Image-guided Epilepsy Surgery

Tatsuya TANAKA, André OLIVIER*, Kiyotaka HASHIZUME, Akira HOZOZUKA, and Hirofumi NAKAI

Department of Neurosurgery, Asahikawa Medical College, Asahikawa, Hokkaido; *Department of Neurosurgery, Montreal Neurological Institute, Montreal, Canada

Abstract

Interactive image-guided techniques used in conjunction with three-dimensional images allow accurate planning and performance of a variety of neurosurgical procedures. The frameless stereotactic Viewing Wand System was used to provide real-time correlation of the operating field and computerized images in over 22 neurosurgical operations carried out for intractable epilepsy. The overall results of the surgery demonstrated favorable results, with class 1 + class 2 outcomes in 86.4% of the present series. Our experience shows that the Viewing Wand System is most helpful as an adjunctive navigational device in the microsurgical treatment of epilepsy.

Key words: epilepsy surgery, Viewing Wand System, neuronavigation, electrocorticography, temporal lobe epilepsy, neocortical epilepsy

Introduction

Recent advances in high-resolution magnetic resonance (MR) imaging and three-dimensional (3-D) reconstruction of these images by computer allow not only accurate preoperative planning of surgery but also guidance for a variety of neurosurgical procedures.15,22 Stereotactic localization for operative procedures has become a mainstay of neurosurgical practice. The authors have used the frameless stereotactic Viewing Wand System since 1996. The present study illustrates the potential utility of the 3-D images of the Viewing Wand System for frameless stereotactic neurosurgery for the treatment of intractable epilepsies. The advantages and disadvantages of this system in neurological surgery are also described.

Clinical Materials and Methods

The Viewing Wand System was used to guide 22 operations for intractable epilepsy in 22 patients, eight females and 14 males aged 10 months to 51 years (mean 26.6 years), between 1996 and 1998.

All 22 patients underwent preoperative assessments according to the presurgical evaluation protocols of Asahikawa Medical College Hospital,14 including long-term video-electroencephalography (EEG) monitoring. Sphenoidal electrodes were used in patients with temporal lobe epilepsy more than 6 years old. Invasive recording was not performed in patients with extratemporal lobe epilepsy in whom the neuroimaging lesion and EEG focus were concordant and focus resection was performed based on intraoperative evaluation by electrocorticography (ECoG) in every patient. When the EEG focus and neuroimaging lesion were not concordant, grid electrodes were implanted subdurally over the lesions detected by neuroimaging.

Neuroimaging was performed by thin-slice MR imaging (1.5 Tesla) for 3-D reconstruction of the images by the Viewing Wand System, computed tomography (CT), and single photon emission computed tomography (SPECT) with technetium-99m-hexamethylpropyleneamine oxime or technetium-99m-ethyl cysteinate dimer during the interictal period and the ictal period. Angiography was performed in all patients including the Wada test when necessary.15 Video-EEG monitoring (SYNAFIT; NEC-Sanei, Tokyo) was conducted (usually over 24 hours) until three habitual seizures were recorded. All recordings were analyzed on-line by computer (Stellate system; Nihon-Kohden, Tokyo). Preoperative and postoperative neuropsychological assess-

This article was presented at the 21st meeting of the Japan Epilepsy Surgery (President Dr. Tatsuya Tanaka) held in October 1998, Asahikawa, Hokkaido.
ments were carried out by a neuropediatrician for children and by a neuropsychiatrist for adults. Surgery was not scheduled in patients with independent seizures recorded from the bilateral temporal lobes. Patients with medically intractable seizures with a possibility of spontaneous remission such as age-dependent, benign partial seizures were also excluded from this study.

I. Frameless stereotactic procedure

The Viewing Wand System (ISG Technologies, Inc., Toronto, Canada) was an arm-based frameless stereotactic system based on an articulated arm supporting the position-sensing Viewing Wand tip. Preoperative MR images (1.5 Tesla; Signa Horizon; General Electronics Yokogawa Medical, Tokyo) were obtained in all patients. Volume-acquisition MR imaging was performed by the spin echo method with the following parameters for T1-weighted images: repetition time 300–450 msec, echo time 14–15 msec, and matrix 256 × 256. The images were stored on digital audiotape (DAT) and transferred to the Viewing Wand System, where 3-D 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 configurations. The system was registered at the beginning of the operation by touching the probe tip to fiducial markers affixed to the patient's scalp or by using anatomical surface landmarks. The image information was transferred to the computer-guided articulated position-sensing arm for neuronavigation during the surgery. If the bone image seemed to be important for the surgery, CT images were also stored on DAT and transformed to the Viewing Wand System for the 3-D images and neuronavigation.

II. Surgical procedures

In all cases, neuronavigation was used to guide both the presurgical simulation of the surgical process and the actual microsurgery. Anterior temporal resection with amygdalohippocampectomy was performed in 10 patients with complex partial seizures (Cases 1–10) (Table 1). Extratemporal surgery was performed in 12 patients with cortical focus (Cases 11–22) (Table 2).

All anti-convulsant medication was discontinued from 1 to 3 days prior to surgery to allow recording of spontaneous EEG seizures during intraoperative ECoG monitoring. Benzodiazepine was not used as a premedication for anesthesia because of its strong suppressive effect on cortical activity. Mayfield's head frame was applied and the patient's head position was calibrated using the tip of the arm by touching the fiducial markers and anatomical landmarks. A small but appropriate mark for the skin incision was designed on the scalp using neuronavigation. Surgery was performed under modified neuroleptanalgesia consisting of fentanyl and pancuronium bromide. All patients underwent intraoperative pre- and postresection ECoG with strip or grid electrodes (Ad-Tech Corporation, Nihon-Kohden). Preresection ECoG monitoring lasted for 30 minutes. The precise techniques of ECoG recording were previously reported.

Patients with cerebral cortical lesions underwent lesionectomy with epileptic focus resection. Patients with temporal lobe epilepsy underwent lateral temporal lobe resection en bloc, basically 5.0 cm along

<table>
<thead>
<tr>
<th>Table 1 Patients undergoing temporal lobe surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case No.</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

the base and 4.0 cm along the sylvian fissure from the temporal pole in the dominant hemisphere, and 5.5 cm and 4.5 cm, respectively, in the non-dominant hemisphere, according to Olivier.14) The procedure was performed under neuronavigation guidance. The vein of Labbé was always left intact. After anterior temporal lobectomy, the anterior part of the hippocampus (hippocampal head) and para-hippocampal gyrus were resected under neuronavigation guidance. The resected hippocampus was immediately frozen and sent for histological examination. The uncus and amygdala were also resected subpially by CUSA or suction. Postresection ECoG was performed in all patients and any residual epileptiform foci were resected with subpial suction when possible. Postresection ECoG was graded according to Jay et al.12

Table 2 Patients undergoing extratemporal surgery

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age</th>
<th>Sex</th>
<th>Seizure type</th>
<th>Seizure frequency</th>
<th>EEG focus</th>
<th>Intraoperative ECoG*</th>
<th>Operation</th>
<th>Postresection ECoG (grade)**</th>
<th>Diagnosis</th>
<th>Seizure outcome (class)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1/F</td>
<td></td>
<td>PS, SGS</td>
<td>1/day</td>
<td>lt frontal</td>
<td>+/-</td>
<td>lesionectomy</td>
<td>A</td>
<td>cavernoma</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>24/F</td>
<td></td>
<td>PS, SGS</td>
<td>1-2/wk</td>
<td>lt frontal</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>B</td>
<td>DNT</td>
<td>3</td>
</tr>
<tr>
<td>13</td>
<td>7/F</td>
<td></td>
<td>PS, SGS</td>
<td>10/day</td>
<td>rt parietal</td>
<td>+/-</td>
<td>lesionectomy</td>
<td>A</td>
<td>cortical dysplasia</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>9/M</td>
<td></td>
<td>CPS, SGS</td>
<td>2/day</td>
<td>lt temporal</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>A</td>
<td>cortical dysplasia</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>30/M</td>
<td></td>
<td>SGS</td>
<td>1-2/wk</td>
<td>lt parietal</td>
<td>+/-</td>
<td>lesionectomy, callosotomy</td>
<td>B</td>
<td>DNT</td>
<td>2</td>
</tr>
<tr>
<td>16</td>
<td>17/M</td>
<td></td>
<td>SGS</td>
<td>4-5/wk</td>
<td>lt fronto-parietal</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>C</td>
<td>cortical dysplasia</td>
<td>2</td>
</tr>
<tr>
<td>17</td>
<td>46/M</td>
<td></td>
<td>SGS</td>
<td>3-4/mo</td>
<td>rt frontal</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>A</td>
<td>glioma</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>8/F</td>
<td></td>
<td>PS, SGS</td>
<td>5-6/day</td>
<td>lt parietal</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>B</td>
<td>ganglioglioma</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>10 mos/M</td>
<td>tonic GS</td>
<td>4-6/day</td>
<td>lt temporo-occipital</td>
<td>+/+</td>
<td></td>
<td>lesionectomy, focus resection</td>
<td>A</td>
<td>cortical dysplasia</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>19/M</td>
<td></td>
<td>PS, SGS</td>
<td>4-5/day</td>
<td>lt temporal</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>A</td>
<td>cavernoma</td>
<td>1</td>
</tr>
<tr>
<td>21</td>
<td>23/F</td>
<td></td>
<td>CPS, SGS</td>
<td>1-2/wk</td>
<td>lt temporo-occipital</td>
<td>+/-</td>
<td>lesionectomy, focus resection</td>
<td>A</td>
<td>AVM</td>
<td>1</td>
</tr>
<tr>
<td>22</td>
<td>51/M</td>
<td></td>
<td>PS, SGS</td>
<td>1/wk</td>
<td>lt frontal</td>
<td>+/-</td>
<td>lesionectomy</td>
<td>B</td>
<td>glioma</td>
<td>2</td>
</tr>
</tbody>
</table>


III. Histological examination

All resected materials were processed for conventional histological study and, when necessary, immunohistochemical staining for glial fibrillary acidic protein and neuron-specific enolase. The frozen hippocampal specimen was further processed for Timm's staining in recent cases of anterior temporal resection.

IV. Postoperative review

Every patient was assessed at 1 month, 6 months, and 1 year postoperatively by neurological examination and EEG studies. Subsequently, assessments were made yearly. Follow-up MR imaging was scheduled for 1 month and 1 year postoperatively. The postoperative seizure outcomes were graded according to Engel et al.8: class 1 (free of disabling seizures), class 2 (rare disabling seizures), class 3 (worthwhile improvement), and class 4 (no worthwhile improvement). The clinical follow-up period ranged from 6 months to 3.2 years (mean 1.6 years).

Results

The clinical findings for the 22 patients are summarized in Tables 1 and 2. MR imaging demonstrated organic lesions in 18 patients and unilateral hippocampal atrophy in four. Preoperative long-term video-EEG monitoring revealed unilateral epilepsy focus in all patients. Interictal SPECT revealed unilateral focal abnormalities in 15 of 20 patients. Ictal SPECT detected focal abnormalities in 14 of 20 patients.

The accuracy of the Viewing Wand System during the operation was judged using anatomical landmarks such as the pterion, zygomatic arch, sylvian fissure, sylvian vein, temporal tip of the brain, etc. If the error exceeded more than 5 mm, re-registration was performed using these anatomical landmarks.

Neurol Med Chir (Tokyo) 39, December, 1999
Thus, the estimated error during surgery varied from 2 to 5 mm. Postoperatively, MR images were assessed to verify whether precise excision was performed or not. In all cases, the planned procedures were performed.

Postoperatively, 15 patients (68.2%) became seizure free (class 1), four (18.2%) were class 2, two (9.1%) were class 3, and one (4.5%) was class 4.

**Case Studies**

A 10-month-old boy (Case 19) had suffered from tonic spasms since 2 months old. He was treated by adrenocorticotropic hormone therapy and tonic spasms stopped. However, frequent tonic seizures appeared four to six times a day. The seizures were intractable and unresponsive to medical treatment. MR imaging revealed a heterotopia in the white matter of the left temporo-occipital region (Fig. 1).

---

He was transferred for assessment of surgical treatment.

On admission, digital EEG detected an epileptic focus and a dipole source in the left posterior temporal region. Interictal SPECT demonstrated a hypoperfusion area in the left occipital region and ictal SPECT demonstrated a hyperperfusion area in the same place (Fig. 2). 3-D images of the Viewing Wand System demonstrated a periventricular nodular heterotopia around the posterior horn and calcar avis of the left lateral ventricle, which extended to the occipital lobe as a focal cortical dysplasia (Fig. 3). Right homonymous hemianopsia was suspected but was not well characterized due to his age.

Intraoperative ECoG demonstrated widespread high amplitude spikes and spike and wave complexes over the posterior temporal and occipital lobes (Fig. 4). Spike focus resection and lesionectomy were performed under neuronavigation guidance. Postresection ECoG demonstrated no spike activities at the cut edge of the posterior temporal cortex.

Postoperative MR imaging confirmed excision of the heterotopia (Fig. 5). Postoperative course was satisfactory and the patient became seizure-free and started to demonstrate normal development. Follow-up EEG demonstrated no spike activity. However, the possible right homonymous hemianopsia should be carefully followed up for further plasticity and reorganization of the visual pathways during his development.

---

**Fig. 1** Preoperative T₁-weighted magnetic resonance images demonstrating periventricular heterotopia of the posterior horn of the left lateral ventricle (arrows).

**Fig. 2** Interictal single photon emission computed tomography (SPECT) scan (left) demonstrating a hypoperfusion area in the left occipital region (arrow). However, ictal SPECT scan (right) demonstrates hyperperfusion (arrow) in the same area.

**Fig. 3** Three-dimensional reconstruction of the magnetic resonance imaging demonstrating periventricular nodular heterotopia and focal cortical dysplasia in the left parieto-occipital region (red arrows).
Discussion

Recent advances of epilepsy surgery makes it possible to have a seizure-free life in patients with intractable epilepsy.1-5,7,9,10,13,16,17,21 However, these surgical procedures produced a certain proportion of failure cases.19,20 In the present study, epilepsy surgery using neuronavigation was introduced and the surgical results were compared with previous reports.

All surgery was performed under operative microscope. The accuracy of measurement of deep-seated lesions varied from 2 to 5 mm. In cases of error greater than 5 mm, the reference points were re-registered during surgery and the error was corrected. When there was remarkable brain shift due to brain retraction or cerebrospinal fluid aspiration, lesions of convexity demonstrated greater errors. However, lesions close to the skull base, midline lesion, or hippocampal lesion did not show any shift during surgery and correlation was excellent during the surgery. In recent cases, the operative microscope with the picture-in-picture system (OME-8000; Olympus, Tokyo) was introduced into epilepsy surgery. In this system, the 3-D images of the Viewing Wand System are always captured in a quarter or a half visual field of the operative microscope (splitting image), and can be controlled with a foot switch. Under such circumstances, the surgeon has no necessity to look back to confirm the exact location of the pointer in the 3-D images of the monitor. Consequently, correct resection of the focus or lesion was performed under real-time neuronavigation. In all cases, postoperative MR imaging con-
firmed the exact excision of the lesion or structures due to accurate neuronavigation by the Viewing Wand System. However, our data demonstrated that our surgical results were almost the same with previous reports of epilepsy surgery.

In conclusion, our experiences show that the Viewing Wand System is most useful for guiding neurosurgical procedures in epilepsy surgery with an excellent neuronavigation system to allow prompt localization of structures and lesions of interest. Recent advances in the operative microscope with the picture-in-picture system will permit further accuracy of the surgery. The Viewing Wand System is a reliable and accurate tool to allow neurosurgical approaches to a small epileptogenic lesion in the brain.

References

18) Tanaka T: [Presurgical evaluation]. Neurosurgeons 12: 78–85, 1993 (Jpn, with Eng abstract)

Address reprint requests to: T. Tanaka, M.D., Department of Neurosurgery, Asahikawa Medical College, 1–1–1 Higashi 2, Midorigaoka, Asahikawa, Hokkaido 078-8510, Japan.