ISSN: 2690- 909X

Short Review Article

Advances in Neurology and Neuroscience

Deep Brain Stimulation Surgery for Movement Disorders

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Submitted: 20 July 2020; **Accepted**: 24 July 2020; **Published**: 30 July 2020

The Basal Ganglia

Despite its discovery in the early 20th century and the decoding of its physiological circuitry later, these subcortical grey matter islands remain a mystery in functionality and pathophysiology. Deep brain lesioning & stimulation of precise programmed centres have elicited promising results in a very specific subgroup of patients. We delve into the basics of movement disorder surgery for the uninitiated in order to sensitise physicians and the general public themselves regarding the promises of these novel techniques as well as the immense potential of future discoveries in this neurological final frontier.

Movement Disorders

These consist of a group of disorders that originate from disease or dysfunction of the dep nuclei of the brain resulting in either impairment or exaggeration of movement incompatible with normal life.

Phenomenology

Movement disorders are either Hyperkinetic, Hypokinetic or a mixture of both. The movements can either be regular, rhythmic or chaotic in regularity. They can also be focal, involving one or a part of one aspect of the body or generalised in nature. Finally movement disorders can be disorders of posture and tone reducing the ability to produce purposeful motion or produce exaggerated non purposeful motion that impedes activities of daily living

HYPERKINESIAS	HYPOKINESIAS	MIXED
Parkinsonism Tremors palsy Chorea Myoclonus Dyskinesia Dystonia Tics Akathisia Stereotypies	Bradykinesia syndromes	Parkinsonism Progressive supranuclear Lewy body dementia Multisystem atrophy

Diagram1: showing the different types of movement disorders classified according to movement

Pathophysiology

For the purpose of simplicity and skinticity, we discuss the anatomic localisation for certain surgically remediable conditions along with surgical options required for their correction. The depths of electrophysiology have not been delved into but are essential for a thorough understanding of the disease. These can be gone into later.

Tremor

The commonest cause has been discovered to be the presence of the thalamic oscillator which is the Ventro-Intermediate Nucleus of the thalamus (VIM) Another cause could also be the loss of Globus Palidus interna interna (GPii) inhibition of the Ventro-Basal nucleus (VOP) and subthalamic nucleus (STN) where oscillations of unsteady peripheral stretch reflex arcs result in a repetitive cycle of impulse generation leading to tremors. 90% of all tremors (especially essential tremors) involve the VOP and VIM nuclei.

Rigidity and Dystonias

These result from a loss of joint selectivity leading to abnormal bursts of neurons in the GPii. A popular theory is the segregated loop hypothesis. Here the connections between the Cortex and the Basal Ganglia and the Thalamocortical pathways for different functions involve different anatomical locations within the same structure. Hence although movement can be effected, tone which is reinforced by the segregated loop is enhanced to the limit making movement impossible.

Effects on Stimulated Nuclei

Once stimulation is achieved there is an observable regularization of Pathologic activity with the onset of compensatory Responses, widening of therapeutic Latencies, anatomic Reorganization along with modification of synaptic Plasticity.

Surgery for Movement Disorders

History

Spiegel and Wycis were the first who looked at deep nuclei surgery where they pioneered globus pallidus coagulation. Hassler ablated Ventro-Anterior and Ventro-Posterior nuclei for tremors and found good success. Pool introduced thalamus and hypothalamus stimulation for chronic pain. Laitinen performed the first pallidotomy. Siegfried and lippitz have the unique distinction of performing the first Deep Brain Stimulation of Gpii. Ehringer and Hornykiewicz Discovered dopamine secreted in the Basal Ganglia which lead

to further medical progress in Parkinson's disease management. Surgery for movement disorders suffered a major setback when Cotzias and Carlson discovered Levodopa as an effective treatment for Parkinson's disease. The efficacy and safety of the treatment convinced movement disorder neurologists that surgery wasn't needed for such disorders, thereby denying the need to further investigate and discover newer nuclei for stimulation or lesioning. No further significant discoveries have impacted movement disorders since, but strict protocols have been set in place inorder to define the scope of surgery and deep brain stimulation for these disorders.

Patient Selection

The most important part of the surgical process is patient selection. In properly selected individuals, success is highly effective, but if not done punctiliously, failure can be devastating to surgeon and patient alike. Indications can be grouped into definitive, where FDA approval and level 1 and 2 evidence exist to support therapy, and possibly useful, where no level 2 or even 3 recommendations exist but incidental reports suggest mild to moderate improvement of some clinical symptoms after surgery. The other conditions are not suitable for surgery and present poor outcomes if operated upon.

Definitive indications include Idiopathic Parkinson's Disease, Essential tremor and Primary dystonias. (These indications are limited to movement disorders. Other uses such as psychosurgery, surgery for pain and epilepsy surgery are not covered here.) Possibly useful indications include Tardive dyskinesia, Myoclonic dystonia, Huntington's chorea, Tic disorders, Cerebellar tremor, Midbrain (Rubral) tremor and Orthostatic tremor. These have poor responses to the treatment but have incidental reports of success, making the outcomes unreliable at best. However due to the extremely poor prognosis otherwise as well, many patients agree to take the surgical risk in the hope of at least some recovery. Movement disorder surgery is not recommended for Multisystem Atrophy, Paroxysmal Supranuclear Palsy, Cortico-Basal Degeneration, Secondary dystonias and Parkinsonism of any other aetiology (drug induced, vascular, etc)

As mentioned above, 30% of Deep Brain Surgery failures can be attributed to improper patient selection. Hence a thorough 5 part process is used to determine suitable candidates for surgery. These include

- Neurological categorization
- Neurosurgical exam
- Neuropsychiatric assessment
- Imaging
- Medical clearance

Neurology

The key step in the process involves determining the diagnosis as well as identifying unfavourable factors such as poor Levodopa response in Parkinson's disease and/ or presence of Dementia. The initial assessment is critical in establishing a clinical baseline for therapy. Often surgery is successful but still finds few takers as unreasonable expectations and an improper assessment of the baseline disability give rise to an apparent failure of treatment. Thus, accurate documentation and assessment remain key before subjecting a patient for surgery. Severity is diagnosed by the UPDRS-III score which determines appropriate surgical substrates.

Neurosurgery

Once the diagnosis and associated features are established rigorous counselling of the patient vis-à-vis expectations needs to be done. Neurosurgeons specially trained in movement disorders need to analyse the risk-benefit ratio and thereby justify the procedure and its risks to the patient as well as decide upon the type of procedure and modality to be used. For Tremors the best target for modulation is the VIM thalamic nucleus. For Parkinson's disease, the STN, and Gpii targets are recommended. STN is preferred for rigidity predominant Parkinson's disease while Gpii is preferred for dystonias. Gpii is also preferred for Tic disorders along with the medial thalamic nucleus.

Psychiatry

This crucial step is used to detect the presence of pre-existing neuropsychiatric illness which may impact post-op recovery and improvement. This is especially important in STN DBS which has been known to be associated with cognitive decline in elderly patients. A thorough neuropsychiatric assessment is thus essential before surgical planning can occur. (PPRS score used)

Imaging

Presurgical planning is mainly done using MRIs with extremely thin slices (functional protocols)

MRI are generally used to detect structural lesions, anatomical distortions that interfere with targeting and to rule out MSA, PSP in Parkinson's disease (as these present poor prognosis)

SPECT are sometimes used in differentiating atypical Parkinson's from idiopathic Parkinson's disease. Before the onset of navigation and advanced steriotaxy, the commissural line was identified, and the STN and other targets were identified in relation to it.

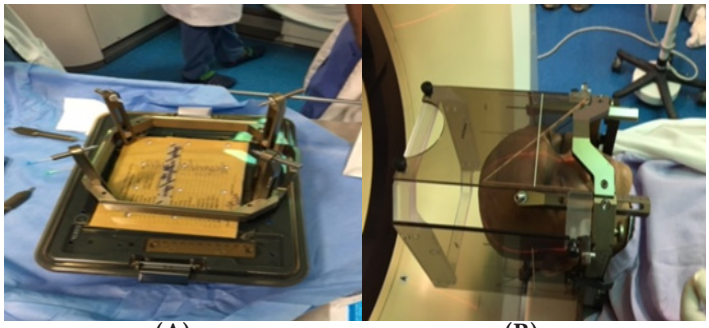
The final decision is made taking into account the Severity (UPDRS-III scores), duration of the illness, age of the patient, response to drugs (like levodopa), Cognitive status, presence or absence of psychiatric disease (PPRS scores), Social support of the patient and presence of counselled realistic expectations

Surgery

Once all this is completed and planning has been done, surgery is planned. Treatment can either be DBS (Deep brain stimulation) or DBL (Deep brain lesioning) We will briefly discuss both below.

Deep Brain Stimulation

DBS is a safe and effective therapy to treat motor symptoms of movement disorders. Instead of merely destroying the centre producing the periodic electrical discharges, DBS provides inhibitory electrical stimulus similar to the working of the pacemaker. The procedure however involves precise targeting and pulsatile stimulation of deep nuclei of the brain resulting in symptomatic remission. Navigation MRIs are made to reduce distance errors. Pre navigation planning involved locating the Mid-commissural point and plotting the location of the target manually. Locations are placed on the WRT in the commissural line. The VIM for example lies 3mm anteriorly, 14mm laterally and 2mm superiorly to Posterior Commissure on the commissural plane. Nowadays 3D localization on the Leksell frame provides a much more accurate targeting experience. Here the MRI of the brain is merged with 3D images to localize nucleus [Figure 1].

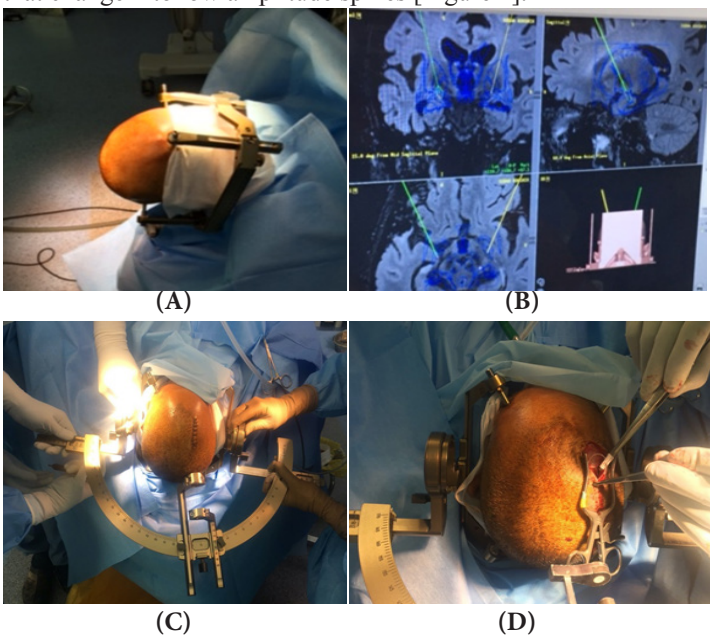


(A) (B)

(C) (D)

Figure1: PLANNING: The Leskel Frame used in the case [A], the CT marking cage placed after the frame is fixed into the scalp for planning the trajectory of the probes [B], The planning CT scan in [C] which is merged with the MRI of the same patient at the same level to plan the coordinates [D]

Microelectrodes placed through Burrholes and micro durotomies record specific neuronal firing patterns. These glass encased tungsten or iridium-platinum alloy electrodes with exposed metallic tips allow current of upto 2mA to flow in a biphasic square wave per pulse. Somatosensory receptor effects are recorded to detect the presence and proximity to the target. In VIM, pulse waves are seen in response to deep sensory stimuli, Gpii show 20-40 Hz border cell activity spikes while STN electrodes show broad amplitude waves that change into low amplitude spikes [Figure 2].

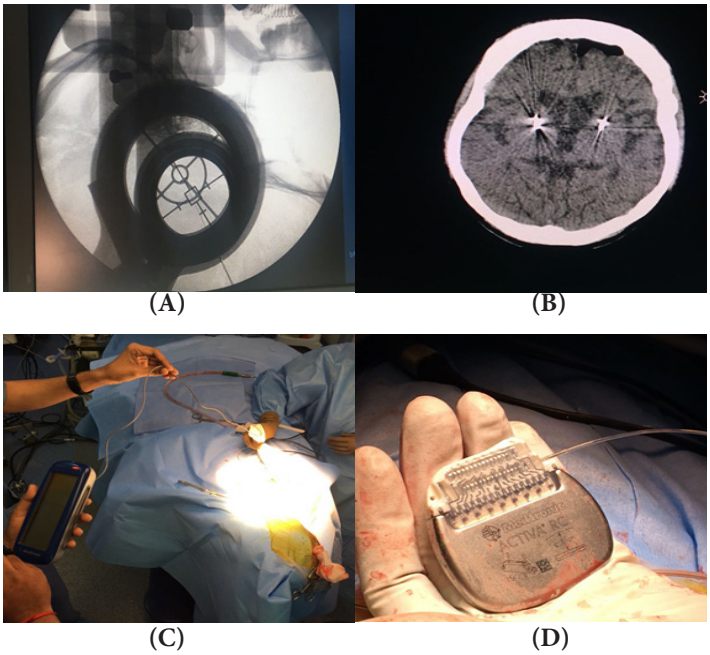


(A) (B)

(C) (D)

Figure2: PREPARATION: The patient with the frame are shifted to the OT in [A], the MRI positioning system decides the location of the Burrholes in [B], the frame accessories are attached in [C] and the Burrholes made in [D]

Once the target is acquired and located in accordance to coordinates predetermined by CT, MRI and other imaging modalities the stereotactic frame is applied to head and held on a pin fixator in neutral position. Mapping electrodes are entered from the Burrholes and electrophysiological mapping and confirmation of the target site is made. Stimulation electrodes are the placed and checked with a stimulator, which is then tunnelled to a device (Implanted Pulse Generator or IPG) fixed under the clavicle subcutaneously [Figure 3].



(A) (B)

(C) (D)

Figure3: POSITIONING: The electrode positioning is confirmed on intraoperative X-ray in [A], and the final position of the electrodes are confirmed in a post procedure CT in [B] The wiring Is tunnelled through to the chest in [C] and the Implantable pulse Generator (IPG seen in [D]

Programming

After recovery from the surgery programming of the IPG is done. Multiple sessions are required to titrate the appropriate dose to the appropriate target. Symptom recovery is also varied. Time must also be allowed for washout between sessions. Hence patience and skill is required to ensure proper symptomatic recovery.

Complications

These include apraxia, dysarthria, dysphasia, abulia which are rare. Damage to the internal capsule can occur in pallidotomy by poor targeting making the electrode exceed its trajectory.
Deficits generally last 1-3 weeks and recover spontaneously.

Prognosis

Essential tremors treated with VIM DBS, have the best prognosis. 5-year disease control is 100% with eventual turning off of stimulators after 2-3 years of therapy. In some cases there are 2-3 years of meaningful benefit followed by refractory tremors. Parkinson's disease responds worse than essential tremor. STN DBS treats PD tremors as well as bradykinesia and rigidity. Bradykinesia responds the worst, but meaningful improvement is possible with Gpii DBS.

Newer Advances

The advances in the recent decade are generally aimed at fine

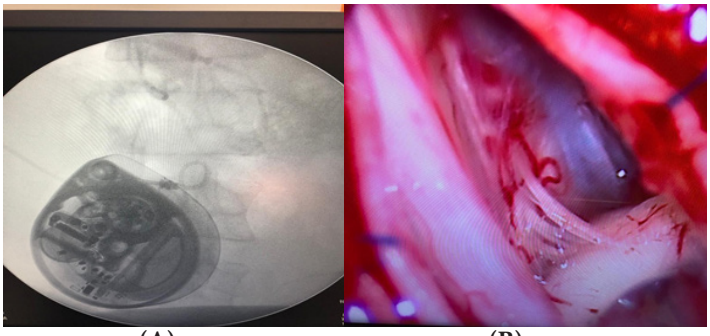
tuning targeting protocols as well as searching for new targets to focus on such as the Pedunculopontine Nucleus. Voltage control vs current control is an ongoing discussion where voltage gating appears to overcome the difficulties encountered due to the variable impedance and resistance offered by the brain substance, in current controlled IPGs. Battery life is a difficult problem which has now been circumvented with remote charging transcutaneous charging and longer battery life IPGs.

Other Procedures for Spasticity & Dystonia

Apart from DBS and DBL, other procedures that are successful in movement disorders include

Spasticity Surgery

These procedures are performed once medical therapy for spasticity is proved ineffective. Selective Dorsal Rhizotomies (SDR) are successful in cerebral palsy patients especially when attempted in spastic CP along with a gracillus tenotomy which helps to overcome the crippling adductor spasm which debilitates children. Another popular procedure is spinal baclofen pump insertion, which offers a continuous injection of Baclofen into the epidural space reducing spasticity. Other procedures include DREZ lesioning where Root entry zone lesioning in the spinal cord is done to reduce feedback and spasticity [Figure 4]



(A) **(B)**

Figure4 [A]: BACLOFEN PUMP: showing an intro-op X-ray showing placement of the baclofen reservoir with the spine in the background and the catheter placed above in the midline. This procedure works well in patients who respond to Baclofen consumed orally.

Figure 4[B]: DREZ LOCALISATION: the figure shows a microscopic dissection of the spine showing dorsal nerve rootlets joining the peripheral nerve. Lesioning of these rootlets under neuro-electric guidance results in relief from spasticity, not responsive to baclofen.

Selective Peripheral Denervation

These procedures are successful in cervical dystonias especially dude to Sternocleidomastoid spasms as well lower limb spasticity involving certain muscle groups predominantly

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