The idea of summarizing and analyzing the various targets used in functional neurosurgery was conceived by Mr. G Narenthiran in early 2002. Using an international electronic mailing list, he gained the cooperation of many neurosurgeons from all over the world and eventually asked me to lead this effort to gather information for analysis and cataloguing.

In order to start this project, I would like to share my personal preferences for targeting deep cerebral structures and describe the approach we use at the University of Illinois at Chicago during functional neurosurgical interventions. Several points will be addressed, such as choice of the imaging modality, parameters used during imaging, use of intra-operative micro-recording, micro- and macro-stimulation, postoperative imaging, and so forth. In the future, the data will be analyzed for outcomes and complication rates if this information becomes available.

General targeting principles

At our institution, we perform stereotactic functional operations with a Leksell-type G frame (Elekta Instruments, Atlanta, GA). Unless the patient has an implanted pacemaker or defibrillator, the targeting is done using magnetic resonance imaging (MRI); we routinely use a 3 Tesla MRI scanner (GE, Milwaukee, WI) that provides high-resolution images in a very short time.

After a fast three-plane localizer, 1.5-mm contiguous images are obtained through the region of interest, covering the plane of the anterior and posterior commissures (AC and PC). The sequence used most frequently is a fast spin echo inversion recovery T2 (FSEIR-T2). The field of view for this imaging is 26 cm so that the entire MRI localizer that is attached to the stereotactic frame is imaged. Image acquisition with a 512-by-512 matrix allows us to get a voxel size of 0.39 mm\(^3\). Since acquisition of each series takes less than 5 minutes, the entire study is usually done in less than 20 minutes.

Patients that have unilateral or bilateral deep brain stimulation (DBS) implants undergo imaging on a 1.5 Tesla MRI scanner, since the safety of 3 Tesla MRI with implanted DBS has not been established. Patients who cannot have MRI at all (such as those with pacemakers and defibrillators) undergo stereotactic CT with 1-mm contiguous axial cuts through the region of interest, including the AC-PC plane.

The stereotactic coordinates are then calculated with a Microsoft Excel\textsuperscript{®}-based program that derives the positions of the AC and PC from their relationship.
to the center of the frame and provides correction for the frame tilt and rotation based on the localizer appearance.

Ventral intermediate nucleus of the thalamus

To place the lesion or insert the electrode into the ventral intermediate nucleus (VIM) of the thalamus, we calculate the target coordinates based on the position of the AC and PC and the size of the third ventricle. Stereotactic MRI is obtained as described above.

The VIM thalamic target is chosen in the axial AC-PC plane, one-quarter of the AC-PC distance in front of the PC and 11 mm lateral to the wall of the third ventricle. The entry point is created about 2.5 cm from the midline and about 2 cm in front of the coronal suture. This usually corresponds to a 60° angle from the frame in the sagittal plane and 10° from the midline in the coronal plane (80° or 100° depending on the side).

To perform intraoperative physiological localization, we use macro-stimulation alone, since in our opinion microrecording does not improve the accuracy of thalamic targeting (4). Macrostimulation is done using a lesioning electrode (TH) made by Radionics (Burlington, MA). The electrode is advanced directly to the target point. First, motor stimulation is performed at 2 Hz, followed by 50 Hz stimulation for sensory testing and 100 Hz stimulation for tremor control. The electrode is moved medially if the motor stimulation threshold is less than 1.5 V and anteriorly if the sensory stimulation threshold is less than 1 V. Usually, paresthesias in the thumb and corner of the mouth indicate adequate laterality of the electrode, but too low a threshold may suggest close proximity to the sensory thalamus.

Depending on the procedure, we either perform radiofrequency thermo-destruction or exchange the stimulation/lesioning electrode for a permanent DBS electrode. In case of thalamotomy, a test lesion is made first at 45°C for 30 sec, after which the patient’s strength, sensation, and speech are tested. Permanent lesions are made with a 70-72°C tip temperature for 60 sec. After the first lesion is made, the electrode is pulled out 2 mm and a second lesion is made with the same temperature and duration, followed by a third lesion 2 mm more proximal (4 mm from the original target location).

In cases of thalamic DBS, the position of the macro-stimulation electrode is marked on the screen of the cross-table fluoroscopy machine, and then the macro-electrode is replaced by a quadripolar DBS electrode with a 1.5-mm inter-contact distance. The second contact (#1) is placed at the target location to compensate for potential electrode displacement during skull fixation and the postoperative period.

Within a few hours after the surgery, patients undergo postoperative CT scan to rule out any
hemorrhage, and next day they have an MRI to confirm the position of the lesion (Fig. 1) or electrode. Patients with lesions are usually discharged home 24 hours after surgery, and those with DBS electrodes undergo electrode internalization 48 hours later under general anesthesia. DBS patients are usually tested during the two days between their surgeries to determine the effects of the stimulation; they are routinely discharged home 3 days after the first operation.

At our institution, we perform thalamic surgery one side at a time and stage the procedures 2–3 months apart. In order to prevent the associated with bilateral thalamotomy we use either a combination of thalamotomy with contralateral thalamic DBS or bilateral DBS, depending on the patient’s preference.

Internal segment of the globus pallidus

The target for pallidotomy or pallidal stimulation is also chosen based on AC-PC coordinates. The MRI-based coordinates are calculated at 2 mm anterior to the mid-commissural point and 5 mm below the AC-PC plane. The lateral coordinate is chosen based on the location of the optic tract; the distance between the middle of the optic tracts is calculated on a coronal cut that corresponds to 2 mm anterior to the mid-commissural point and then divided by two.

For better determination of the targeting depth, we routinely use microelectrode recording using a MicroGuide system (Alpha-Omega Instruments, marketed by Nicolet Instruments, Madison, WI) (5). A single bipolar microelectrode is advanced toward the target point and recording is started 20 mm above the target and is continued to 4–5 mm below the target point.

The burr hole opening is made about 2 cm in front of the coronal suture and 2.5–3 cm from the midline. The direction of the approach is approximately 65° from the frame in the sagittal plane and 0° in the coronal plane. This approach allows the microelectrode to penetrate the optic tract that is located immediately under the target. Using the microelectrode recording we focus on the following parameters: spontaneous activity (frequency, pattern, amplitude), kinesthetic activity, location of the pallidal base, and location of the optic tract. Discharge characteristics for the external and internal parts of the globus pallidus (GPe and GPi), border cells, and the optic tract have been extensively described in the past (3). Generally, an experienced neurosurgeon or neurophysiologist can discern all these structures according to their discharge patterns by their graphic appearance on the computer monitor or by an amplified and filtered...
audio signal. To define the optic tract we use a handheld flashlight with the operating room lights dimmed. The notch filter of the microrecording system usually has to be turned off for the optic tract recording. With this approach we can define a safe depth of electrode insertion, which is confirmed by macro-stimulation.

The macro stimulation is done using the same lesioning electrode (TH) as was described in the earlier section. The presence of contralateral twitches at 2 Hz stimulation with a stimulus amplitude less than 2 V indicates proximity of the electrode tip to the internal capsule fibers, indicating that the target must be moved laterally. In response to 50 Hz stimulation, patients usually develop increased tone in the contralateral arm or face. If 2 Hz stimulation results in bright flashes at a stimulation amplitude of less than 4 V, the electrode tip is probably located too close to the optic tract and should be pulled out 1 or 2 mm. Recently, we have started checking tongue movement in response to 2 Hz motor stimulation, since it has been suggested that the reason for speech and swallowing disturbances after pallidotomy, especially if it is done bilaterally, is inadvertent damage to the corticobulbar pathways as they pass within the internal capsule adjacent to the pallidal target (unpublished data).

In case of pallidotomy, the lesion is made in a physiologically defined location with the following parameters. First, we do a test lesion at 80-82°C tip temperature for 10 seconds. If there are no undesirable effects and vision remains normal, a permanent lesion is created at 84°C for 60 sec at the target point and then repeated 2 and 4 mm above it along the electrode trajectory (Fig. 2). This general technique has been described in the past (2) and has been shown to be both safe and effective. In order to prevent the complications of bilateral pallidotomy we prefer to do it in a staged fashion with a 3-month interval between procedures. If there are deficits or complications after the first operation, surgery on the second side may be either postponed or cancelled.

In cases of GPi DBS, a permanent DBS electrode is inserted at the desired depth after removal of the macrostimulation electrode. The depth of DBS electrode insertion is monitored on the fluoroscopy screen to avoid penetration of the optic tract. For this reason (to avoid penetration of the optic tract with the foreign object – an electrode), we put the
most distal contact (#0) at the target position. For GPi stimulation we use DBS electrodes with 0.5-mm intercontact spacing. Bilateral electrode implantation during a single operative session is preferred. If the patient becomes agitated or tired during the surgery, we may skip the microrecording stage on the second side and implant the electrode based only on macrostimulation results.

Patients are usually discharged home the day after the pallidotomy. After DBS electrode insertion, patients are kept in the hospital for a 5- to 7-day stimulation trial and then undergo electrode internalization under general anesthesia. Depending on their condition, patients may be discharged home or to rehab the day after the internalization.

Subthalamic nucleus

So far, we have not performed any subthalamotomy, but will update this paper as our experience grows. In regard to subthalamic nucleus (STN) DBS, we prefer to perform bilateral electrode insertion in a single session, usually starting with the more symptomatic or dominant side.

Stereotactic MRI is obtained as described above, but to calculate the target coordinates we use both an empiric (atlas-based) technique and a direct visualization approach (6). With the atlas-based technique, STN coordinates are calculated at 12 mm lateral, 3 mm posterior, and 6 mm inferior to the mid-commissural point. Direct visualization of the STN allows more accurate targeting of the nucleus. The STN is an almond-shaped structure about 6 mm in its largest diameter that is always located immediately superior to the substantia nigra. Because of its oblique shape, on the more inferior images the STN is positioned somewhat medial to the substantia nigra, although the center of the STN is lateral to the center of the substantia nigra. The STN can be seen on axial and coronal planes lateral to the anterior portion of the red nucleus and medial to the internal capsule. On T2 images the STN appears as a hypointense (darker) object immediately adjacent to the more lateral and anterior internal capsule. In our experience, the atlas-based coordinates provide a general location for the STN and give the surgeon rough approximation of the area where the STN should be located. Once
the coordinates of the STN center are calculated on either side, they are rechecked on other views (coronal and sagittal) (Fig. 3).

In the operating room, the burr hole is placed in the standard location. A 60° sagittal inclination of the trajectory relative to the frame with a 10–15° angle from the midline in the coronal plane generally puts the track of the electrode along the longest axis of the STN. We always perform microelectrode recording for intraoperative STN localization. It is done in a way similar to that described above for pallidal localization. A single bipolar microelectrode is advanced to the target point and recording is started 15–20 mm above the target. As the microelectrode reaches the STN, the discharge pattern changes dramatically, and one can immediately notice changes in both frequency and amplitude of spontaneous neuronal activity. STN neurons have different discharge patterns; these patterns have been described in the literature in the past (1). The important point, in our experience, is the interval during which these characteristic discharges are present. In other words, if STN-type activity appears only over 2 mm along the electrode track, then most likely the electrode is going through the edge of the STN. On the other hand, if this activity is observed over 5 to 7 mm of the track, then it is very likely that the microelectrode is passing through the central part of the nucleus. Frequently, exit from the STN is indicated by a rather abrupt decrease in discharge intensity. This silent zone is followed in many cases by large-amplitude high-frequency discharges that indicate entrance of the microelectrode into the substantia nigra. The target for subthalamic stimulation is 1 to 2 mm above the inferior level of the STN as indicated by the disappearance of STN-related activity during microelectrode recording. Usually this happens 2 to 3 mm below the predicted target position.

Although it is possible to perform stimulation through the microelectrode (micro-stimulation) or through its housing cannula (macro-stimulation), we prefer to replace the microelectrode with a macro-stimulation electrode that, in addition to the desired stimulation settings, provides us with a nice track for subsequent permanent electrode placement. The dual goal of macro-stimulation is to determine the proximity of motor, sensory, and oculomotor pathways and also to see if the high-frequency stimulation does indeed improve the patient’s tremor and rigidity. The appearance of contralateral choreiform movements resembling levodopa-induced dyskinesias during high-frequency stimulation or even from the macro-electrode insertion itself is generally considered a good indication of the correct electrode position.

After the macro-stimulation is completed, the macro-electrode is replaced with a DBS electrode and live fluoroscopy with the electrode position marked on the screen is used to place the DBS electrode at the desired depth. In cases of STN stimulation we prefer...
to put the second contact (#1) at the target location. Since we use DBS electrodes with a 0.5-mm inter-contact distance and 1.5-mm contact width, this usually allows us to position the two middle contacts (#1 and #2) inside the STN.

In our practice, STN DBS implants are always placed bilaterally during the same surgical session and microelectrode recording is performed on both sides. After the electrodes are implanted, they are secured to the skull with a miniplate or an IGN Navigus cranial base and cap (Image-Guided Neurologics, Melbourne, FL). Temporary extension wires are passed under the skin and externalized posterior to the original pre-coronal incision (Fig. 4). The patients are transferred to the ICU once the frame is removed. They undergo CT of the head postoperatively to rule out hemorrhage, and within the next few days they have an MRI of the brain using a 1.5 Tesla scanner to check the DBS electrode position (Fig. 5). Internalization of the electrodes with implantation of the pulse generator is usually performed 5 to 7 days later under general anesthesia. During this time the patients are tested with different stimulation settings using an external screening device.

Summary

With this brief overview of our targeting practice we would like to launch the database of functional targets. All readers are invited to submit their experience in functional neurosurgical targeting and share their experience with certain procedures. As our database gets larger we will try to summarize the experience of other centers and point out similarities.
and differences in individual techniques.

The list of stereotactic targets is extremely large. The fact that this report discussed only three locations should not limit our database. In fact, we welcome submissions on other stereotactic targets that are used in surgery for movement disorders, chronic pain, psychiatric disorders, and epilepsy. We are interested not only in the coordinates of the various targets but also in techniques for target refinement, such as micro- and macroelectrode recording, micro- and macrostimulation, frameless and intraoperative guidance, and preoperative and postoperative imaging. We would also like information on outcomes and associated complications.

All interested readers are welcome to send their questions, comments and inquiries in addition to their personal experience to either Konstantin Slavin, MD at kslavin@uic.edu or Ganesalingam Narenthiran, MB ChB MRCSE at g_narenthiran@hotmail.com.

References:

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