Deep Brain Stimulation for Parkinson’s Disease

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Presentation Outline

- Parkinson’s Disease Overview
- Deep Brain Stimulation
  - Physiology and Working Principle
  - Patient Selection Criteria
- Surgical Procedures
  - Frame Based Stereotactic Surgery
  - Frameless Stereotactic Surgery
- Discussion
Movement Disorder Diseases

- Parkinson’s Disease
  - Neurodegenerative disorder
  - Tremor
  - Rigidity
  - Postural instability

- Dystonia
  - Muscle contractions
  - Abnormal postures
  - Symptoms increased with movement
Parkinson’s Disease Celebrity

Michael J. Fox  Muhammad Ali  Brian Grant

Deng Xiaoping  Salvador Dali  Pope John Paul
Deep Brain Stimulation

Surgical implantation of a brain pacemaker to generate electrical impulses and stimulate specific parts of the brain

- **Target disease**
  - Parkinson’s Disease
  - Dystonia
  - Chronic Depression

- **Electrical characteristics**
  - Voltage (0-7 volts)
  - Pulse width (65-450 msec)
  - Frequency (130-180 Hz)
  - Lead location (4 leads, each 1.5 mm apart)
Motivation from Historical Perspective

- 1940-1950s: Pallidotomy - surgically created brain lesion to control tremor
- 1960s: Levodopa as medicine treatment of PD
- Before 1990s: Dyskinesias - drug induced, involuntary withering and twisting after medication for years or resistive to medication
- 1990s: Benabid (France) first DBS- electrical stimulation of thalamus

DBS is approved for the treatment of symptom

- Parkinson’s disease (PD: FDA 2002)
- Essential Tremor (ET: FDA 1997)
- Dystonia (FDA 2003)
- Over 35,000 patients implanted worldwide
Physiology and Working Principle

- **Neurostimulator**
  - Implantable pulse generator (IPG)
- **Lead**
  - 4 thin insulated, \( \phi 1.27 \text{mm} \)
  - Coiled wires bundled
- **Wire**

Images courtesy of Medtronic and Grégoire Walckiers
Working Principle Cont’d

- Implantable pulse generator: metallic and insulated
- Return current electrode (RCE) for monopolar and unbalanced
- Voltage stimulation vs. current stimulation
- Most are monopolar and voltage controlled stimulation

Images courtesy of Grégoire Walckiers
Patient Selection Criteria

Disease Severity
- Mild
- Moderate
- Severe

Patient Symptoms
- Signs of levodopa “wearing-off”
- Dyskinesia, “On-Off” Motor Fluctuations
- Postural Instability, Freezing, Falls

Treatment
- Agonists
- Levodopa
- DBS

Good DBS Candidate
- Typical PD with tremor
- Good response to individual doses of levodopa
- Dyskinesias
- Wearing-off spells
- Good general health

Poor DBS Candidate
- Atypical parkinsonism
- Poor response to levodopa
- Memory problems, apathy or confusion
- Severe depression or anxiety
- Severe medical problems

Modified from Medtronic’s Activa-DBS-Therapy-Overview
Framed DBS Lead Placement Workflow

MRI Imaging → Preoperative planning → Attach Leksel frame

Lead placement → MRI2CT Registration → CT Imaging

Images courtesy of GE, Elekta, Slicer, Mayo Clinic, katalogo, wiki in order
Framed DBS Tool: Stereotactic Frame

Leksell® Coordinate System
The frame is engraved with a rectilinear coordinate scale, graduated in millimeters. The scale conforms with the X, Y, and Z directions used in CT and MR scanning. Origo (X, Y, Z = 0) is located outside the frame at a point that is superior, lateral, and posterior to the frame on the patient’s right side.

L = left side
R = right side
P = posterior side
A = anterior side

Stereotactic Arc (2 DoF)

Images are modified from elekta.com
Framed Stereotactic Surgery

- Neuroguide® Guide tube
  - Long term implanted with threaded area bonded skull
  - Extends into brain as conduit for electrode introduction

- Neuroguide® Stylet
  - Short-term implant to verify target position

Images courtesy of Renishaw and Patel 2007
Frameless DBS Lead Placement Workflow

1. MRI Imaging
2. Fiducial attached
3. Preoperative planning

- Nexdrive+Nexframe
- Sterile registration
- Non-sterile registration

Images courtesy of GE and Sriki Jvilaikul et al.
Frameless Stereotactic Surgery

Images courtesy of Renishaw, Nathoo 2005 and Haidegger 2008
Frameless Stereotactic Surgery Tracking

\[ \text{Control}_{DRB} = \text{DRB}_{Nav} T \cdot \text{Nav}_{Tool1} T \cdot \text{Tool1}_{Tool2} T \cdot \text{Tool2}_{RW} T \cdot \text{Control}_{RW} \]

Images courtesy of Haidegger 2009 EMBC
Frameless Stereotactic Surgery Calibration

\[
\begin{align*}
\text{pivotPoint} & = R_k \cdot \text{cutterTip} + T_k \\
R_k \cdot \text{cutterTip} - \text{pivotPoint} & = -T_k \\
\begin{bmatrix}
\vdots \\
R_k \\
\vdots \\
\end{bmatrix}
\begin{bmatrix}
\vdots \\
-1 \\
\vdots \\
\end{bmatrix}
\begin{bmatrix}
\text{cutterTip} \\
\text{pivotPoint} \\
\vdots \\
\end{bmatrix}
& = 
\begin{bmatrix}
\vdots \\
-T_k \\
\vdots \\
\end{bmatrix}
\end{align*}
\]

Images courtesy of Haidegger 2008
Confirmation: Microelectrode Recording

Microelectrode Recording: MER increases morbidity
Future trends: miniaturized MER integrated with electrodes

Image and sound data courtesy of Medtronic
Framed and Frameless Surgery Comparison

- **Frame Based Stereotactic Surgery**
  - Time consuming
  - Patient uncomfortable/painful

- **Frameless Stereotactic Surgery**
  - Higher cost
  - Optical tracking
  - Still painful

- **Some issues:**
  - Brain Shift
  - Pain

Stryker’s Patient Registration Mask
Stimulator Placement and Programmable Device

- **Stimulator Implantation**
  - Done immediately or days/weeks later
  - Typically placed below clavicle

- **Programmable Device**
  - Non-invasive adjustment
  - Selection of electrodes
  - Some side-effects after adjustment
Surgery Cost

- **NeuroMate system (stereotactic frame-based version) - $362,430**
  - robotic arm and base
  - central control unit for the arm
  - visualization workstation
  - software for planning and position simulation
- **Stereotactic Frame (+ $88,380 ) + Frameless Stereotaxy (+$236,368)**
  - Head frame + base
  - Specific localizers
  - Ultrasound system
- **Maintenance (+ $61,850/year)**
- **Sterile Operative Cover (+ $250/operation)**
- **Electrode, stimulator, unilateral, bilateral......**

Data courtesy of brown.edu
State of the Art Technology: iMRI

- iMRI: Interventional MRI
  - Imaging during surgery
  - Real-time confirmation
  - Reduced surgical time
  - Increased targeting accuracy

- Challenges:
  - Strong magnetic field
  - Confined space
Discussion

- **Benefits**
  - Bilateral, reversible and adjustable
  - Non-destructive versus ablative procedures
  - Effective pain control
  - Reprogrammable without surgery

- **Complications and Risks**
  - Brain hemorrhage
  - Infection
  - Inaccurate electrode placement
  - Shocking sensation
  - Balance impairment
  - Muscle spasm and contraction

  - Surgery related
  - Stimulation related
Thank you for your time

Questions?

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