Clinical use of a frameless stereotactic arm: results of 325 cases

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The viewing wand is a frameless stereotactic arm that can be used in conjunction with computerized tomography (CT) or magnetic resonance (MR) imaging to provide image-based intraoperative navigation. The authors report a series of 325 cases in which the viewing wand was used and evaluated for its utility, ease of integration into the standard surgical setup, reliability, and real-world accuracy. The use of the system was associated with minimal additional effort or time spent in setting up the procedure as long as a trained technician performed the data transfer and reconstruction. The viewing wand was used in 165 cases in conjunction with CT and 145 cases with MR imaging. The system was reliable, achieving a useful registration in 310 of 325 cases (95.4%). Fiducial-based registration was more accurate than an anatomical landmark–surface fit algorithm method of registration (mean 2.8 vs. 3.6 mm error, respectively, for CT; and mean 3.0 vs. 6.2 mm for MR imaging). The actual error of the system in estimating the position of the probe tip just after registration was judged by the operating surgeon to be less than 2 mm in 92% of MR imaging cases and in 82% of CT cases, between 2 and 5 mm in 7% of MR imaging and 17% of CT cases, and greater than 5 mm in less than 1% of MR imaging and 1.2% of CT cases. The accuracy of the system degraded during the operation, so that by the third evaluation the error was estimated to be less than 2 mm in 77% of MR imaging and 62% of CT cases.

Overall, the viewing wand was found to be reliable and accurate. This real-world accuracy was sufficient for a broad range of applications including glioma resection, cerebrospinal fluid shunting procedures, resection of small subcortical masses, and temporal lobe resection. The system is a useful navigational aid that allows a direct approach to intracranial pathology without the drawbacks of application and the limitations of a stereotactic frame.

Key Words • frameless stereotaxy • viewing wand • stereotactic guidance • stereotactic surgery

“Lead on: one only will in us both.
Thou art my guide. . . .”
—Dante Alighieri

SURGICAL techniques using stereotactic frames permit neurosurgeons to perform biopsies and to resect deep-seated and previously inaccessible lesions. These frame-based techniques, however, have several limitations. The stereotactic frames themselves are bulky and may interfere with the surgical exposure. Patients complain about the weight of the frame and the pain associated with its application. Despite new arc-based systems, the surgeon is typically limited to target points on a linear trajectory. Most importantly, these frame-based stereotactic systems do not provide ongoing feedback to the surgeon about anatomical structures encountered in the surgical field. Consequently, several investigators, beginning with Roberts19 in 1986, have developed frameless stereotactic systems.3–5,7,12–16,18–23

All frame-based and frameless systems rely on transformation of the digital data of imaging studies to the stereotactic space of the operative field. In conventional frame-based systems, the frame provides fiducial points that are visualized on the imaging study. These points define the stereotactic space by virtue of the rigid attachment of the frame to the patient’s head.18 In frameless systems, at least three fiducial markers are attached directly to the patient’s scalp. The markers are usually small beads composed of material that is obvious on either computerized tomography (CT) or magnetic resonance (MR) imaging. Recently, the patient’s scalp itself has been used as a fiducial marker.21 When the position of the markers is measured with a digitizing device, it can be correlated with the position of the markers on the imaging study.
From this correlation, the imaging data can be transformed to the stereotactic space of the operative field.\textsuperscript{9, 11, 24} The position of the tip of the digitizing device is said to be registered with the imaging data so that any point on the patient’s head can be mapped to its corresponding point in the imaging study and vice versa.\textsuperscript{11} The critical component in any frameless system is the digitizing, or localizing, mechanism. Since Roberts\textsuperscript{19} initial description of an ultrasonic digitizing system,\textsuperscript{7} several technologies have been incorporated as the basis of localizing systems. Ultrasonic systems use ultrasonic pulse emitters mounted on a viewing wand, surgical instruments, or the operating microscope.\textsuperscript{3–5, 7, 18, 19} A microphone array detects the pulses, and a computer calculates the position of the localizing device based on the delay between the production and reception of the pulse.\textsuperscript{3} Electromagnetic systems are a more recent development.\textsuperscript{13, 21} The position of the localizing device is calculated by the signal induced in sensors by a low-frequency electromagnetic field transmitter.\textsuperscript{21} Along with other investigators, we have used a digitizing mechanical arm or probe.\textsuperscript{1, 11, 14, 16, 17, 22, 23} Mechanical digitizing devices rely on an articulated arm in which the position of the arm or probe tip is calculated from the angles of the various joints through a range of motions.\textsuperscript{12, 23} The most persistent question concerning frameless stereotactic devices is their accuracy compared to frame-based systems and the adequacy of their accuracy for the demands of neurosurgical procedures.\textsuperscript{24} Furthermore, their integration into routine neurosurgical practice so that they are quick and easy to use has not been achieved. Previous reports on frameless stereotactic devices in clinical use have stressed the mechanical accuracy of the device under optimum conditions without giving details on its accuracy in a large series of patients.\textsuperscript{9, 16, 22} The applied accuracy of the devices (their accuracy in a real-world setting)\textsuperscript{9} has not yet been addressed.

We therefore evaluated the utility, ease of integration into the standard surgical setup, reliability, and, most importantly, the real-world accuracy of the viewing wand in a large variety of neurosurgical cases. The system was used for 3 years in more than 300 procedures, which is the largest reported series of cases performed with the assistance of frameless stereotactic guidance.

Clinical Material and Methods

Patient Population

Between October 1991 and October 1993, the viewing wand was used in 325 operations performed at our institution. In 15 (4.6\%) of these cases, the use of the system was abandoned because of technical failure before registration or because the registration was considered unreliable. This left 144 males and 166 females in the study with a mean age of 41.5 years (range 1–83 years). In the 15 cases in which use of the viewing wand was discontinued, the surgeon reverted to the usual practice, estimating the position of the bone flap and trajectory by mental correlation of the imaging studies with the patient’s anatomy. No case had to be abandoned because of registration failure. This reflects the importance of sound surgical planning without exclusive reliance on any guidance device.

Patient selection was at the discretion of the operating surgeon. Most of the craniotomies were performed for malignant cerebral gliomas (54 of 310 cases). In addition to craniotomies for intra- and extraxial tumors, the system was used in cases of arteriovenous malformation (AVM) resection, cavernous malformation resection, aneurysm debulking, cerebrospinal fluid shunt placement, and surgery for intractable epilepsy. All patients or their guardians gave informed consent for participation in this study of the use of the viewing wand, in compliance with the procedures of the Institutional Review Board of St. Joseph’s Hospital and Medical Center.

Stereotactic Equipment

The viewing wand system (ISG Technologies, Inc., Mississauga, Ontario, Canada), an arm-based frameless stereotactic system, uses the Surgicom (Faro Technologies, Inc., Lake Mary, FL), a 6-df, articulated, position-sensing arm married to sophisticated three-dimensional (3-D) imaging software. Analog–digital converters transfer the data from the sensors in the three arm joints to an interface processor that calculates the position of the viewing wand tip. The tip position is updated 30 times per second. The position data are transferred to an image processor that displays the superposition of the viewing wand tip on a 3-D reconstruction of the imaging studies. The system is 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.

Imaging Protocol and Registration

Imaging studies, either CT or MR imaging, were obtained the night before or, in most cases, on the morning of the procedure, after application of the fiducial markers. Patients were instructed not to disturb the fiducial markers taped to the scalp. The imaging protocol for CT used 3-mm thick slices with 3-mm spacing (that is, no intervening space or overlap). Volume-acquisition MR imaging was performed with the following parameters for T\textsubscript{1}-weighted images: spoiled gradient recalled acquisition in the steady state sequence: flip angle, 35\(^\circ\); repetition time, 34.0 msec; echo time, 4.7 msec; 256 \times 256 image matrix; field of vision, 24 cm; and contiguous slices of 2.0-mm thickness.

The data from the imaging study were transferred to magnetic tape and transported to the operating room for reconstruction. Computer-aided medical reconstruction algorithm and Allegro programs (ISG Technologies, Inc.) were used to process the imaging studies. A single technician was responsible for data reconstruction and intra-operative operation of the viewing wand system, and the overall time for data reconstruction and entry was approximately 30 minutes per case. When the patient was brought to the operating room, the fiducial markers were checked to identify those that may have been displaced or otherwise disturbed.

Overall, 165 operations were performed using CT guidance, and 145 operations used MR imaging. For the first 73 cases of the series (21 CT, 52 MR), registration using scanned fiducial markers applied to the scalp was compared to registration using a surface-fitting algorithm with
visual anatomical fiducial points. For the fiducial registration, the positions of a number of fiducial points on the patient were correlated with the analogous positions of imaged fiducial markers using the viewing wand probe. For the anatomical landmark–surface fit registration, anatomical landmarks such as the tragus, medial and lateral canthi, nasion, and glabella were used as fiducials. A number of different points on the surface of the scalp were also entered in the registration, again using the viewing wand probe. The accuracy of each registration was evaluated using “check” fiducial markers. These check fiducials, which were not included in either registration, were used to check the registration by placing the viewing wand probe on the fiducial and observing the position demonstrated on the image dataset. If sufficient accuracy was not obtained in either registration, use of the system was discontinued. After the first 73 cases, both fiducial and anatomical landmark–surface fit registrations were performed, but only the more accurate registration was used during the operation and for evaluation of accuracy.

Evaluation of Accuracy

The accuracy of the viewing wand during the operation was judged as follows. In all cases, the bone surface itself or small holes drilled into the cranium using the C-1 bit of the drill were used as landmarks. During the operation, the operating surgeon checked the accuracy of the viewing wand one to four times after registration. The viewing wand probe was touched to the bone surface or bone landmark, and the surgeon estimated the error in the position demonstrated on the image dataset. The estimated error was judged as less than 2 mm, 2 to 5 mm, or more than 5 mm of discrepancy, respectively. The trip planar two-dimensional images were used for these assessments. For the comparison of fiducial and anatomical landmark–surface fit registrations in the first 73 cases, the probe tip was touched to the check fiducial. This position was entered into the computer. The imaging program then calculated the distance from the indicated position to the position of the check fiducial in the dataset as determined by the operator. In 15 cases, the use of the system was abandoned because of technical failure before registration or because the registration was considered unreliable. In most of these cases, a software error prevented proper loading of the program or there was serious doubt about the integrity of the fiducial markers from the time of the scan to the time of operation. Omitting these 15 left 310 cases in which the system was used and evaluated for accuracy and effect on the operation.

To judge the utility of the system and its contribution to surgery, the operating surgeons were questioned briefly during wound closure as follows: 1) was the viewing wand useful in planning the craniotomy? 2) was the viewing wand useful in defining intraoperative anatomy? 3) was the viewing wand useful in locating the lesion? 4) was the viewing wand useful in defining the margins of the tumor compared to the surrounding brain? and 5) was the viewing wand useful in determining the extent of tumor or brain resection? Acceptable responses were “yes,” “no,” or “not applicable” if the surgeon thought the question was irrelevant to the procedure or pathology. The accuracy data were analyzed en masse and also as a function of imaging modality. The questionnaire responses were categorized according to operative pathology.

### Results

#### Accuracy of Registration

On the initial evaluation of accuracy, the probe tip position was judged to be within 2 mm of its actual position in the field in 82% of the CT cases and in 92% of the MR imaging cases. Table 1 summarizes the errors as judged by the operating surgeon just after registration (Evaluation 1) and at subsequent points in the operation (up to four evaluations). No response indicates that the surgeon failed to judge the discrepancy between the imaged probe position and the actual probe position. In many cases a third or fourth evaluation was not performed and was thus recorded as not rated. Although the level of accuracy decreased with subsequent evaluations, it remained within 5 mm in more than 90% of the cases regardless of imaging modality. Overall, the accuracy associated with MR imaging was slightly greater than that associated with CT. Through all evaluations, discrepancy that was estimated to be less than 2 mm was more frequently reported for the MR imaging cases (Table 1).

When compared with the anatomical landmark–surface fit registration, fiducial registration resulted in greater accuracy as measured by the computer comparison of the calculated position to the true position on the scan as indicated by the system operator. For CT scans obtained in 21 cases, the fiducial registration error was on average 2.8 mm, compared to 5.6 mm for the anatomical landmark–surface fit algorithm method. For MR images obtained in 52 cases, the respective mean errors were 3.0 mm.

### Table 1

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* Computerized tomography (CT) was performed in 165 patients and magnetic resonance (MR) in 145.

† Evaluation 1 is just after registration. Subsequent evaluations were performed serially during the operation.
and 6.2 mm. Postoperative checks showed a slight decrease in accuracy in both registration methods, which was consistent with the findings in the overall group. Additionally, MR imaging was slightly less accurate than CT in terms of the initial fiducial registration, although this difference was no longer apparent by the end of the operation.

Clinical Utility

Seven different attending surgeons used the viewing wand system. The responses of the operating surgeons to the queries about the utility of the system were tabulated according to operative pathology (Table 2). In the planning phase, the system was perceived to be most useful for planning craniotomies for patients with AVMs, metastases, or cavernous malformations (87%, 83%, and 78% “yes” responses, respectively). The system was perceived to be useful for defining intraoperative anatomy in shunt placement, epilepsy surgery, and AVMs (100%, 92%, and 80% “yes” responses, respectively). In locating lesions, the system was judged most useful for gliomas, cavernous malformations, and other primary brain tumors (76%, 78%, and 79% “yes” responses, respectively), reflecting the subcortical location of these tumors. Similarly, the viewing wand was judged most useful in defining the tumor margin in cases of glioma (82% “yes” responses). Finally, it was judged useful in determining the limits of resection in cases of epilepsy surgery, glioma, and skull base tumors (85%, 76%, and 70% “yes” responses, respectively).

Associated Complications

No adverse effects were attributable to the use of the system. In one case, an unrecognized error in registration led the operating surgeon to conclude that a burr hole had been placed off midline, when, in fact, it was dangerously close to the superior sagittal sinus. However, the sinus was not penetrated, and the patient was uninjured. Overall, similar errors were avoided because the system was abandoned as soon as it was considered unreliable (that is, as soon as intraoperative evaluation of its accuracy revealed obvious errors in localization, which occurred in 11 cases). Viewing wand usage was often discontinued as soon as the lesion was encountered because the resection then became straightforward. In cases of glioma, the system was used to approximate the extent of resection, with the obvious proviso that this estimation was inherently unreliable due to errors induced by the shifting of the brain during resection. When the lesion was adjacent to the skull base or other convenient landmarks such as the tentorial edge, the system remained useful for judging the extent of tumor resection by comparison to these surrounding landmarks.

Case Studies

The following cases illustrate the clinical utility of the viewing wand in operations in which frame-based stereotaxy is the only alternative, and in cases in which, until now, there have been no useful adjuncts for intraoperative guidance.

Case 1. This 36-year-old woman had a 12-year history of episodic headaches and visual field narrowing. Four years before admission, she developed intermittent left-sided numbness. Magnetic resonance imaging revealed a cavernous malformation of the right frontal lobe (Fig. 1). Anticonvulsant medications did not ameliorate the symptoms. After a transient episode of speech difficulties, she was referred for surgical consultation. Surgical resection was recommended because of the accessibility of the lesion, its symptomatic nature, and the patient’s age. A right frontal craniotomy was performed with viewing wand guidance. Preoperative MR images were obtained.
Frameless stereotactic arm

with scalp fiducial markers for localization. The system was used to limit the size of the craniotomy and to select the sulcus for the surgical approach (Fig. 2). A transsulcal approach was used to resect the cavernous malformation completely (Fig. 3). One hour elapsed from the induction of anesthesia to the skin incision. The operation lasted 3 hours, and the patient was discharged home in excellent condition on the 3rd postoperative day.

Case 2. This 20-year-old man had a Spetzler21 Grade 4 right frontal AVM. He had previously undergone intraoperative and transfemoral embolization for control of headaches. He suffered from seizures as well. Magnetic resonance imaging was performed preoperatively with scalp fiducials affixed for use with the viewing wand. The system was used to help trace and extend the old craniotomy, especially in the region of the midline and superior sagittal sinus. During the dissection of the AVM, the system helped to ensure that the malformation was encircled completely and removed. Despite entrance into the ventricle at the depth of resection, the viewing wand remained useful, precisely localizing the septal vein (Fig. 4). Thirty-five minutes elapsed from induction of anesthesia to skin incision; the operation lasted 9 hours and 40 minutes. The patient was discharged to the inpatient rehabilitation service on the 7th postoperative day in excellent condition except for a mild left-sided hemiparesis. He subsequently recovered completely.

Case 3. This 13-month-old girl was dependent on ventriculoperitoneal shunting after neonatal intraventricular hemorrhage and Group B streptococcal meningitis. She had already undergone numerous shunt revisions for cystic loculation of the ventricular system. During a previous endoscopic cyst fenestration, the differentiation of cyst walls from normal ependymal surface was difficult because of scarring and fibrinous exudate. Viewing wand guidance of the endoscope was therefore used to ensure fenestration of all loculated spaces in the ventricular system. Magnetic resonance imaging guidance was used for the operation. The child was placed in pediatric Mayfield pins. A burr hole was drilled for a new ventricular catheter under guidance from the viewing wand, which was used to position a plastic peel-away sheath on the walls of the

Fig. 1. Preoperative T2-weighted axial magnetic resonance image showing a right frontal cavernous malformation.

Fig. 2. Viewing wand triplanar display image (left) and corresponding intraoperative photograph (right) showing selection of sulcus for approach to cavernous malformation.
various cysts. The endoscope was then exchanged for the probe through the sheath. In this way the cyst walls were easily fenestrated, and the tip of the endoscope localized to the cyst walls. The operation lasted 2 hours and 35 minutes. The patient did well and was discharged home on the 3rd postoperative day.

Discussion

Like other frameless stereotactic systems, the viewing wand system provides real-time anatomical and position information for the surgeon while remaining out of the way when not needed. In fact, when the utility of this system became obvious to other neurosurgeons in our institution, its popularity outstripped its availability. Minimal additional effort was required from the surgeon when a technician prepared the imaging dataset and helped maintain the viewing wand system in and out of the operating room. Most important, the system was sufficiently accurate for routine intraoperative localization and guidance.

Accuracy in Clinical Use

Zinreich, et al.,24 found that the mechanical accuracy of the viewing wand system, when tested on a plastic model of the skull, was within an average of 1 to 2 mm. Ninety-five percent of errors fell within 3.7 mm. This degree of accuracy is comparable to that of standard frame-based stereotactic systems.10,24 These data were obtained using CT scanning and serve as limits of the best accuracy that can be expected in vivo.

We found in the clinical setting that correlation of the imaged probe position with its position in the operative field was within 2 mm in 82% of the CT cases and 92% of the MR imaging cases on the initial determination. Accuracy remained within 5 mm in more than 90% of cases, regardless of imaging modality. The greater accuracy of MR imaging compared to CT-based registrations probably occurred because the CT cases were performed earlier in the series. The registration process became faster and more precise as familiarity with the system increased. Kondziolka, et al.,15 determined that discrepancies between localization with CT and MR imaging could be accounted for entirely by a one-pixel difference in target localization between observers. Because of the general familiarity with MR imaging reconstruction in multiple planes, registration with this modality may be easier and more precise despite greater problems with patient movement and magnetic field artifacts. In our own series, it appeared that MR image-associated errors decreased with increasing experience so that a higher proportion of the later MR imaging cases in our series reported registration errors of less than 2 mm. A second confounding factor is the method of estimating the error. In our first 73 cases, the computer calculated the discrepancy between the imaged and actual positions of the probe tip. In the overall series, the surgeon’s estimation of the discrepancy was used.

As mentioned, it is difficult to compare the accuracy of the viewing wand in this clinical experience to previous reports based on other frameless stereotactic systems. Most reports on mechanical arm-based systems have indicated accuracies of 1.5 to 3 mm. Watanabe, et al.,25 tested the accuracy of their system in 30 of 68 patients undergoing craniotomy. They reported a maximum error of 2.5 mm, limited in their opinion by the thickness of the CT scan slice. This degree of error is less than reported maximum errors from studies that used frame-based systems.10 Guthrie and Adler12 reported errors of less than 3 mm for their system, which they used in approximately 40 cases. Laborde, et al.,16 reported an accuracy of 3 mm based on 50 cases. Galloway, et al.,9 reported a total 3-D uncertainty of 1.6 mm based on 50 operative cases. Our experience with the system confirms comparable accuracy across a large number of cases, using both CT and MR imaging guidance. The decrease in accuracy during the course of
the operation reflects the real-world errors of head movement relative to the system, even when the viewing wand is affixed to the Mayfield clamp itself.

Sources of Error

In our experience, the greatest sources of error in the use of this system were attributable to the registration process and to patient movement relative to the viewing wand during the operation. These sources of error plague all frameless stereotactic systems.

The registration process introduces error in scanning of the fiducials and in the correlation of the physical position of fiducial markers with the imaged position. Because the fiducial markers are affixed to the skin, a movable and deformable structure, their immobility is not guaranteed after imaging. Additionally, the more time that elapses between imaging and registration in the operating room, the greater the likelihood that the position of the fiducial markers will change. Even with instructions to the contrary, patients are still apt to meddle with the fiducial markers or otherwise distort their location. To combat these errors, we attempted to perform the imaging as close to the time of surgery as practical. This strategy, however, does not help to reduce the error introduced by the mobile nature of the skin. Registration in the operating room is performed once the Mayfield clamp is affixed to the patient. Fixation by the clamp distorts the scalp slightly, especially in patients with loose skin. To reduce registration error further, we touched the center of the fiducial marker or skin structure as lightly as possible, attempting to avoid any significant deformation of the skin. Practice at this technique improves the registration accuracy and may account for the improved accuracy of registration in the patients undergoing MR imaging compared to those undergoing CT scans. The surface-fitting computer algorithm is another attempt to reduce the effects of scalp shift in the registration but, in our hands, resulted in greater registration error. The likely explanation for this outcome is sampling error introduced by the uneven grouping of scalp points chosen for the registration. Despite these several sources of error, we achieved a registration accuracy of within 2 mm in more than 90% of the MR imaged cases.

In a multicenter clinical trial of the viewing wand, the manufacturer reported mean errors associated with the fiducial registration of 1.8 mm for CT and 3.1 mm for MR imaging (C Hall, personal communication, 1994). The corresponding anatomical landmark–surface fit algorithm errors were 3.0 mm for CT and 4.8 mm for MR imaging. In our own experience and in the multicenter trial, the fiducial registration was more accurate, regardless of imaging modality. Computerized tomography imaging with fiducial registration was the most accurate registration in the multicenter trial, whereas in our experience with a large number of cases, MR imaging with fiducial registration was slightly better on initial registration and comparable throughout the operation.

The degradation in accuracy registered as the operations proceeded reflects an inherent limitation in the system as it now stands. In spite of our best efforts, including securely fixing the viewing wand arm directly to the Mayfield tongs, movement of the patient’s head relative to...
the viewing wand arm occurred and decreased accuracy. Although reregistration might counteract this error partially, practically speaking, the loss of accuracy occurred late enough in the operation to make reregistration superfluous.

Clinical Utility

The viewing wand proved useful in unforeseen circumstances. During corpus callosotomy, the viewing wand was accurate in predicting the length of the corpus callosum division as judged by the postoperative MR image scan. It was also helpful in judging the posterior margin of anterior temporal lobe resection for epilepsy. Touching the viewing wand to the tentorial edge, a structure that remained fixed during temporal lobe resection, supplied a reference point for hippocampal resection. The system proved useful in navigating an endoscope through abnormal ventricular systems (Case 3). Even experienced endoscopists can lose their orientation when few normal ependymal landmarks are available. We anticipated that the system would be incapacitated by shifts of the brain during resection. Although this was generally true, the viewing wand remained a useful guide in selected cases of AVM resection (Case 2) and of glioma resection. The smaller craniotomies made possible by frameless stereotactic guidance may have decreased CSF loss and hence lessened the amount of brain shift.

The system was most useful during the resection of small subcortical masses and skull base pathology. As reflected in the responses of the surgeons regarding cases of cavernous malformations (Case 1) and gliomas, the system allowed precise planning of the craniotomy and precise guidance in locating the lesion. In skull base menigiomas, the system provided warning of the proximity of important anatomical structures and identified the possible location of residual tumor. The system allowed less invasive operations by aiding navigation through cisterns and sulci.

Conclusions

The viewing wand represents the next step in the application of stereotactic techniques to neurosurgery. It cannot yet replace traditional frame-based stereotactic surgery when minimum invasion and maximum accuracy are required, such as during limited biopsy of deep-seated and small lesions. Because of its utility and minimum added discomfort for the patient, however, the system can be used in a far greater range of cases in which frame-based stereotaxy is too limiting. The viewing wand provided sufficiently accurate intraoperative guidance data in a series of 310 cases to allow constant updating of the surgeon’s intracranial position with regard to the pathological lesion and surrounding normal structures. We would expect that given enough time and a sufficiently large patient population, outcome measures such as complication rate would be more favorable in cases in which frameless stereotactic techniques are used. These data were obviously not available in our present study. Improvements to frameless stereotactic techniques will allow the identification of smaller or more obscure targets. We have performed operations in a few cases using T₂-weighted MR imaging to delineate low-grade gliomatous lesions more clearly. More importantly, future improvements will allow updating of the imaged dataset to reflect changes in the position of the brain during resection. Until these improvements are made, the viewing wand system is a useful and reliable implement for intraoperative navigation.

References

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