based segmentation and slice-to-slice connectivity to create the desired set of surface contours. These images were then transferred to the mobile viewing wand system, a computer connected to a hand-guided, articulated, position-sensing arm and a screen to display the images.

Operative Procedure

The patient's head was immobilized intraoperatively with a standard Mayfield head holder. Because pilot studies showed greater movement error when the position-sensing arm was attached to the operating table, the arm was attached directly to the head holder (Fig. 1A). A long (15-cm) or short (7.5-cm) probe was connected to the arm, and its length was calibrated; the long probe was used for deep-seated lesions and the short one for surface procedures. Five or more features of the patient's face were then identified using the probe and correlated with the reconstructed three-dimensional image (Fig. 1B). Several random points on the skin surface were also identified using the probe and correlated with the computer images. During this registration process, the angulation of each joint of the arm was monitored by the computer so that the position of the probe was known at all times.

The accuracy of the registration was confirmed visually by placing the probe on three features of the patient's face easily recognizable on the three-dimensional and triplanar images. If an error was thought to be greater than 2 mm, the registration was repeated to increase accuracy. The images were displayed as three-dimensional, triplanar, and on-line, similar to those obtained with an ultrasound probe.

The patient's scalp was prepared and draped; the position-sensing arm was draped separately with a sterile plastic cover and the probe was disconnected and sterilized. After opening the soft tissue but before the craniotomy, four to five small holes were drilled in the calvaria around the planned craniotomy window as secondary reference points; these points were registered with the probe to assess movement between the patient's head and the position-sensing arm during the bone work and were checked again before the microsurgical dissection. If there was a movement of greater than 2 mm, the reference points were reregistered to correct the error. Once registration ended, the surgeon used the probe to provide information on the location of structures of interest (Fig. 1C).

Summary of Cases

The viewing wand system was used to guide the following 31 operations in 30 patients (15 females and 15 males) with medically refractory epilepsy: five selective amygdalohippocampectomies, 10 lesion removals, three callosotomies, five temporal reoperations, five neocortical resections, and three placements of depth electrodes. The mean patient age was 26 years ± 7.8 years (range 12 to 49 years). In the cases in which the lesions were removed, the sizes varied from 1.5 to 3 cm in diameter and included two cavernous angiomas, two gangliogliomas, five astrocytomas, and one gliosis.

Discussion

Techniques for microsurgical resections and indications for lesion removal in the surgical treatment of epilepsy have been described in the literature.[2,8,10,11] When indicated in our cases, neuroleptic anesthesia was used, which did not affect use of the viewing wand system and was well tolerated by the patients.

Accuracy of Measurements

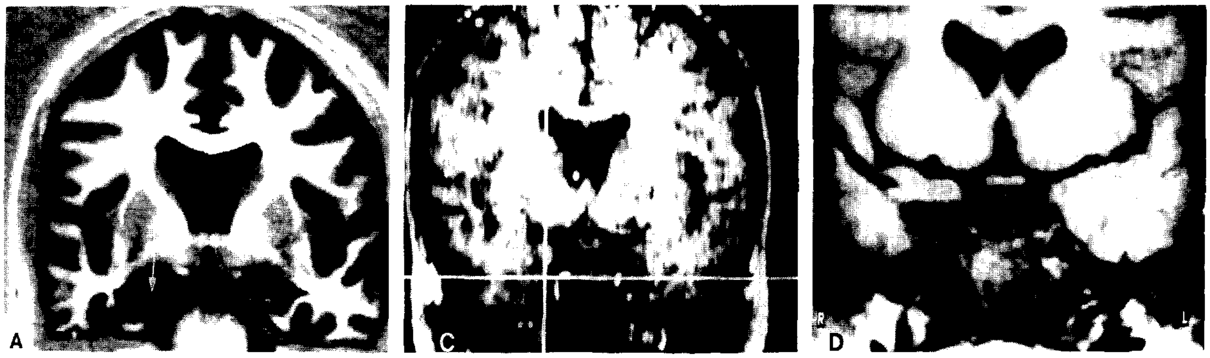
Two types of movement error were identified. First, movement of the head in relation to the position-sensing arm during the craniotomy was less than 2 mm in 28 (90%) of 31 cases; in cases of error greater than 2 mm, the reference points were reregistered and the error was corrected. This error could also be due to partial drift of the articulated arm. Second, the reconstructed three-dimensional image showed only the preoperative anatomy, and there was no real-time feedback to update the information. This error occurred after retraction or removal of brain tissue and had minimal impact on measurement of the anteroposterior dimension of fixed structures, such as the corpus callosum and the hippocampus. In the three callosotomy cases, the discrepancy between the intraoperative anteroposterior measurements and postoperative MR images was 3 mm. Similar results were found during resection of the hippocampus in 12 temporal lobe cases. However, lateromesial measurements in temporal and parietal cases had an error of greater than 3 mm in all cases. This was probably because of cerebrospinal fluid drainage during the microsurgical dissection and progressive mesial displacement of the brain due to gravity. The error did not interfere with the prompt localization and gross total removal of the lesion or structure of interest.

Operative Advantages

Use of the position-sensing arm reduced the size of the craniotomy and optimized the surgical exposure in all cases. During electrocorticography, the probe was used to point to each surface electrode on the patient's cortex. The position of each electrode was displayed on the screen, showing the neurologist its exact location. This was particularly helpful in five reoperations of the temporal lobe and in planning the position of the burr holes in peritorcular cases. For selective amygdalohippocampectomies, the probe was used during the transulcal dissection to confirm the direction toward the temporal horn of the lateral ventricle. The system allowed us to optimize the anteroposterior length of the hippocampal resection and was also helpful in the callosotomy cases. The viewing wand assisted with implantation of electrodes in the hippocampus and amygdala in the four patients who required electrocorticography with depth electrodes. The system promptly located all eight deep-seated lesions, which reduced the extent of microsurgical dissection (Fig. 2). In the five neocortical resections, the system was very useful for integrating the three-dimensional image with the surgical anatomy, especially when identifying pre- and postcentral areas. The precentral gyrus could be easily identified on the screen by locating the inferior, middle, and superior frontal sulci and their intersection with the precentral sulcus. The position of the probe was adjusted until the precentral gyrus was properly identified on the patient's cortex. Intraoperative electrocorticograms and motor mapping confirmed the localization of the central area.

System Limitations

The preoperative reconstruction of the three-dimensional images, including data transfer, required 1 to 2 hours; the intraoperative calibration of the probe and registration of facial features delayed the beginning of the surgical procedure by 45 to 60 minutes. Once the operation had begun, however, the lesion could then



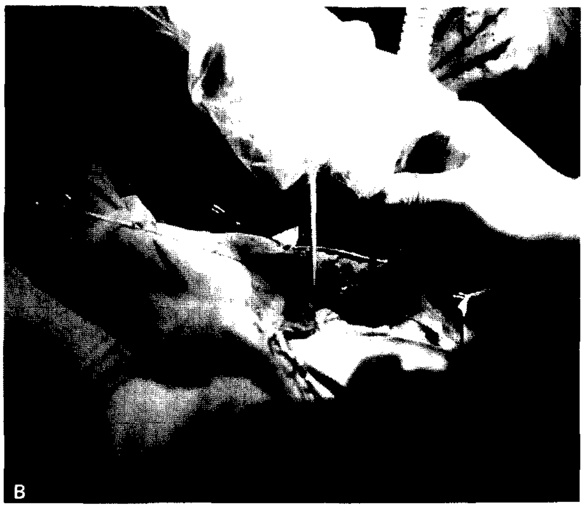


FIG. 2. A: Coronal magnetic resonance (MR) image (TE 20 msec, TR IR 2000 msec, TI 428 msec, angle LR-25) revealing a small cystic lesion *(arrow)*, inferior and mesial to the left temporal horn and involving the hippocampus, in a 29-year-old woman with a 12-year history of medically refractory complex partial epilepsy of temporal lobe origin. (Postoperative histological examination found a ganglioglioma.) B: Operative photograph showing approach to the lesion through a microsurgical dissection of the sulcus between the superior and middle temporal gyrus. During the dissection, the probe directs the surgeon by confirming the trajectory first toward the temporal horn, then to the lesion. C: Coronal MR image showing the crossing of the lines corresponding to the intraoperative real-time position of the probe in the patient's brain. D: Postoperative coronal MR image showing removal of the lesion and the anterior two-thirds of the hippocampus (TR 640 msec, TE 20 msec).

be located more quickly, and the overall duration of the procedure was not significantly lengthened. The use of this technique to place depth electrodes was limited by the lack of display of cerebral angiographic data in conjunction with the MR images.

A number of refinements and added capabilities, such as incorporating the probe into one of the surgical instruments (microsuction, ultrasonic aspirator, microbipolar forceps), are being developed to improve the viewing wand system for epilepsy surgery and to allow continuous feedback to the surgeon. A display of the three-dimensional and MR images through the operating microscope would obviate the need for the surgeon to turn away from the operating field. We are in the process of developing a system to integrate digital angiography with MR data,[5] which would be very helpful during placement of depth electrodes. The addition of MR angiography data should be useful in a variety of cases; the ability to write letters and numbers on the screen would aid the surgeon and the neurologist during electrocorticography.

Conclusions

Our experience shows that the Allegro Viewing Wand system is most useful in guiding surgical procedures for the treatment of refractory epilepsy. A scientific assessment of this device is beyond the scope of this study; however, we believe that it is not yet as accurate as conventional stereotactic headframe systems.[7] Nevertheless, this system can be used as a navigational device to allow prompt localization of structures and lesions of interest. The lack of compensation for intraoperative distortion in epilepsy surgery, which could be a serious limitation in debulking large supratentorial masses, interferes only minimally with its use. Relatively fixed structures such as the hippocampus and corpus callosum undergo minimal displacement during surgery. Researchers have stressed the importance of a more complete resection of these structures for treatment of the epilepsies.[1,2,9–11] The viewing wand system provides satisfactory intraoperative measurements that aid in resection.

The accuracy of this device in reproducing computerized tomographic coordinates from marker phantom targets should be tested under rigorous experimental conditions.

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Disclosure

The authors have no financial interest in the instrumentation described in this paper.

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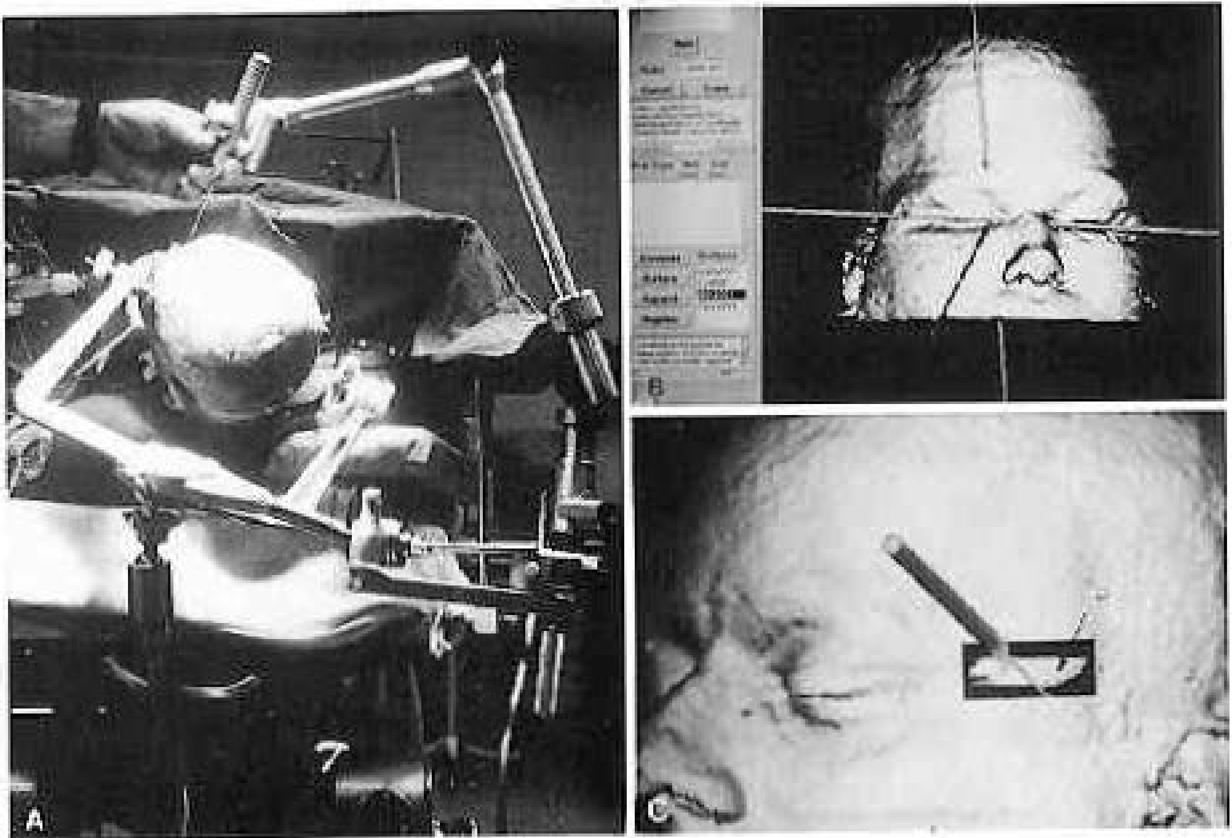
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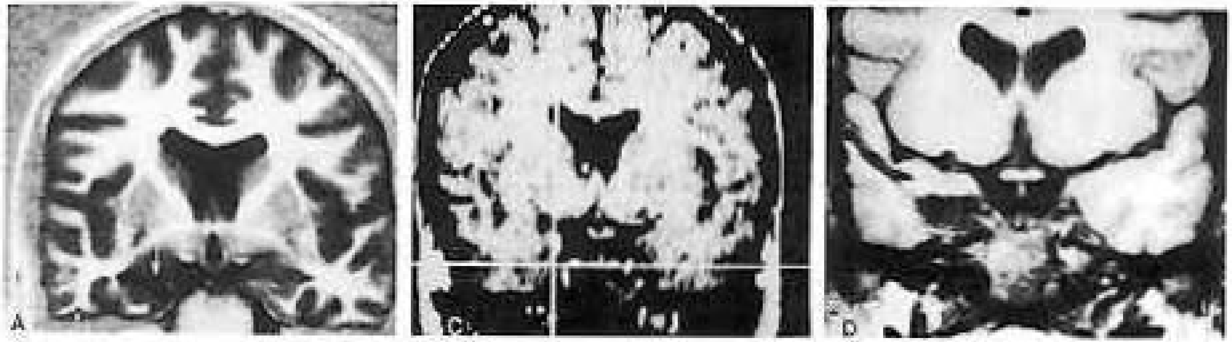

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