EFFECT OF BRAIN SHIFT ON THE CREATION OF FUNCTIONAL ATLASES FOR DEEP BRAIN STIMULATION (DBS) SURGERY

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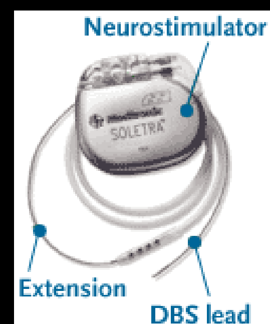
Outline

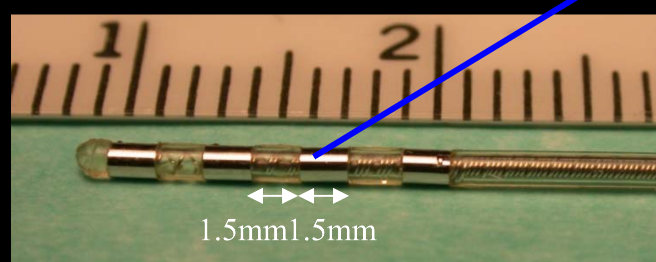
- Introduction to Deep Brain Stimulation (DBS) surgery
- Background on atlases for DBS and intra-operative brain shift during DBS surgery
- Method to study the effect of brain shift on building functional atlases of intra-operative data
- Results
- Conclusion & Future Work
- Acknowledgements

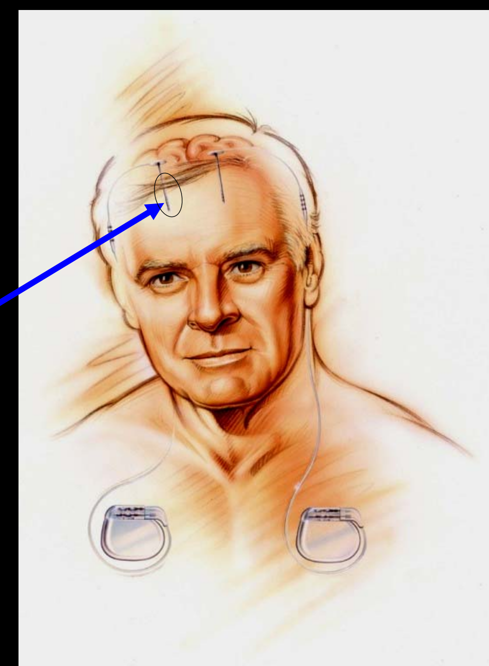
Introduction

- Deep Brain Stimulation (DBS) is a neurosurgical treatment for movement disorders. It stimulates target nuclei in the deep brain with mild electrical signals. Popular targets for DBS are the Sub-Thalamic Nucleus (STN), Ventralis Intermedius Nucleus (Vim) and the Globus Pallidus Internus (GPi).

- Common movement disorders treated by DBS are Parkinson's Disease (PD), Essential Tremor (ET) and Dystonia.







Courtesy of Medtronic, Inc.

A complex process involving a number of specialties

Patient Selection	Planning	Placement	Programming	Outcome Assessment
Neurologists Neurosurgeons Physical Therapists	Neurosurgeons	Neurosurgeons Electrophysiologists Neurologists	Neurologists	Neurologists Physical Therapists

- We have a suite of visualization software called ***CranialVault*** with separate modules for the planning, placement and programming stages of DBS.
- These modules communicate with our central electrophysiological atlas database via the internet.
- Interested cites/users can contact info@cranialvault.com to get a trial copy with a live username and password.

Background – Atlases for DBS

- Over the years a number of anatomical, histological and electrophysiological atlases have been built for DBS.
  - Schaltenbrand Wahren atlas, 1977
  - Finnis *et al.*, IEEE Trans. On Med. Img., 2003
  - D'Haese *et al.*, IEEE Trans. On Med. Img., 2005
  - Nowinski *et al.*, Neurosurgery, 2005
  - Guo *et al.*, D'Haese *et al.* MICCAI, 2005
  - Castro *et al.*, IJCARS, 2006
  - Chakravarty *et al.*, NeuroImage 2006
  - Yelnik *et al.*, NeuroImage, 2007
  - Bardinet *et al.*, J Neurosurg, 2009
- Electrophysiological atlases have gained prominence because of lack of consensus on the precise anatomical locations of targets in DBS.
- Their underlying assumption: Anatomical structures do not move between pre-operative imaging and intra-operative recording. However, this assumption is not valid.

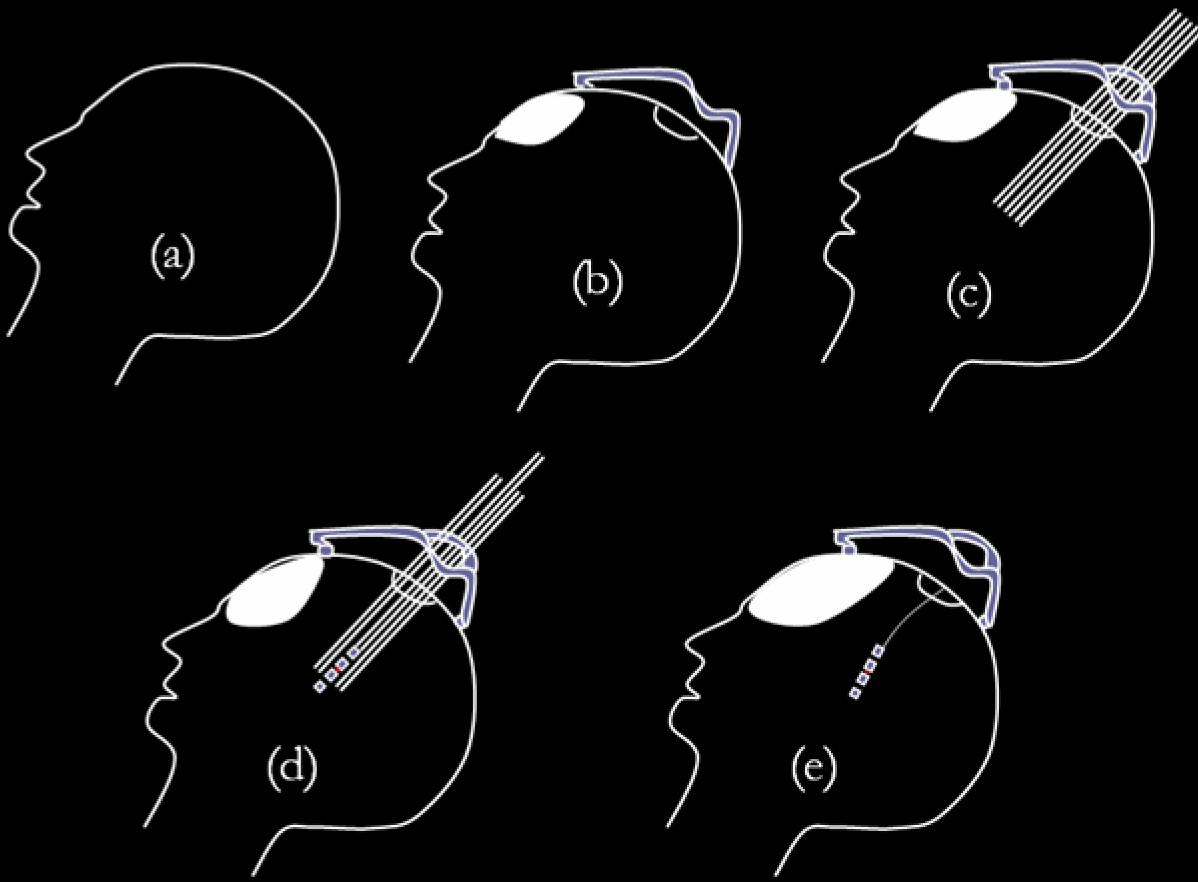
Background – Intra-operative brain shift in DBS

- Brain shift can happen due to CSF leakage, negative intra-cranial pressure and air invasion.

- Martin *et al.*, Magn Reson Med, 2005
  - Intra-operative brain movement of up to 2 mm at the STN.
- Khan *et al.*, Stereotact Funct Neurosurgery, 2008
  - Shift up to 4 mm in the deep brain by non-rigidly registering pre- and post-op MRI.
- Miyagi *et al.*, Neurosurgery, 2007
  - Medial, posterior and inferior shifts at the commissures.
- Halpern *et al.*, Stereotact Funct Neurosurg, 2008
  - Shift impacted number of micro-electrode tracks required.

- DBS for PD study group, *N Engl J Med*, 2001
  - The higher the number of microelectrode passes the higher the risk of intracranial bleeding.

Background – Various stages of brain shift



(a) Pre-Op.

(b) Dura opened, air invasion, brain shift.

(c) Platform mounted, cannulae in, hold brain in place at the target, ready for mapping.

(d) Final electrode implanted, cannulae remain in.

(e) Cannulae removed, brain free to move.

Impact:

The coordinates of intra-op data are different from those of their actual anatomical locations because the coordinates of the data are in frame reference system which is based on the skull that does not move while the data come from soft tissue which can move due to brain shift.

Methods - Studying the effect of intra-operative brain shift on atlas creation

- Somatotopy (73 data points from 24 STN implantations) and stimulation responses (52 data points from 17 STN implantations) data were used.

- <u>Definition</u>: A somatotopic response is said to be observed at a certain location when a noticeable change in micro-electrode recordings is observed due to physical stimulus. Somatotopy data are precise and highly localized observations. Their locations are obtained from the frame just like those for stimulation responses and other intra-operative data.

- Patients were grouped into low, medium and large brain shift groups based on pneumocephalus in the post-op immediate CT.

- Instead of a single atlas, multiple atlases were created on the same reference volume; one for each brain shift group.

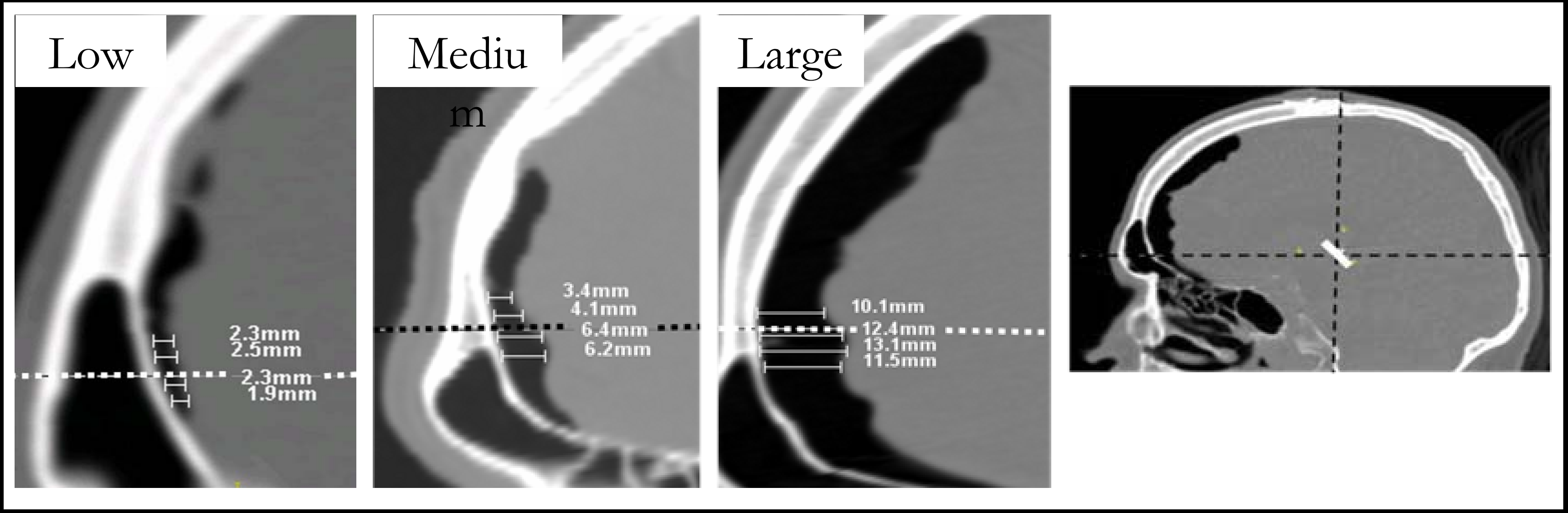
- The locations of somatotopy data and maps of stimulation responses on the different brain shift atlases were used to study the effect of brain shift on atlas creation.

Methods - Grouping patients into various brain shift groups based on pneumocephalus

- Rosenbaum *et al.*, ASSFN, 2008 and Halpern *et al.*, J of Stereotact and Funct Neurosurg, 2008: brain shift in the deep brain is proportional to the amount of air invasion or pneumocephalus.

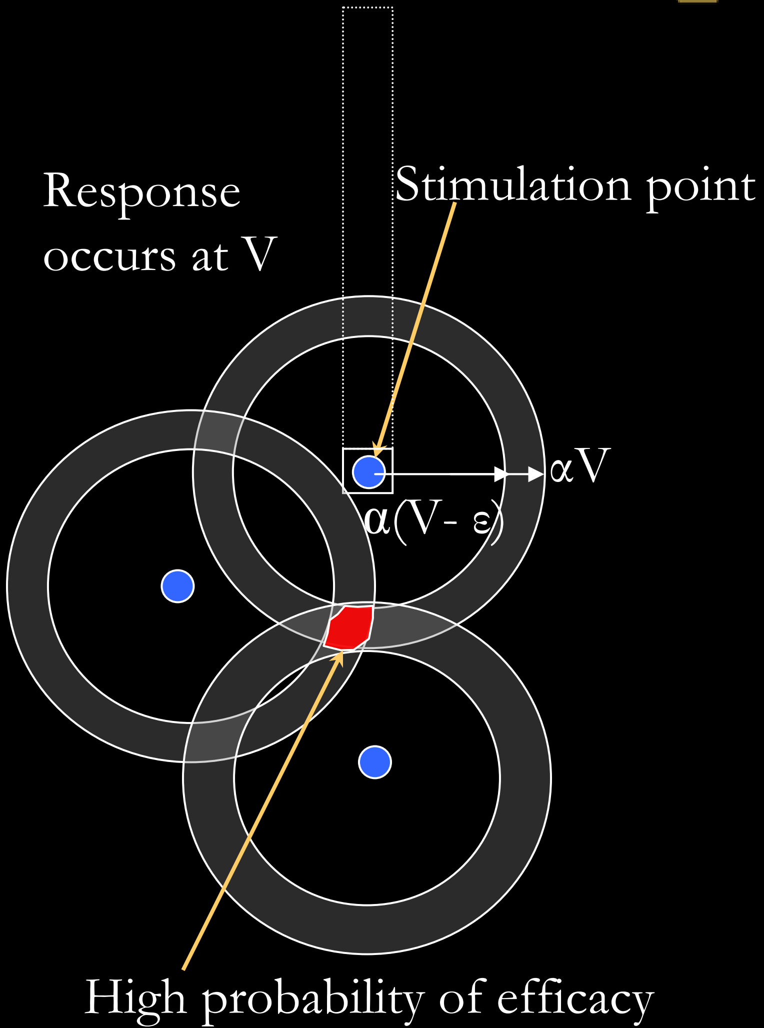
- Patients were classified into low, medium and large shift groups based on the amount of pneumocephalus; Average Air Pocket Width (AAPW) at the cortical surface around a vector passing through the implant in the direction of gravity.

- Low: AAPW ≤ 3 mm, Medium: 3 mm < AAPW ≤ 7 mm, Large: AAPW > 7 mm



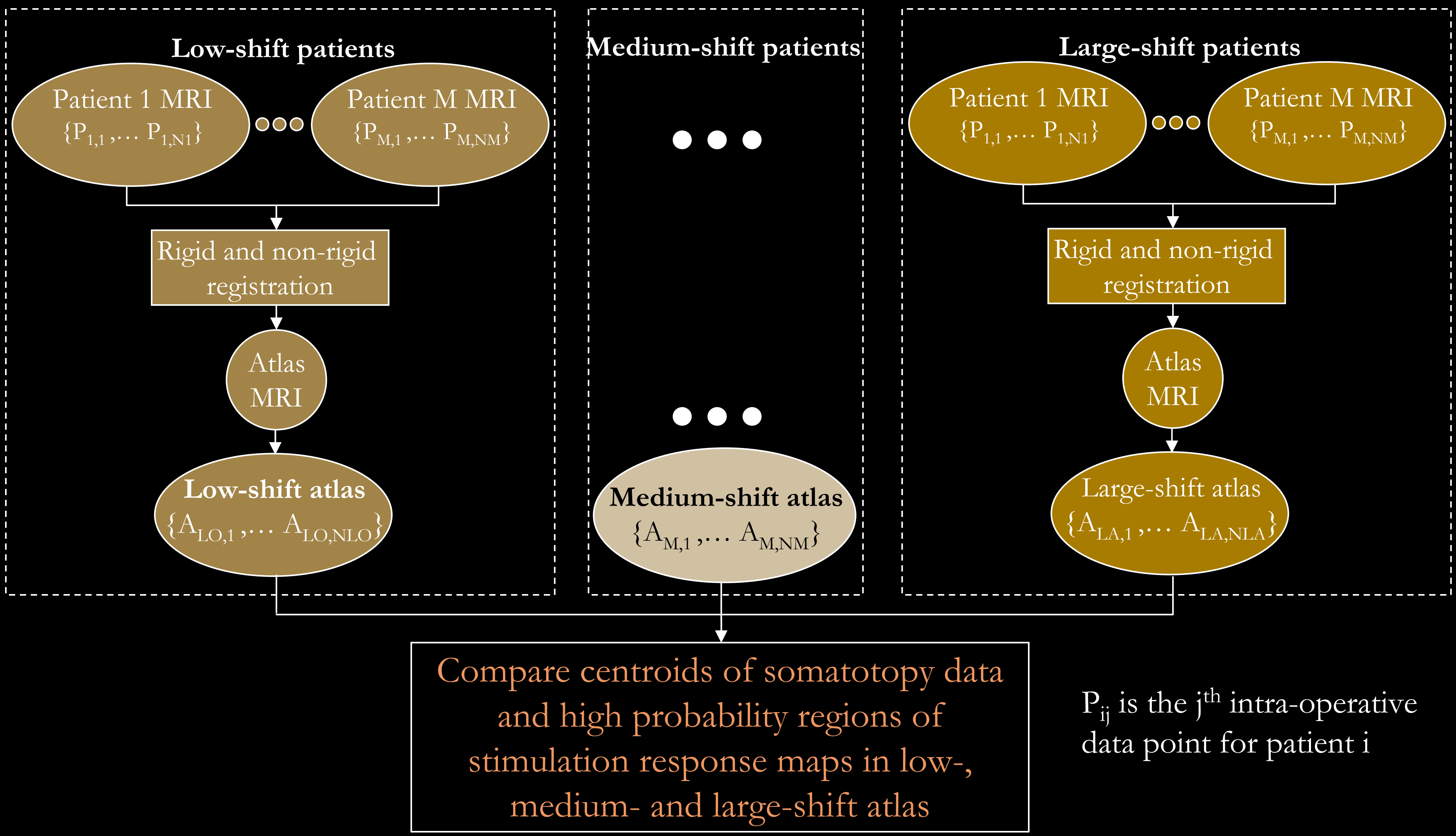
Methods - Spherical shell model*

- Assumption:
  - If a response occurs at voltage V but not at the previous step of (V-ε) then the responsive neurons are located somewhere in between the regions activated by these voltages.
  - The radius of activation is proportional to stimulation voltage or current)#.
- Model
  - Associate a uniform probability density function with each stimulation point in a spherical 3D shell.
  - Sum over all stimulation points and normalize.



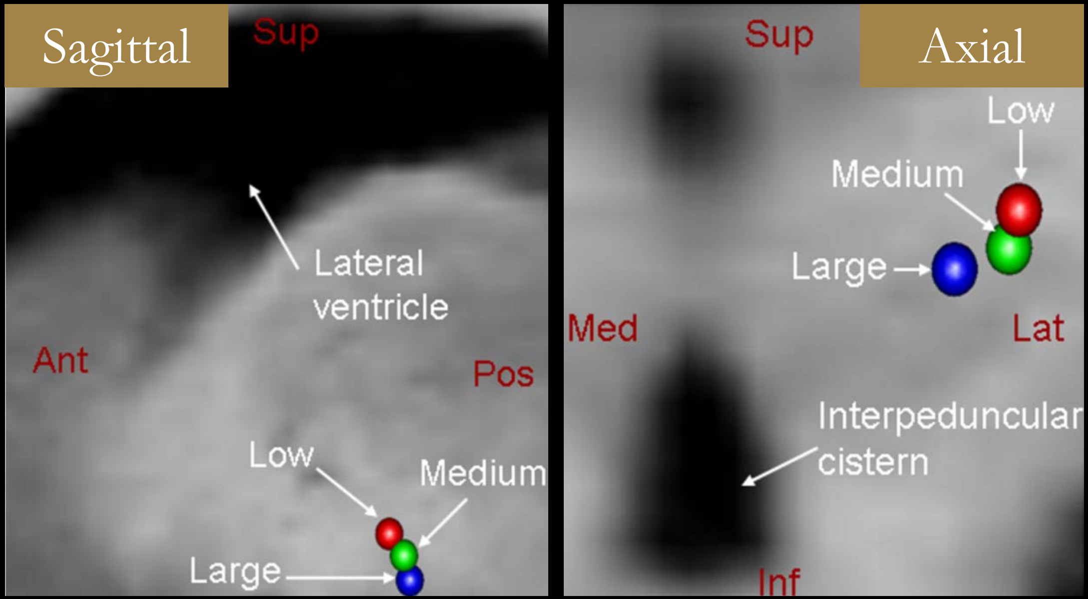
*Pallavaram *et al.*, MICCAI 2009
#Butson *et al.*, Brain Stimulation, 2008

Methods – Creating and comparing various brain-shift atlases



P_{ij} is the j^{th} intra-operative data point for patient i

Results - Cluster centroids of somatotopy data for various shift group atlases

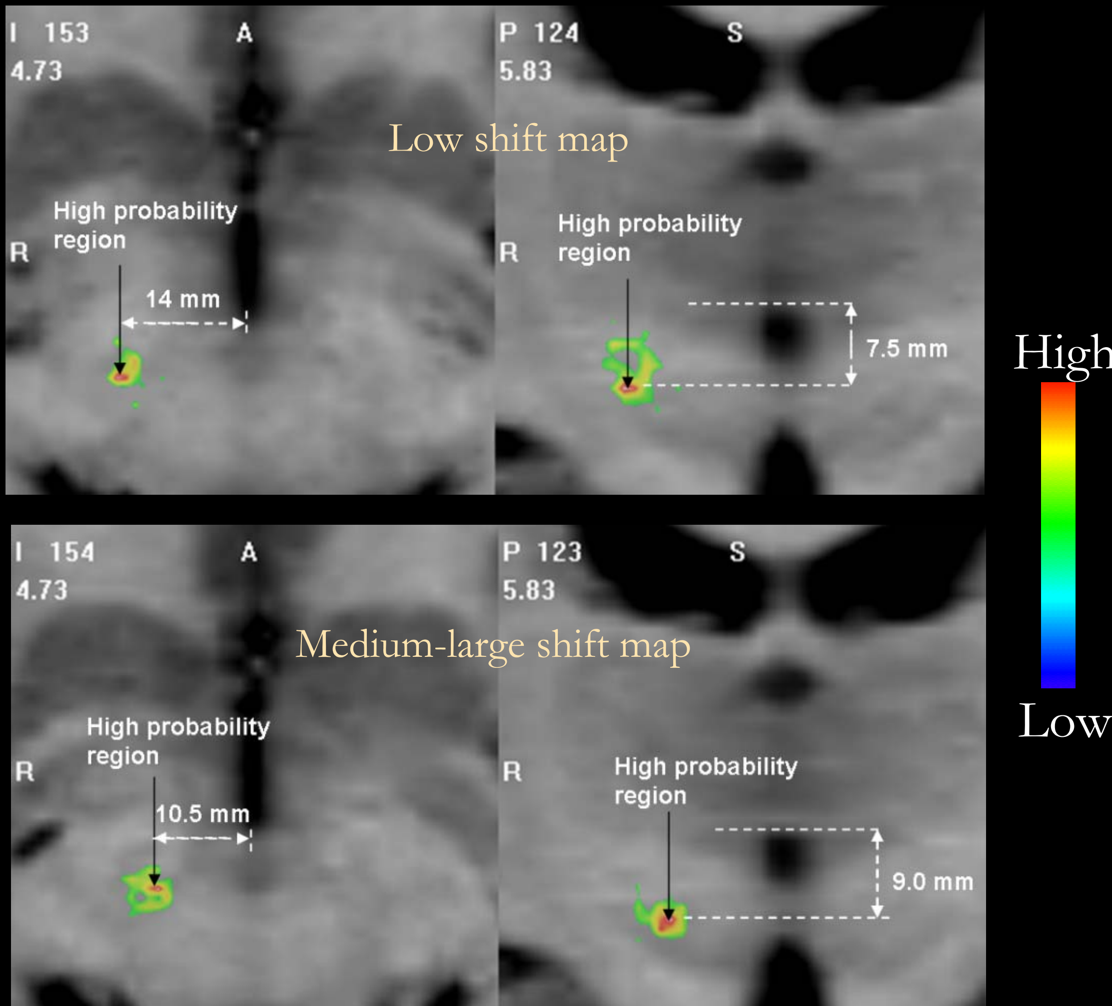


	Cluster centroid (mm)		
	Low	**Medium**	**Large**
Posterior	**1.94**	**2.90**	**3.06**
Lateral	**13.92**	**13.57**	**11.27**
Inferior	**3.20**	**4.53**	**5.36**

- The larger brain shift clusters are posterior, medial and inferior to lower shift clusters.
- The distance between the low and large shift clusters was as high as 3.59 mm.

The somatotopy clusters show substantial difference between the atlases of various brain shift groups.

Results - Low and medium-large shift eye deviation maps



- Axial and coronal slices containing the high probability regions in the two maps.
- The distance between the high probability regions low and medium-large maps is 4.06 mm.
- The stimulation maps also show substantial difference between the atlases of various brain shift groups.

Therefore, brain shift should be accounted for when building functional atlases.

Conclusions and Future Work

- Using intra-operative electrophysiological observations of somatotopy micro-electrode recordings and stimulation response data it was shown that brain shift has a substantial effect on atlas creation.
- Therefore, care must be taken when interpreting and using electrophysiological atlases of intra- and post-operative data in the various stages of DBS.
- Care must also be taken when using intra-operatively acquired electrophysiological for the validation of other atlases like histological atlases.
- Work in ongoing to develop a method to account for brain shift in order to build shift-corrected atlases
- Shift-corrected atlases will be correlated with patient-specific intra-operative and post-operative programming observations.

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