Neuroanatomy for the DBS Programmer

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February 2026

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Association of Movement Disorder Advanced Practice Providers

Leonardo Brito de Almeida – Relevant Financial Relationships

- Speakers' Bureau, consultant, and/or advisory board member for Medtronic and Boston Scientific.

All relevant financial relationships have been mitigated

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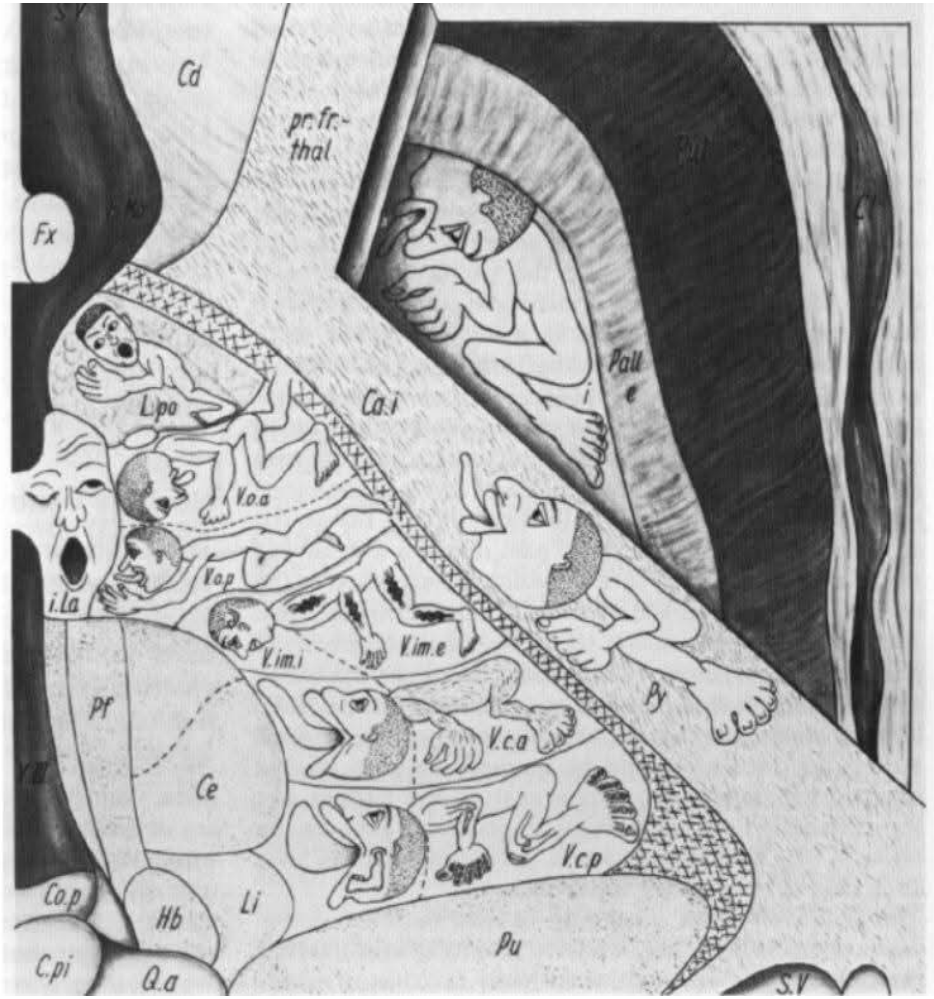
Why is Anatomy So Important?



Hassler E. Architectonic organization of the thalamic nuclei in Schaltenbrand G, Walker AR (eds): Stereotaxy of the Human Brain. Stuttgart: Thieme, 1982, Phd 142-180.

- In the correctly selected patient…
  - Successful DBS results -> Programmable lead
    - Lead in the correct target (or fibers related to it)
    - Enough spacing away from nearby structures whose stimulation would lead to side effects
- Sometimes the intraoperative team does its best but
  - Patient-specific anatomic variations
  - Blood vessels in the way of the ideal location
  - Target edema
  - Brain shift (sagging of the brain after opening dura)
  - Lead migrations

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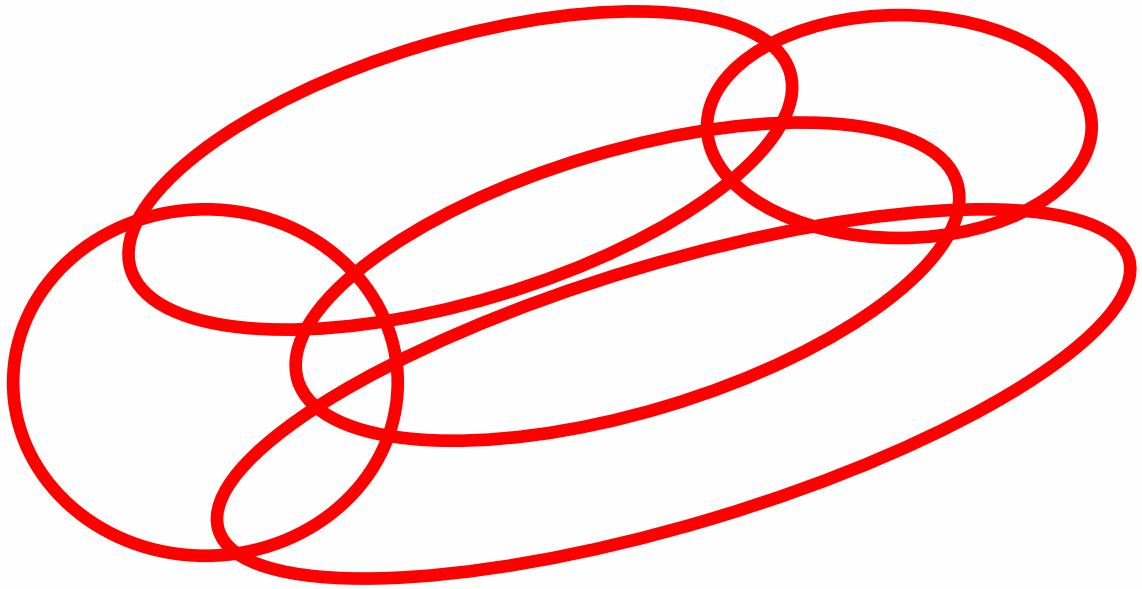
Therefore, even though computers are there…

- There is no more powerful computer than your brain
  - If the model fails, with basic concepts you can still succeed with programming and/or troubleshooting certain situations
- Be familiar with the surrounding anatomy of your target
- Be familiar with the trajectory of the implanted electrode
  - Most traditional surgical approaches are lateral to medial and anterior to posterior
    - The bottom contact of your electrode is always the closest to medial and posterior
    - The top contact is always the closes to lateral and anterior
- Lead models matter
  - Spacing between contacts
  - Number of contacts available on the lead

Thalamus

Specifics on the anatomy - Thalamus

<- Posterior – Anterior ->

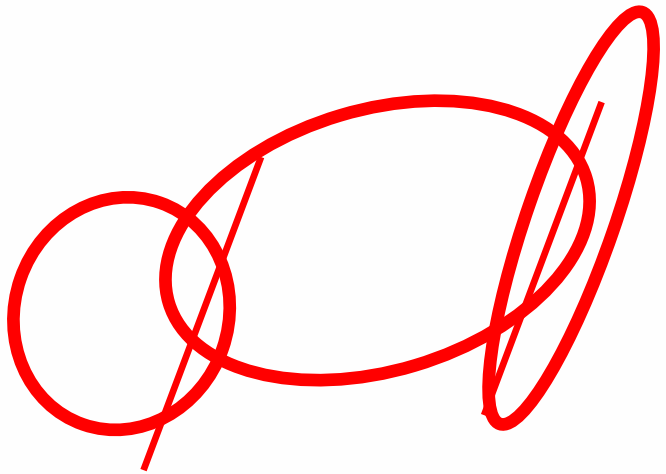


- The way Leo's brain remembers
  - AN – most anterior
    - Papez circle – limbic
  - Pulvinar – most posterior
    - Visual stuff (visual association areas)
  - Medial to AN and Pulvinar
    - Limbic stuff (limbic association areas)
  - Lateral to AN and in front of Pulvinar
    - Upper part (LD and LP)
      - Connections from limbic, visual learning, visuospatial processing, visual processing
      - Basically, what connects AN to Pulvinar
    - Lower part
      - What matters to DBS in tremor
      - Anterior to posterior
        - Motor planning
        - Motor execution
        - Sensory

Aibar-Duran JÁ et al. (2025) New technique for direct targeting of the ventral intermediate nucleus using magnetic resonance-guided focused ultrasound. Front. Radiol. 5:1588379

Specifics on the anatomy - Thalamus

<- Posterior – Anterior ->



- Taking the part that matters for DBS
  - You want the lead in VIM
    - That is where cerebellar fibers are entering the thalamus (DRTT)
      - Greater stimulation of these fibers -> greater tremor control
  - In front of VIM
    - Ventralis oralis posterior
      - Also a target for tremor
  - Behind VIM
    - Ventral caudal (VC) nucleus
      - Also known as the combination of ventral posterolateral (VPL) and ventral posteromedial (VPM) nuclei
      - Sensory nucleus -> paresthesias
  - Posterior-anterior border of VIM
    - 3.0-4.0mm average

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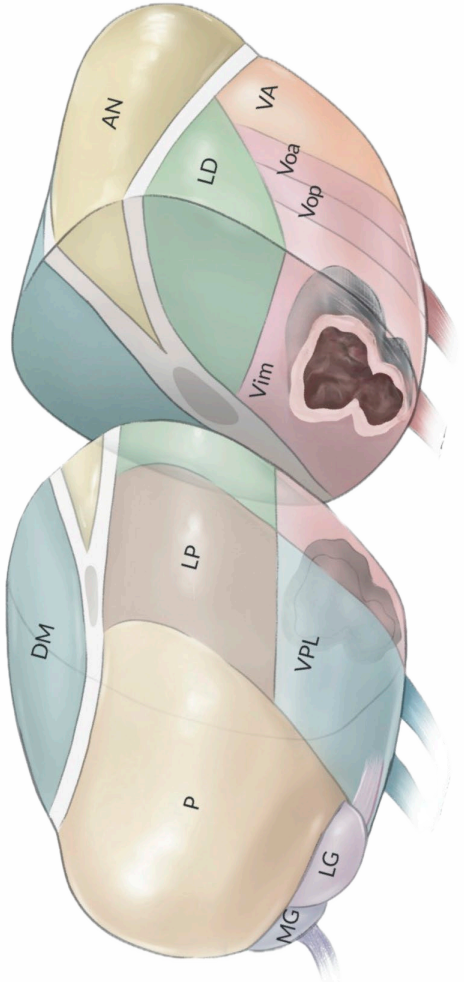
Specifics on the anatomy - Thalamus

<- Medial – Lateral ->



Internal capsule

- How about the medial to lateral anatomy
  - Medial to VIM
    - Clinically, you would see minimal/no benefit
      - Because you are probably missing effective stimulation of the DRTT fibers
    - You would need to be very medial to get into other nuclei enough to cause cognitive problems, etc, associated with those limbic associative relay areas
  - Lateral to VIM
    - Internal capsule
      - More specifically, posterior limb of internal capsule
        - Voluntary muscle control
        - Pulling

Adapted from: Aibar-Duran JÁ et al. (2025) New technique for direct targeting of the ventral intermediate nucleus using magnetic resonance-guided focused ultrasound. Front. Radiol. 5:1588379

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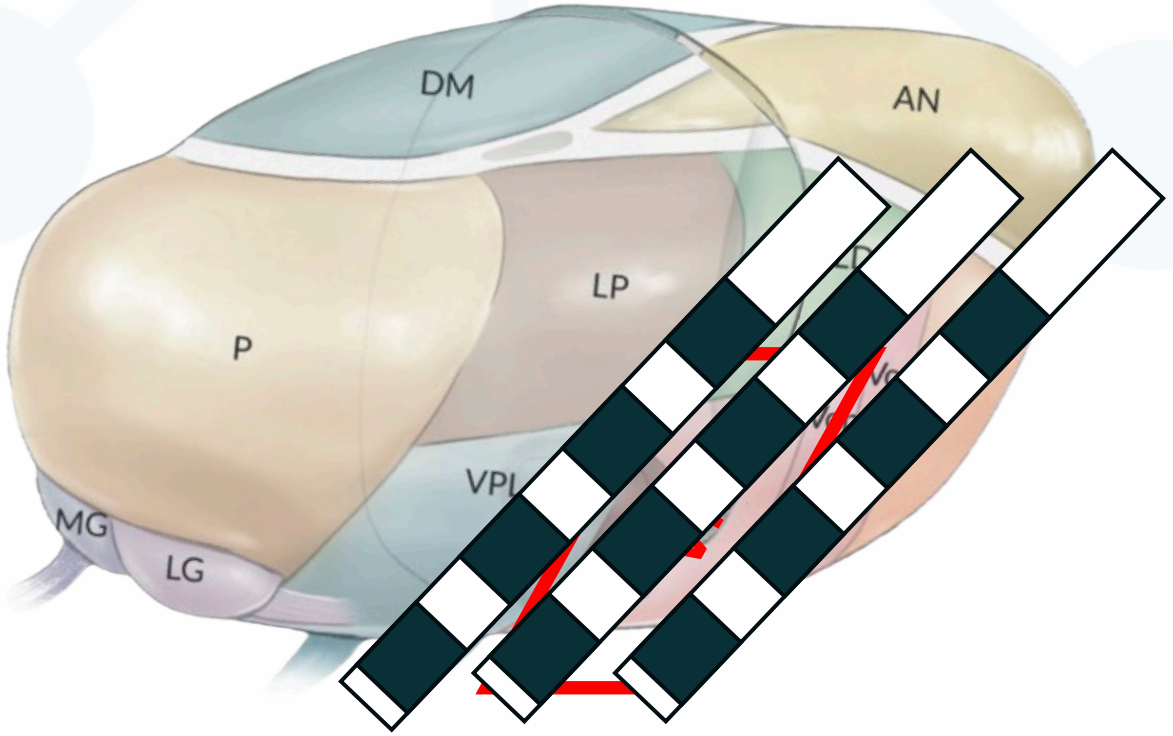
Thalamic anatomy into clinical context

- Consider how long the DBS electrode is
- Consider entry points and angles/trajectory

- Anterior-posterior
  - Well-placed leads
    - You may get paresthesias in the deepest contact
    - The therapeutic window for paresthesias widens as you move higher on DBS electrode
  - More posteriorly-placed leads
    - Paresthesias in multiple contacts
    - Very narrow therapeutic windows for paresthesias across contacts
  - More anteriorly-placed leads
    - No paresthesias at the bottom
    - If missing DRTT -> minimal/no benefit

<- Posterior – Anterior ->



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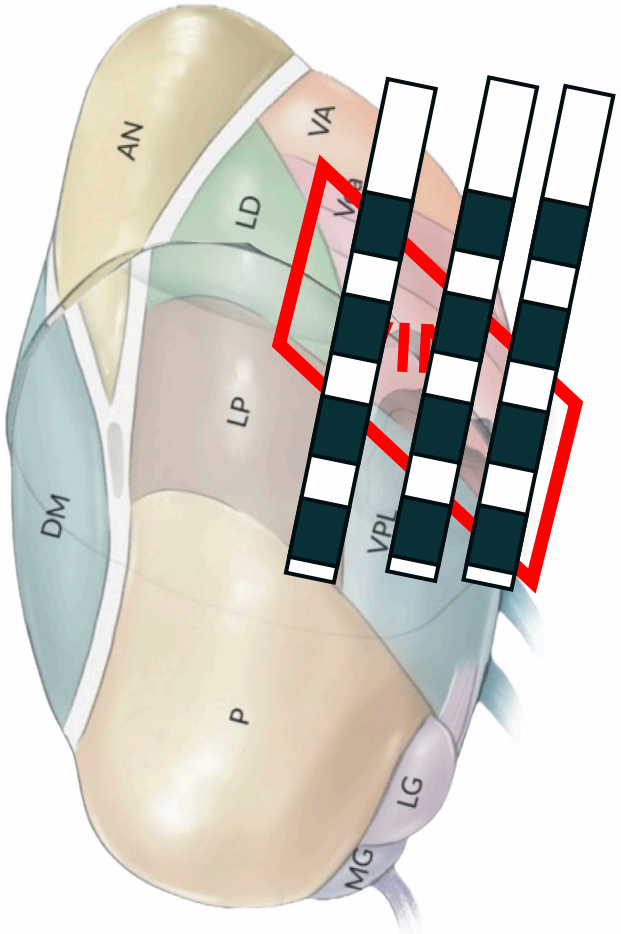
Thalamic anatomy into clinical context

- Consider how long the DBS electrode is
- Consider entry points and angles/trajectory

<- Medial – Lateral ->



Internal capsule

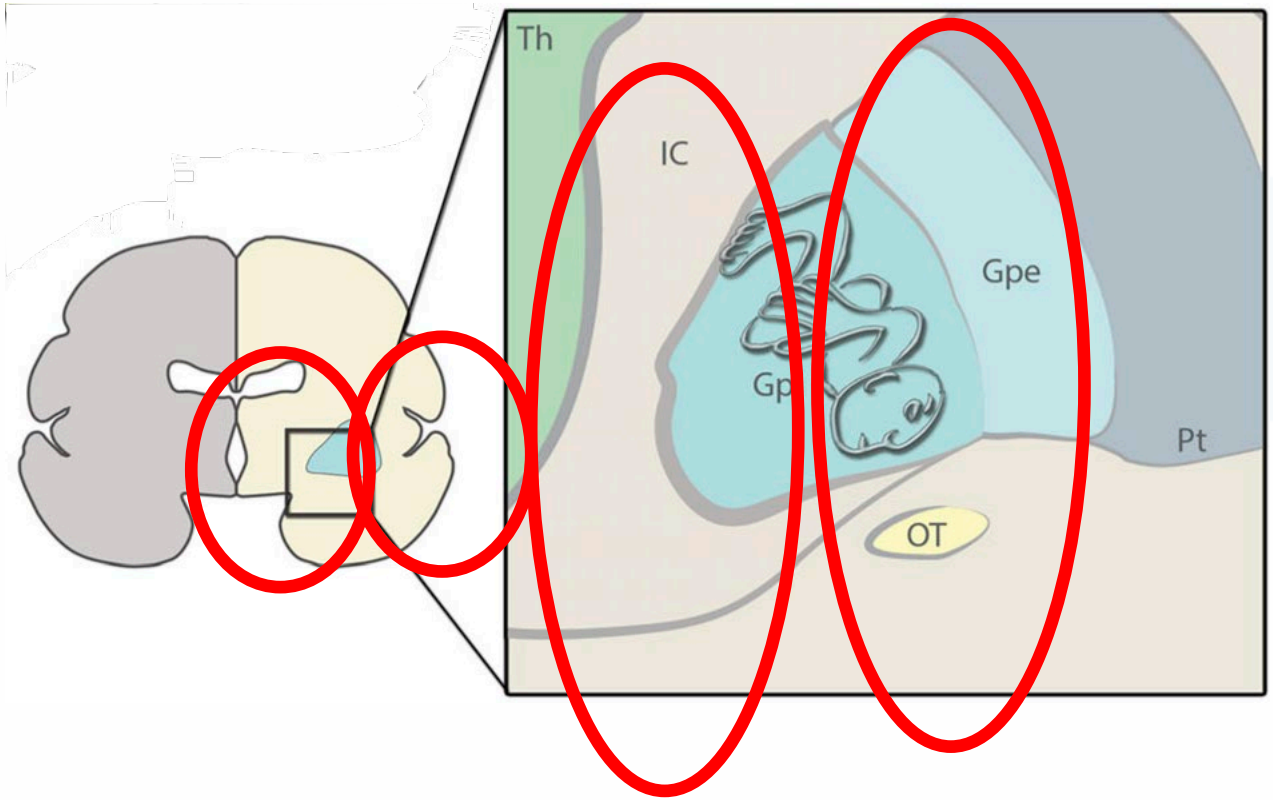
- Medial-lateral
  - Well-placed leads
    - You may get some capsular pulling in the most superficial contact
    - Therapeutic windows for capsular pulling narrows as you move higher on the electrode
  - More laterally-placed leads
    - Pulling in multiple contacts
    - Narrow therapeutic windows for pulling across contacts
  - More medially-placed leads
    - No pulling at high amplitudes at the top
    - If missing DRTT -> minimal/no benefit

Globus pallidum interna

GPi – location

Au K et al. Globus Pallidus Internus (GPi) Deep Brain Stimulation for Parkinson's Disease: Expert Review and Commentary. Neurol Ther. 2021 Jun;10(1):7-30.

GPi - Boundaries



- Medial-lateral
  - Medial – internal capsule (posterior limb)
    - Pulling
  - Lateral – GPe
    - GPe-GPi border
      - Potential stimulation-induced dyskinesias

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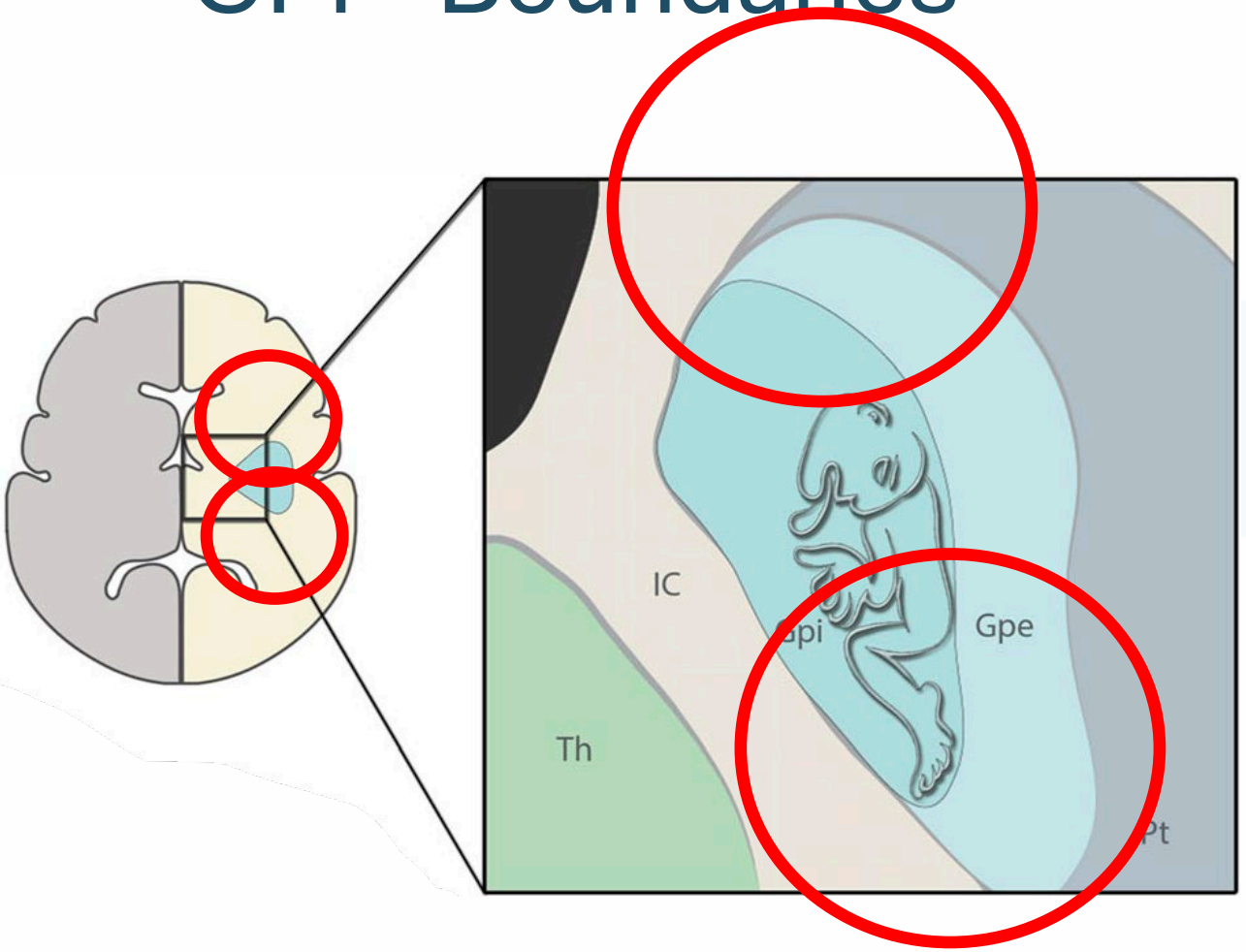

- Anterior - posterior
  - Some GPe, anterior limb of internal capsule
  - Missing the motor regions-less/no benefit
  - Posterior
    - Internal capsule – pulling
    - Inferior and posterior – optic tract
      - Phosphenes

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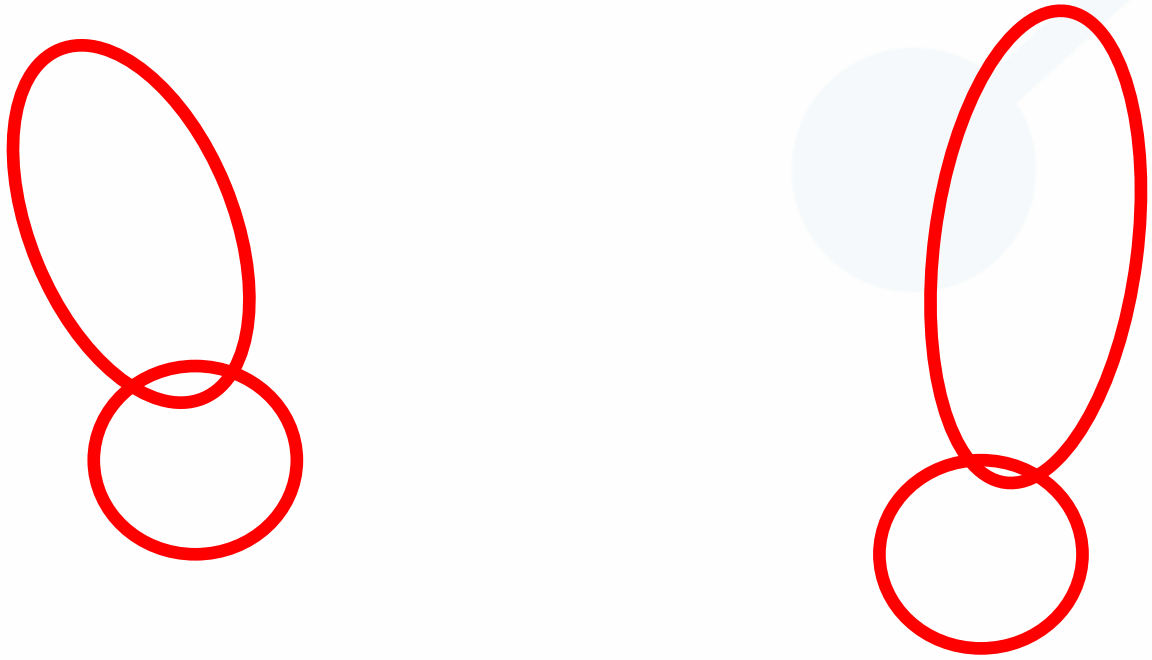
Functional distribution of GPi

Wong JK et al. Time for a New 3-D Image for Globus Pallidus Internus Deep Brain Stimulation Targeting and Programming. J Parkinsons Dis. 2021;11(4):1881-1885.

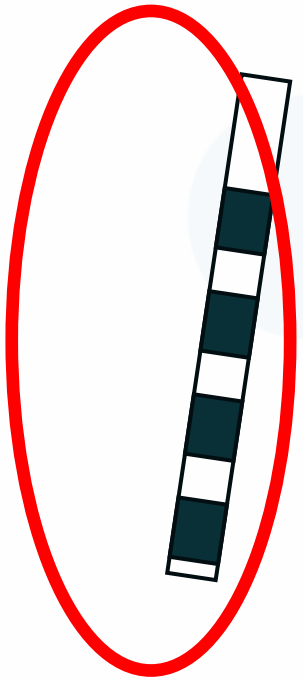
GPi anatomy into clinical context



- Well-placed leads
  - You may get some capsular pulling in the deepest contact
  - Capsular therapeutic window widens as you move higher on the DBS electrode
    - Away from capsule

Wong JK et al. Time for a New 3-D Image for Globus Pallidus Internus Deep Brain Stimulation Targeting and Programming. J Parkinsons Dis. 2021;11(4):1881-1885.

GPi anatomy into clinical context



- Medially-placed leads
  - Contacts closer to capsule
  - Lower thresholds to cause pulling

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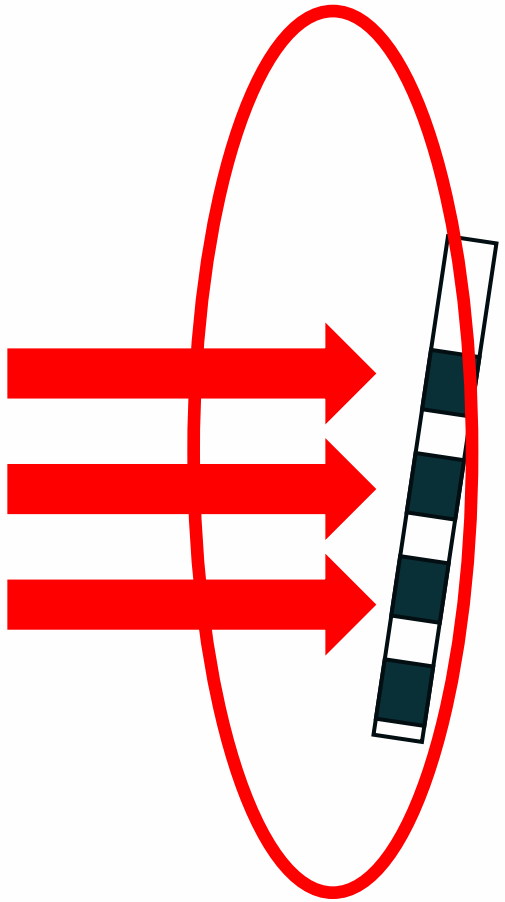
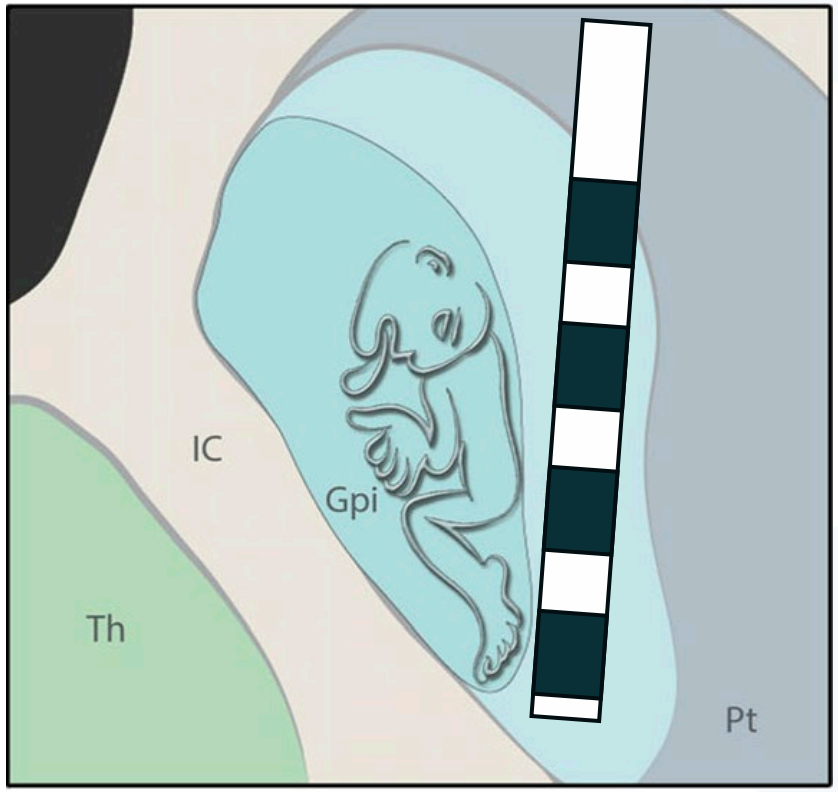
GPi anatomy into clinical context





- Laterally-placed leads
  - Contacts away to capsule
  - Wider thresholds to cause pulling
  - Closer to dyskinesia-inducing fibers
  - If in GPe, may miss the motor GPi (where you want to stimulate)
    - Greater amplitudes to get benefit
      - Higher energy comsumption

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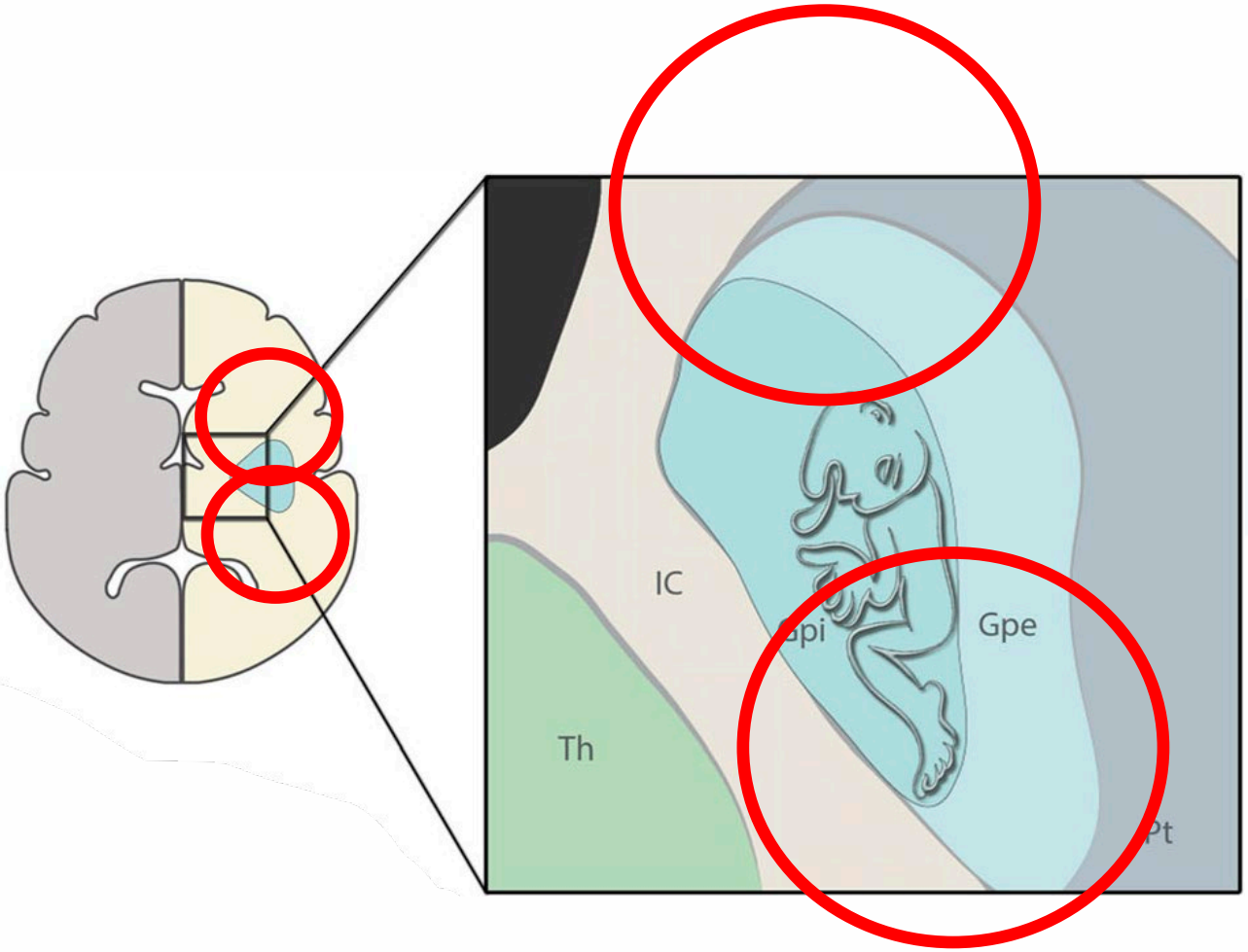
GPi anatomy into clinical context

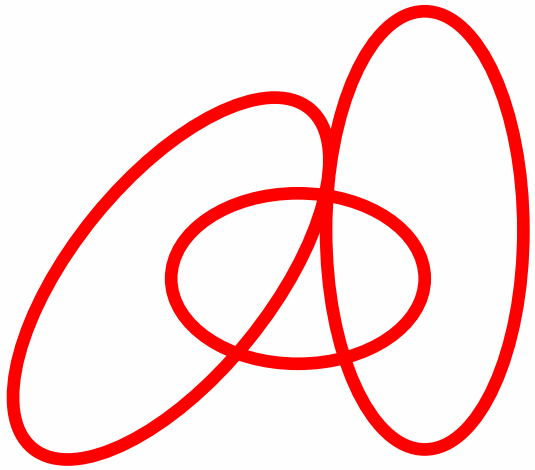


Au K et al. Globus Pallidus Internus (GPi) Deep Brain Stimulation for Parkinson's Disease: Expert Review and Commentary. Neurol Ther. 2021 Jun;10(1):7-30.

- Anterior leads
  - May miss the region of interest
  - Higher amplitudes to produce effect
- Posterior leads
  - Contacts are closer to pulling
  - Narrower therapeutic windows for pulling
  - Posterior and deep – optic tract
    - Phosphenes

Subthalamic Nucleus

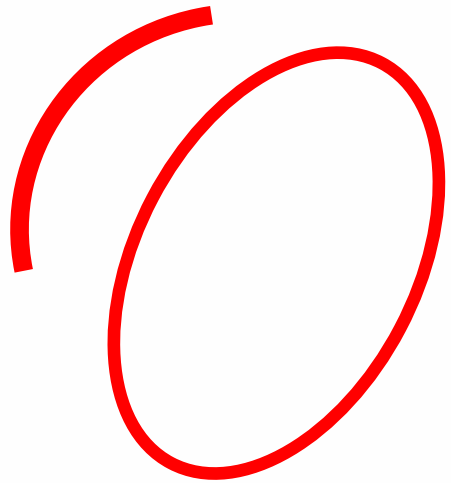
STN – location



- Below the thalamus (sub-thalamic)
- Above substantia nigra
- Anterior-posterior borders
  - Anterior – internal capsule
    - Pulling
  - Posterior - medial lemniscus
    - Paresthesias

Bari AA et al.. Improving outcomes of subthalamic nucleus deep brain stimulation in Parkinson's disease. Expert Rev Neurother. 2015 Oct;15(10):1151-60.

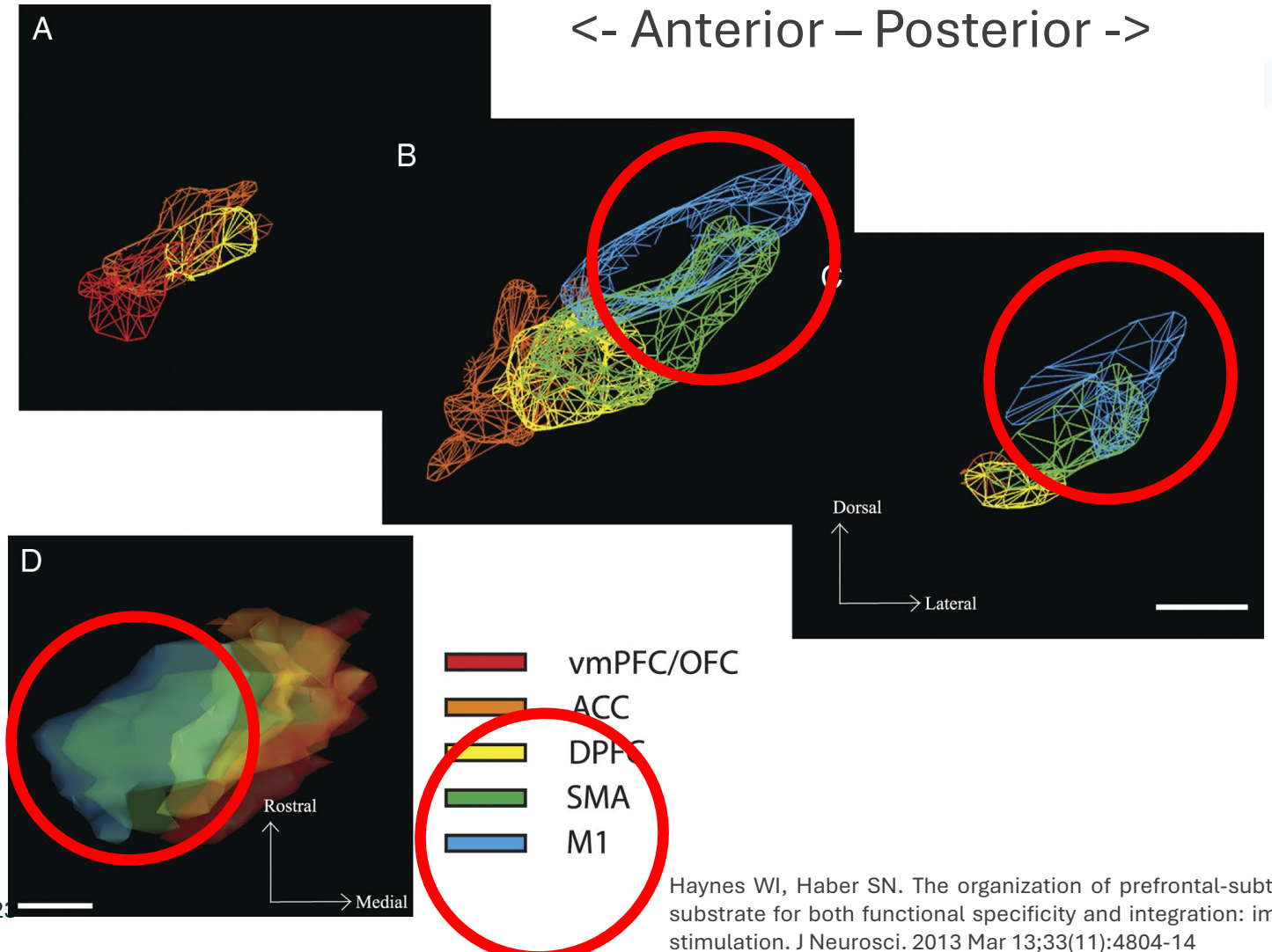
STN – location



- Below the thalamus (sub-thalamic)
- Above substantia nigra
- Anterior-posterior borders
  - Anterior – internal capsule
    - Pulling
  - Posterior - medial lemniscus
    - Paresthesias
  - Lateral – internal capsule
    - Pulling
  - Medial – depends on your depth
    - Oculomotor nerve
    - Medial lemniscus
    - Red nucleus

Bari AA et al.. Improving outcomes of subthalamic nucleus deep brain stimulation in Parkinson's disease. Expert Rev Neurother. 2015 Oct;15(10):1151-60.

Functional and connectomic distribution of STN



- Connections with cortical motor areas
  - Posterior half to two thirds of STN
  - Lateral aspect of STN

Haynes WI, Haber SN. The organization of prefrontal-subthalamic inputs in primates provides an anatomical substrate for both functional specificity and integration: implications for Basal Ganglia models and deep brain stimulation. J Neurosci. 2013 Mar 13;33(11):4804-14

STN anatomy into clinical context

- Reasonably well- placed electrodes (depending on lead length/model)
  - Deepest contact
    - Possible paresthesias
  - Most superficial contact
    - Possible capsular pulling

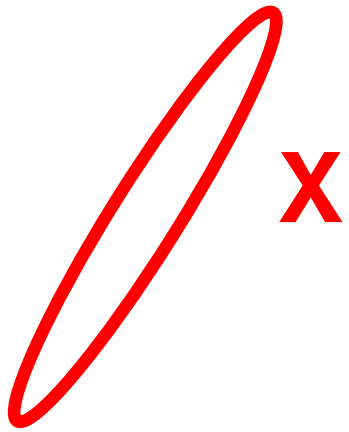
Bari AA et al.. Improving outcomes of subthalamic nucleus deep brain stimulation in Parkinson's disease. Expert Rev Neurother. 2015 Oct;15(10):1151-60.

STN anatomy into clinical context

- Anteriorly-placed leads
  - Closer to internal capsule
    - Lower thresholds for capsular pulling across contacts
  - Further away from medial lemniscal fibers
    - Less/no paresthesias even at the bottom contact
  - If missing the posterior half of STN
    - Reduced/no benefit

Bari AA et al.. Improving outcomes of subthalamic nucleus deep brain stimulation in Parkinson's disease. Expert Rev Neurother. 2015 Oct;15(10):1151-60.

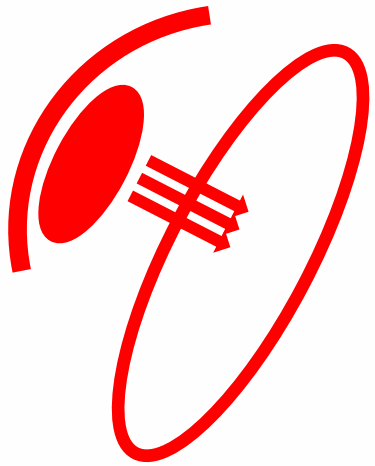
STN anatomy into clinical context



- Posteriorly-placed leads
  - Closer to medial lemniscus
    - Lower thresholds for paresthesias across contacts
  - Further away from internal capsule
    - Less/no pulling even at the top contact

Bari AA et al.. Improving outcomes of subthalamic nucleus deep brain stimulation in Parkinson's disease. Expert Rev Neurother. 2015 Oct;15(10):1151-60.

STN anatomy into clinical context

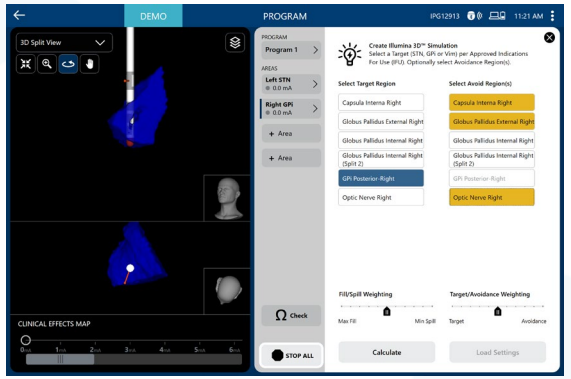


- Lateral leads
  - Contacts closer to internal capsule
    - Pulling at lower thresholds
- Medial leads
  - Leads further away from the posterolateral lateral STN
    - Potential loss of benefit
    - Greater than usual amplitudes to produce benefit
  - Proximity with medial structures
    - Side effects of diplopia, visual symptoms, imbalance, paresthesias, autonomic symptoms, etc

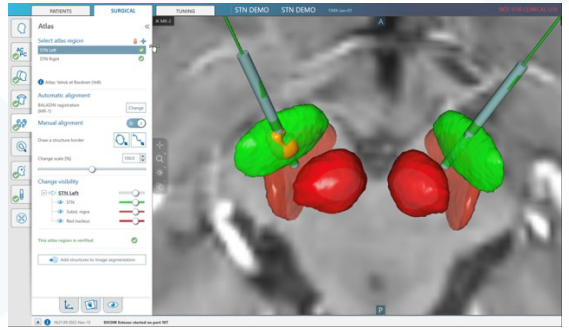
Bari AA et al.. Improving outcomes of subthalamic nucleus deep brain stimulation in Parkinson's disease. Expert Rev Neurother. 2015 Oct;15(10):1151-60.

Image-guided ≠ Anatomy-guided programming

- Commercially-available platforms (alphabetical order)
  - Boston Scientific (Image-guided programming and Illumina 3D
  - Medtronic (SureTune)
- Potential pitfalls
  - It assumes good alignment and processing of images
  - May not account for patient-specific anatomical variations
- Potential advantages
  - May be a great start point for programming
  - Combined with knowledge of anatomy and boundaries, may enable clinicians more accurate/precising programming



Example of Illumina case reproduced in Demo mode



Example of SureTune, courtesy of Medtronic

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Summary

- Evolution of hardware
  - More granularity in programming
  - More refinement in programming
- Knowledge of the neuroanatomy of the targets being programmed can help with
  - More accurate contact selection
  - More accurate avoidance or troubleshooting of stimulation-induced side effects
  - Recognize potential suboptimally-placed DBS leads that may potentially benefit from surgical revision in cases of suboptimal response

Thank you!

- Questions: l.almeida@ufl.edu

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