SEMINAR: FUNCTIONAL AND STEREOTACTIC NEUROSURGERY. PAIN, EPILEPSY, DYSKINESIAS, AND PSYCHOSURGERY. NEURONAVIGATION. IMAGE-GUIDED SURGERY

34484 Pathology of the nervous system

Neurosurgery

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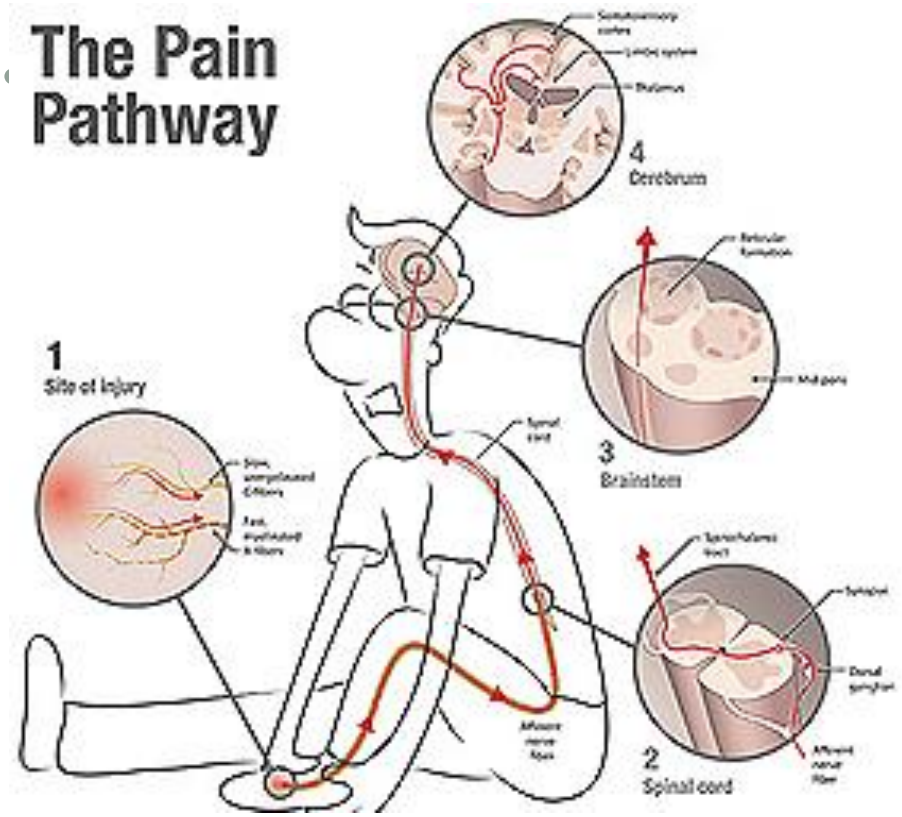
Key study points

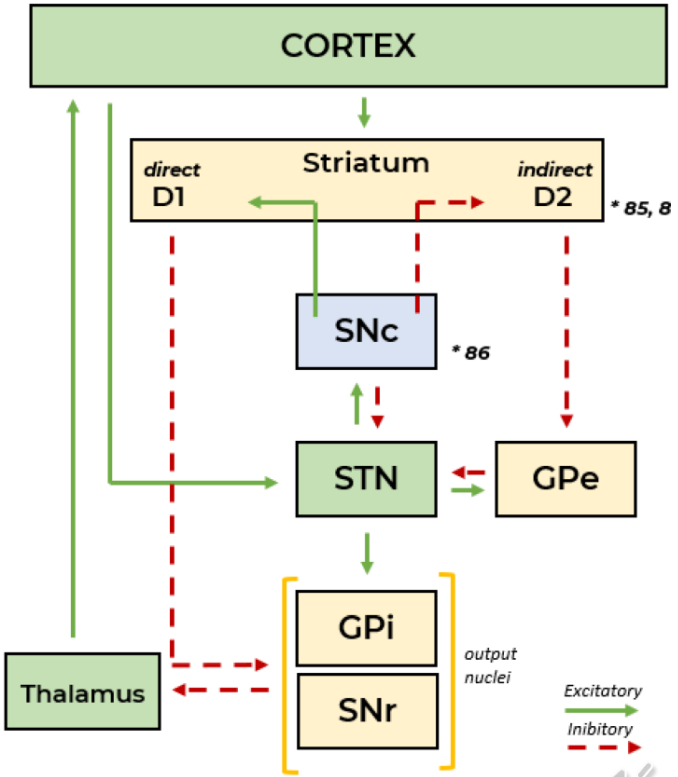
- Functional neurosurgery: concept
- Treatment of chronic refractory pain
  - Trigeminal neuralgia
- Neurosurgical treatment of epilepsy refractory to pharmacological treatment
- Neurosurgical treatment of movement disorders
  - Parkinson's disease, dyskinesias, spasticity
- Psychosurgery
- Stereotaxy
- Neuronavigation
- Image-guided surgery
- Robots in neurosurgery
- Neural prostheses

Functional neurosurgery

- Anatomical and functional. Central, peripheral, and autonomic nervous system **neural circuit disruption to achieve a clinical benefit**

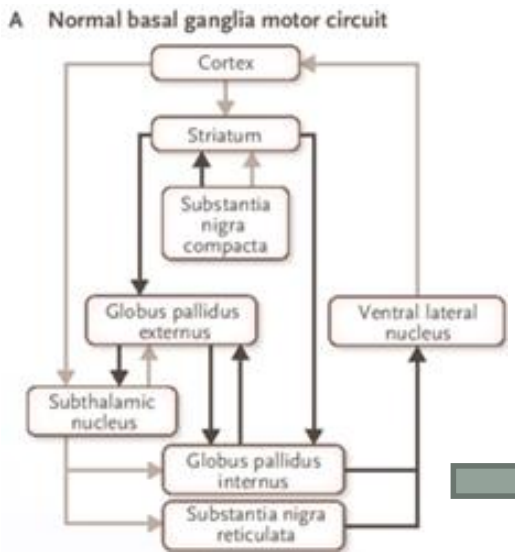


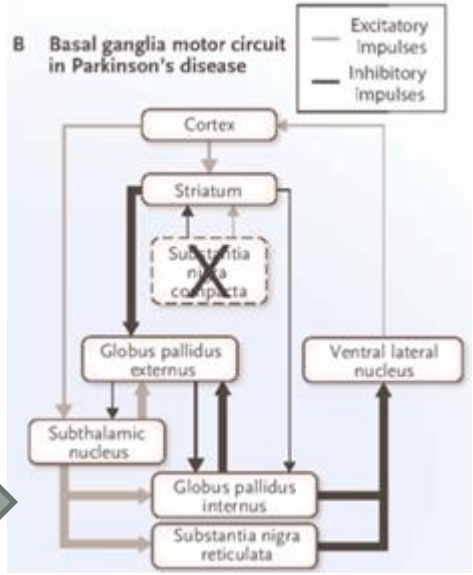
Pain transmission circuits

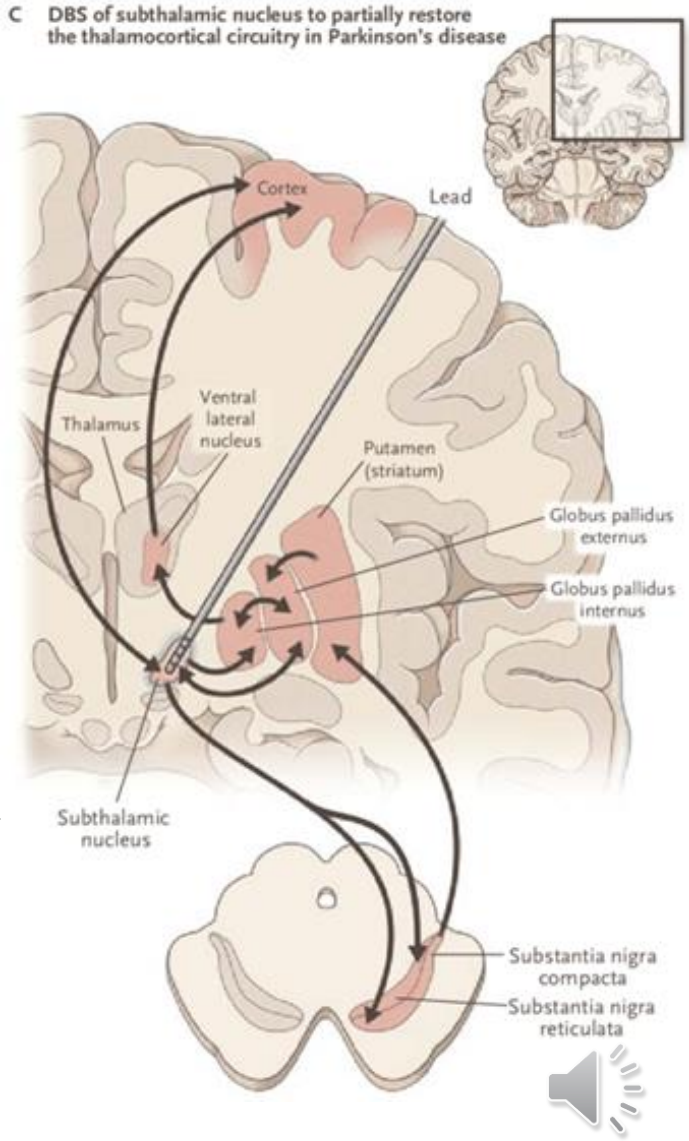


Circuits to modulate motor activity

Functional neurosurgery: extrapyramidal motor circuit block



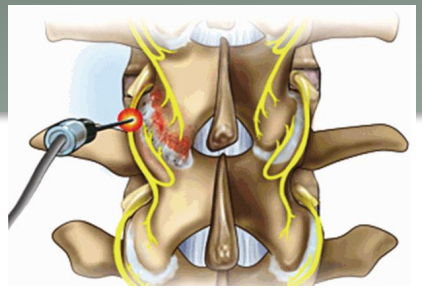




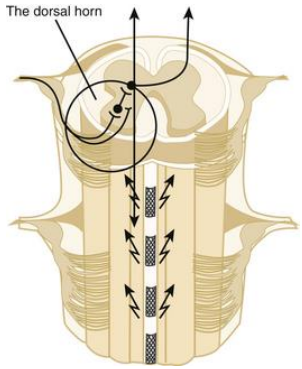
Normal **Parkinson's disease**

Functional neurosurgery techniques

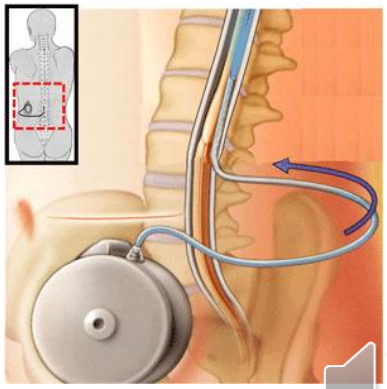
- **Ablation**
  - Definitive surgical lesions
  - Therapeutic and side effects are definitive and irreversible
- **Neuromodulation**
  - Action by electrical stimulation
  - Effect
    - Adjustable by modifying intensity and voltage
    - Reversible when stimulation stops
- **Drug administration**
  - Adjustable and reversible effects when discontinuing drug administration
  - Requires periodic drug refill (usually every three months)
    - Risk of infection



Ablation

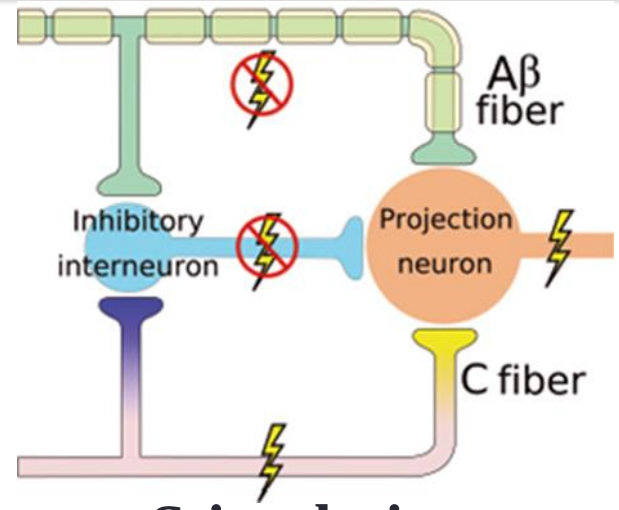


Neurostimulation

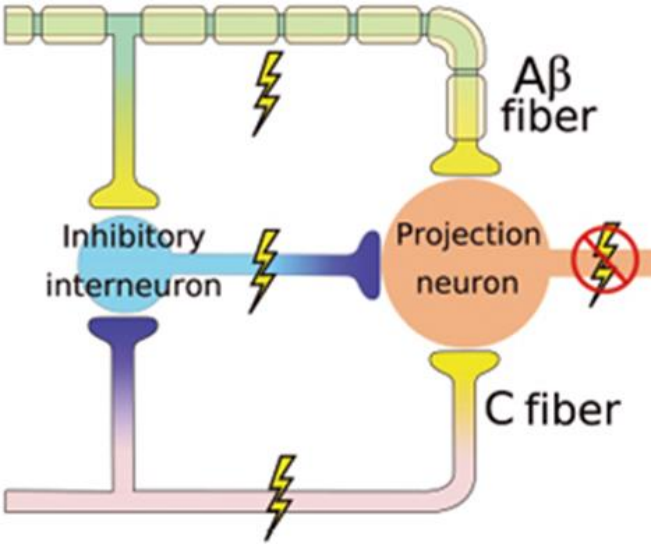


Drug administration

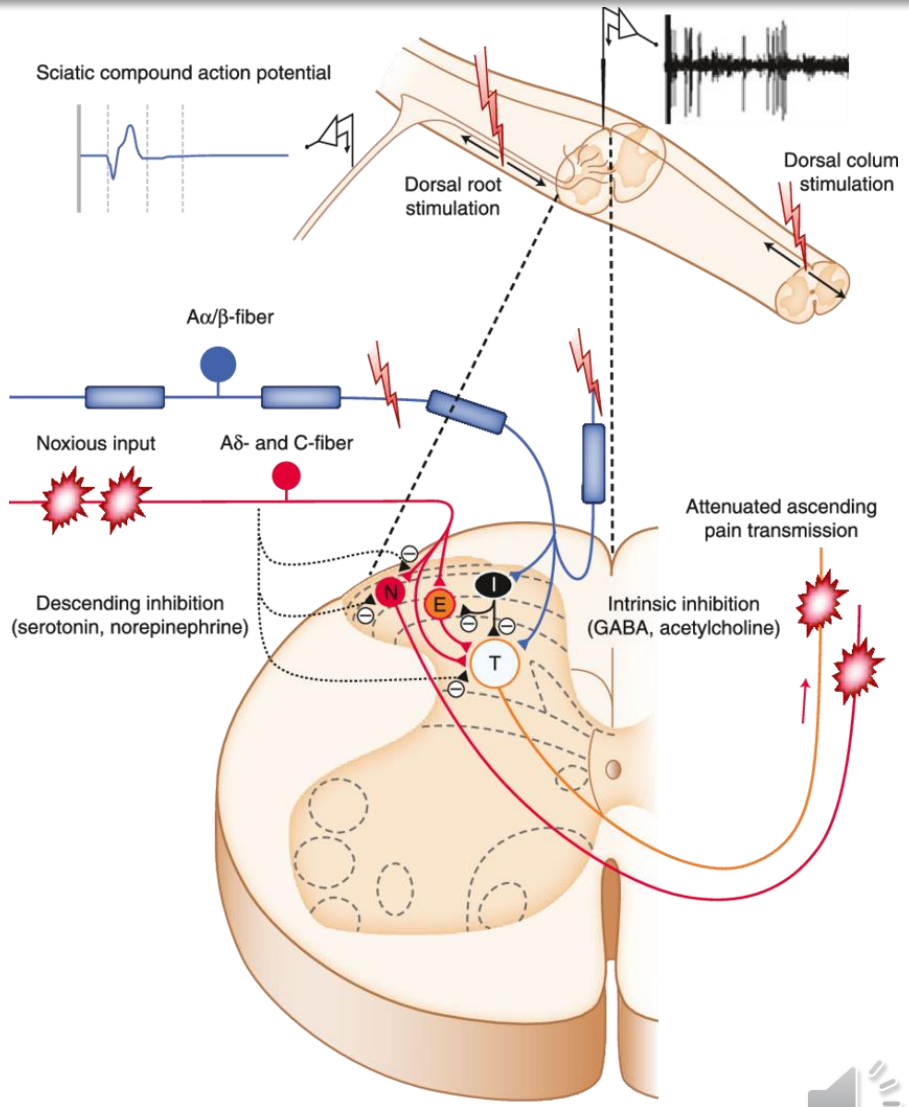
Neurostimulation effects



Stimulation

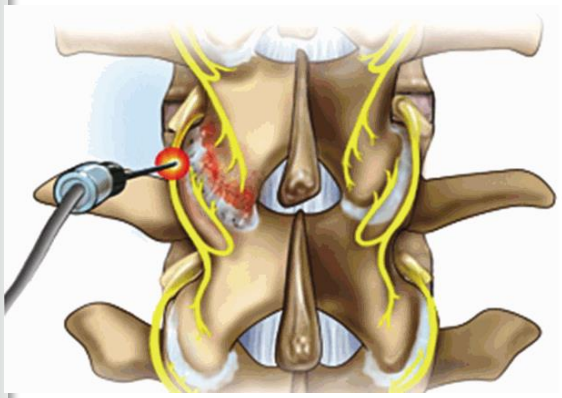


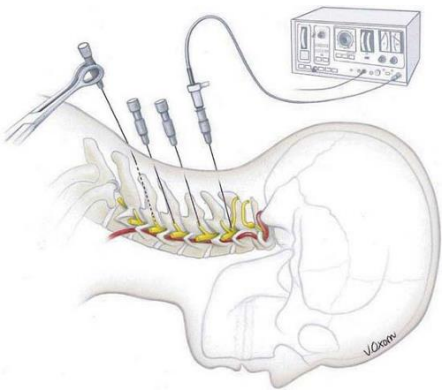
Inhibition



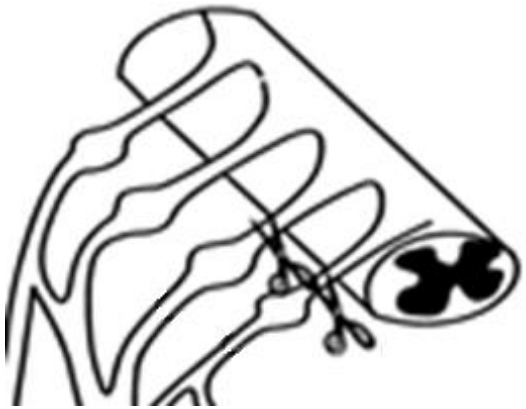
Pain transmission block

Functional neurosurgery techniques

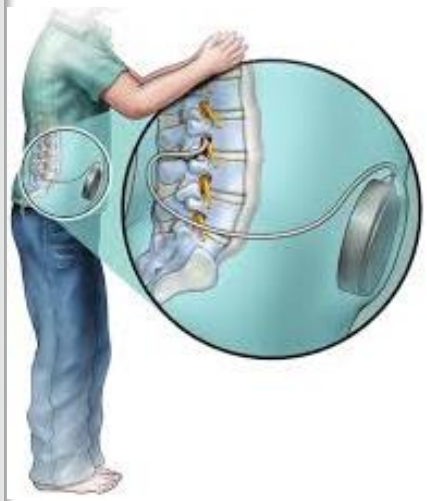




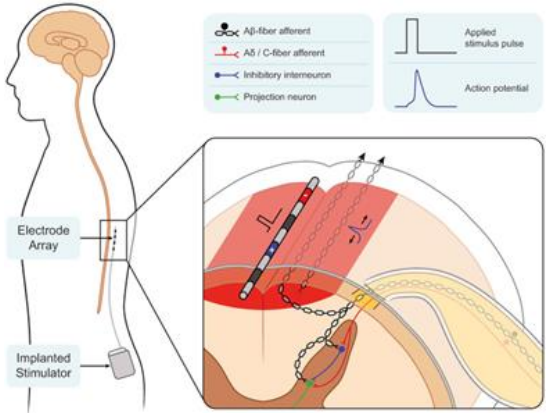
Radiofrequency ablation



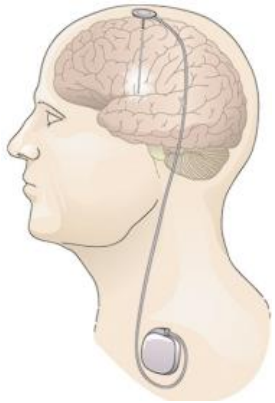
Surgical ablation



Intrathecal drug administration



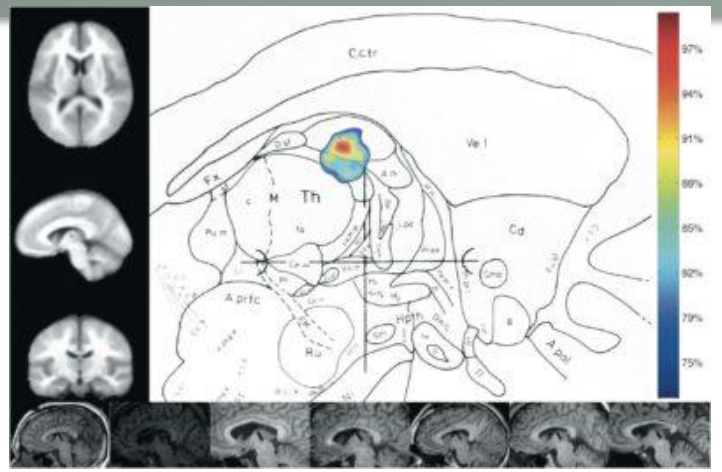
Posterior spinal column stimulation

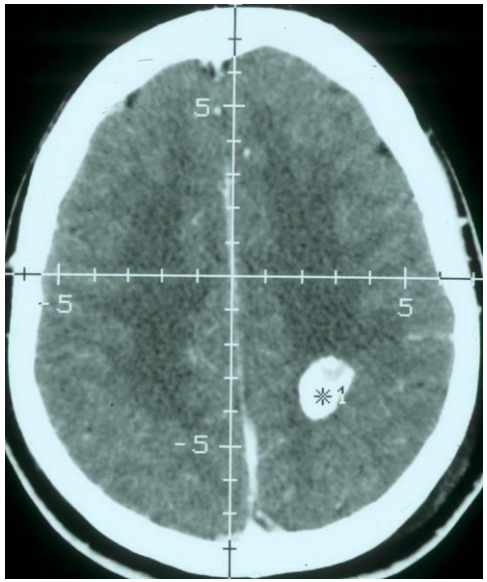


Deep brain stimulation

Location of target points

- Specific points of action located by means of **stereotaxy**
  - Integrates anatomical and neuroimaging references to locate **anatomical targets**



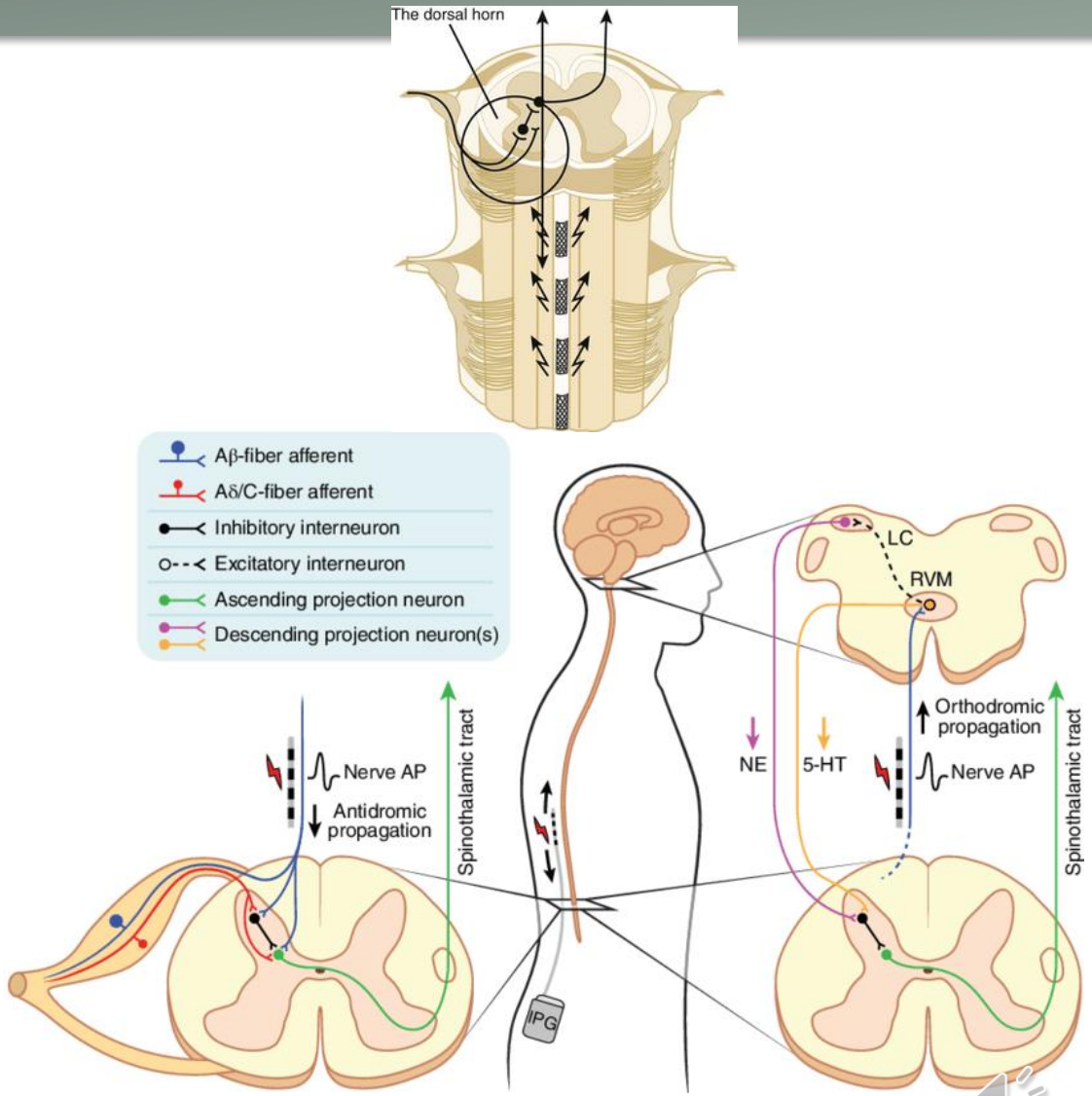


Coordinate calculation

Coordinate use in the operating room

Pain surgery: neuromodulation

- The function of some neurons / circuits are inhibited by electrical currents
- This is voltage /intensity dependent = enabling effect graduation
- It is **reversible** ⇨ increasingly used over time, inducing abandonment of ablative techniques

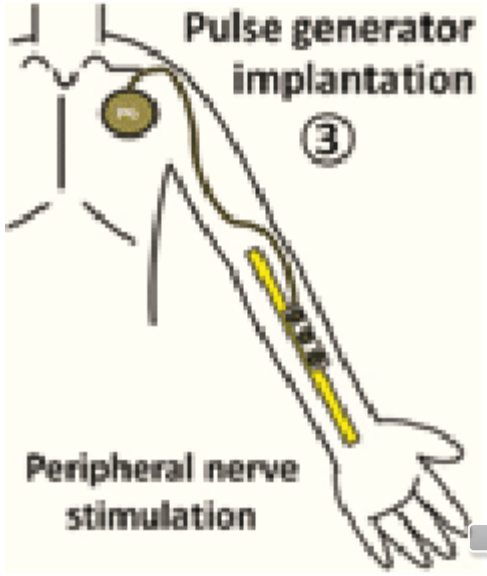


Posterior spinal column stimulation

Neuromodulation for pain: options

- **TENS** (transcutaneous electrical nerve stimulation)
  - Thick myelinated fibers are stimulated through the skin to achieve an analgesic effect
- **Peripheral nerve stimulation**
- **Posterior spinal column stimulation**
- **Deep brain stimulation**
- **Motor cortex stimulation**

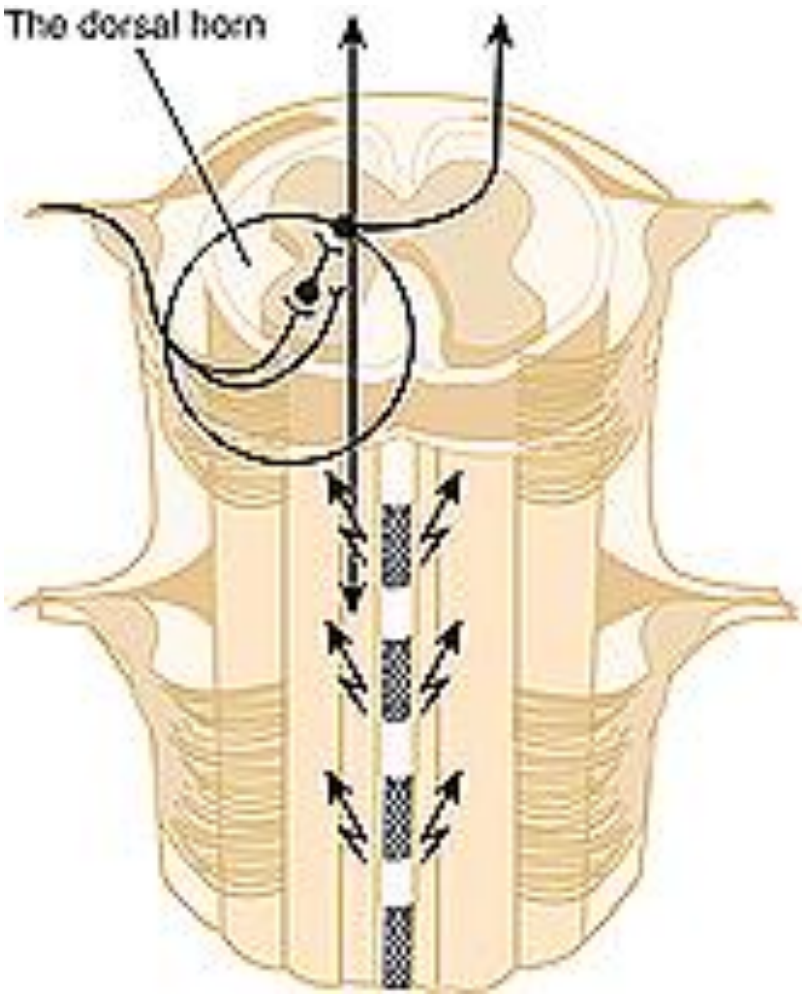
TENS

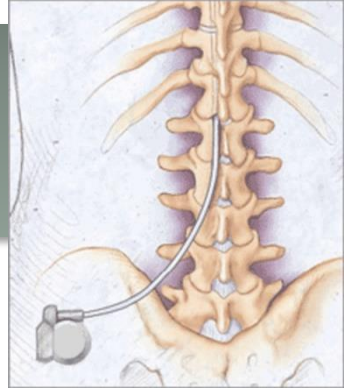


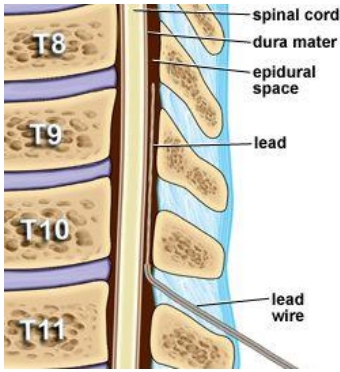
Peripheral nerve stimulation

Posterior spinal column stimulation

- Electrodes implanted **epidurally around the spinal cord**
- Antidromic stimulation of posterior spinal columns blocking spinothalamic tract conduction & inducing endorphin secretion

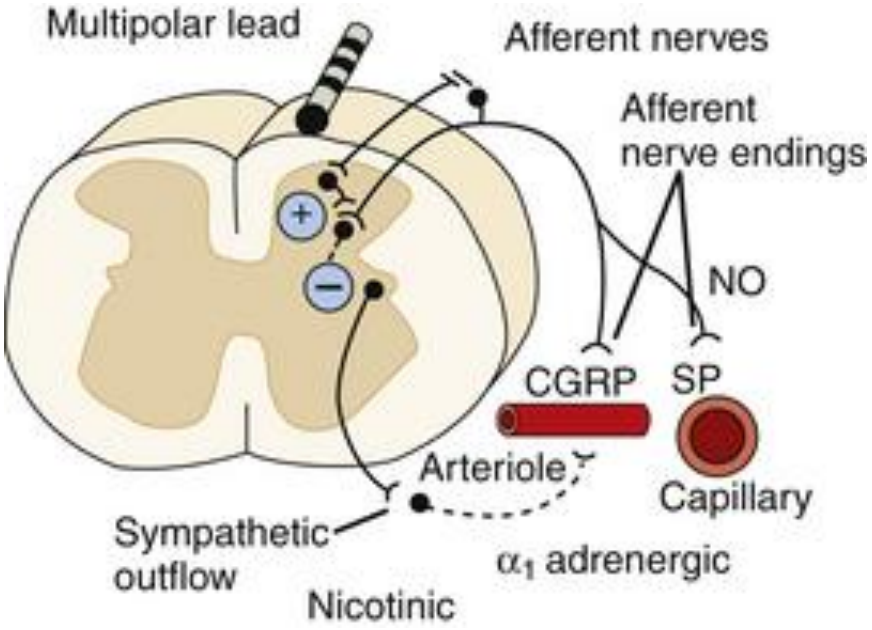


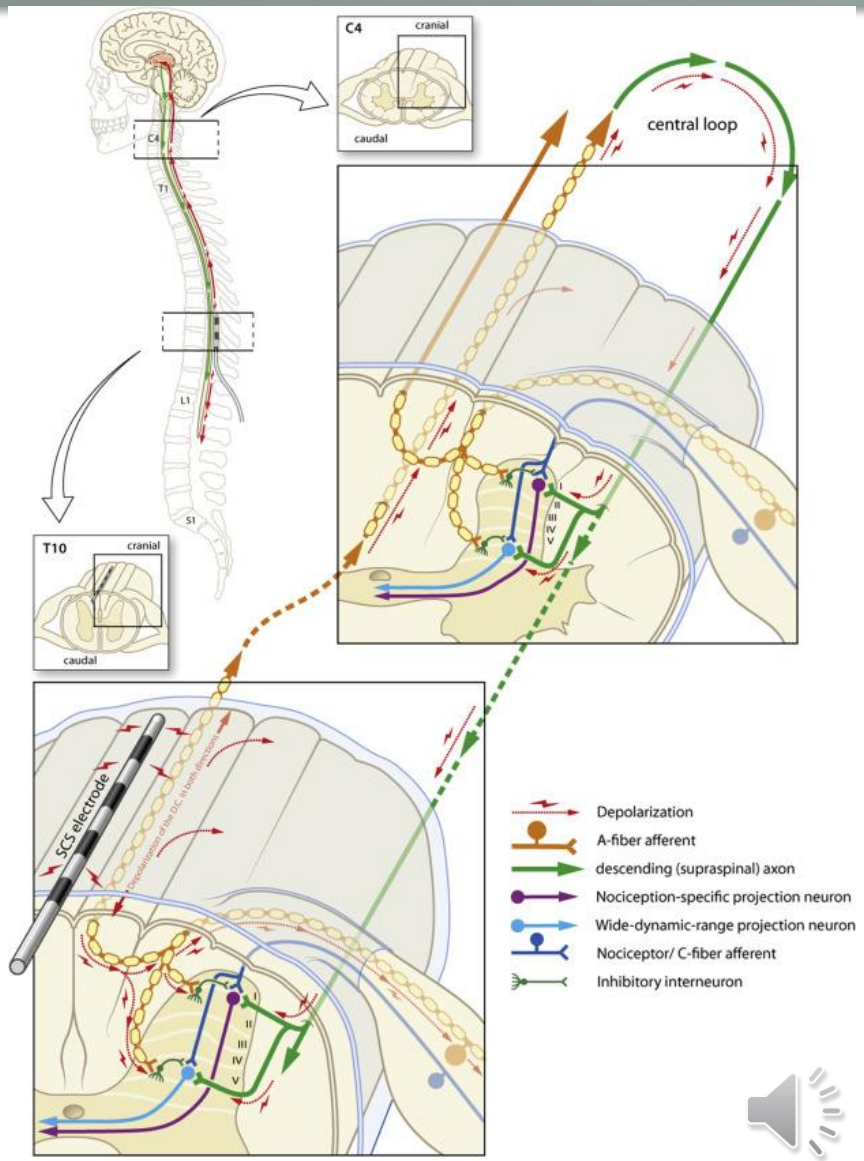




Posterior spinal column stimulation

- Technique: epidural spinal canal stimulating electrode implantation

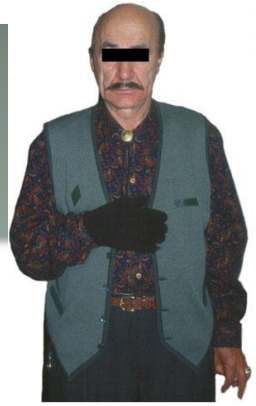




Posterior spinal column stimulation: indications

- **Deafferentation pain** (persistent lumbosciatica from failed back syndrome, reflex sympathetic dystrophy, phantom limb pain, brachial plexus avulsion, etc.)
- **Ischemic pain** (*angina pectoris*, intermittent vascular claudication, etc.)

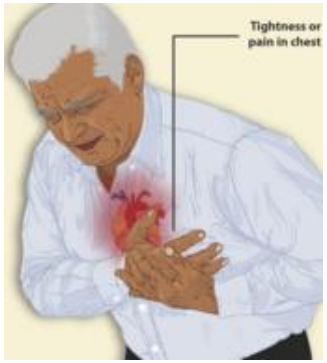
Failed back syndrome



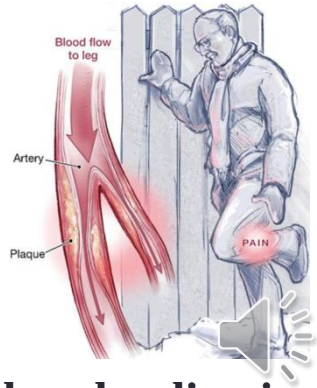
Reflex sympathetic dystrophy

Phantom limb pain

Brachial plexus avulsion



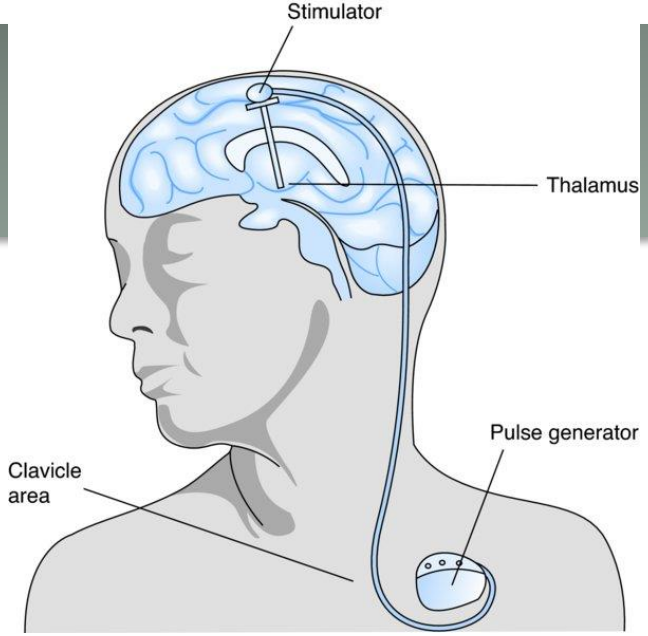
Angina pectoris

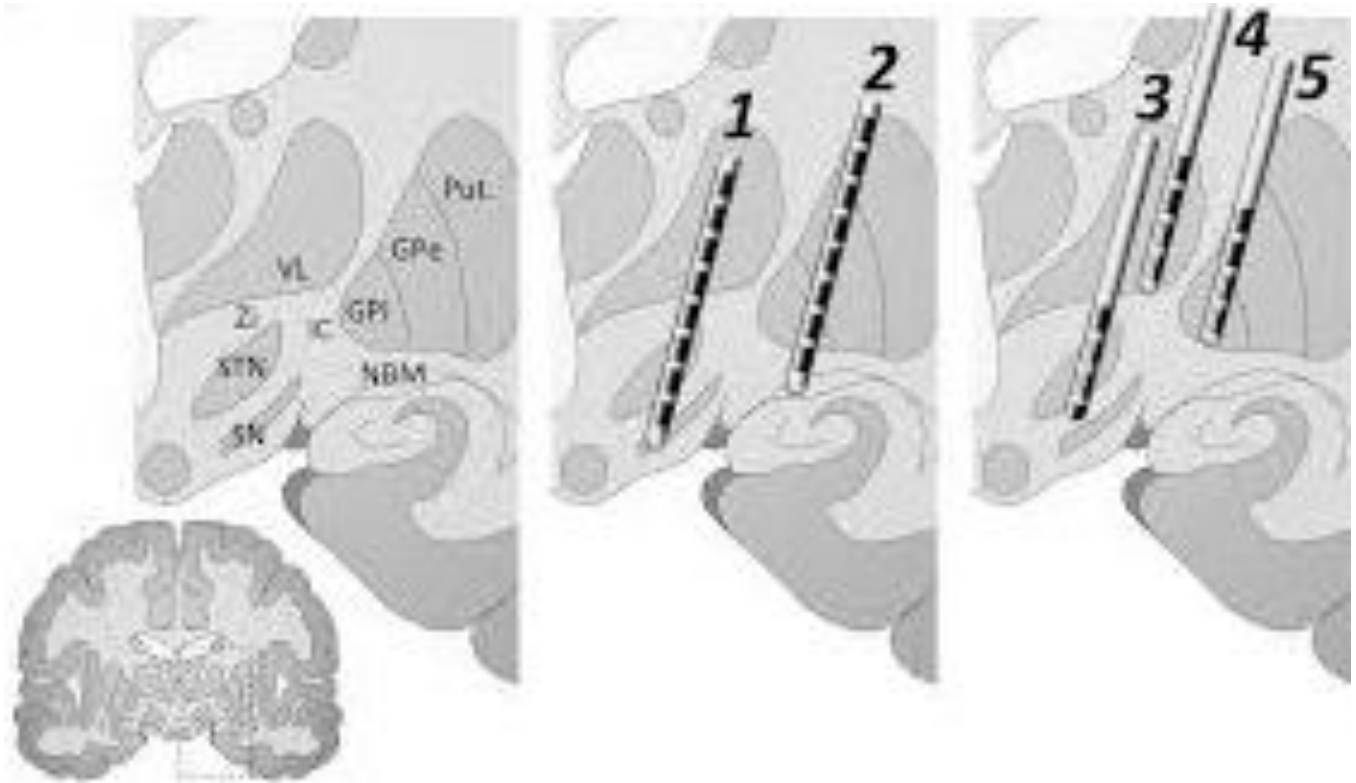


Vascular claudication

Deep brain stimulation

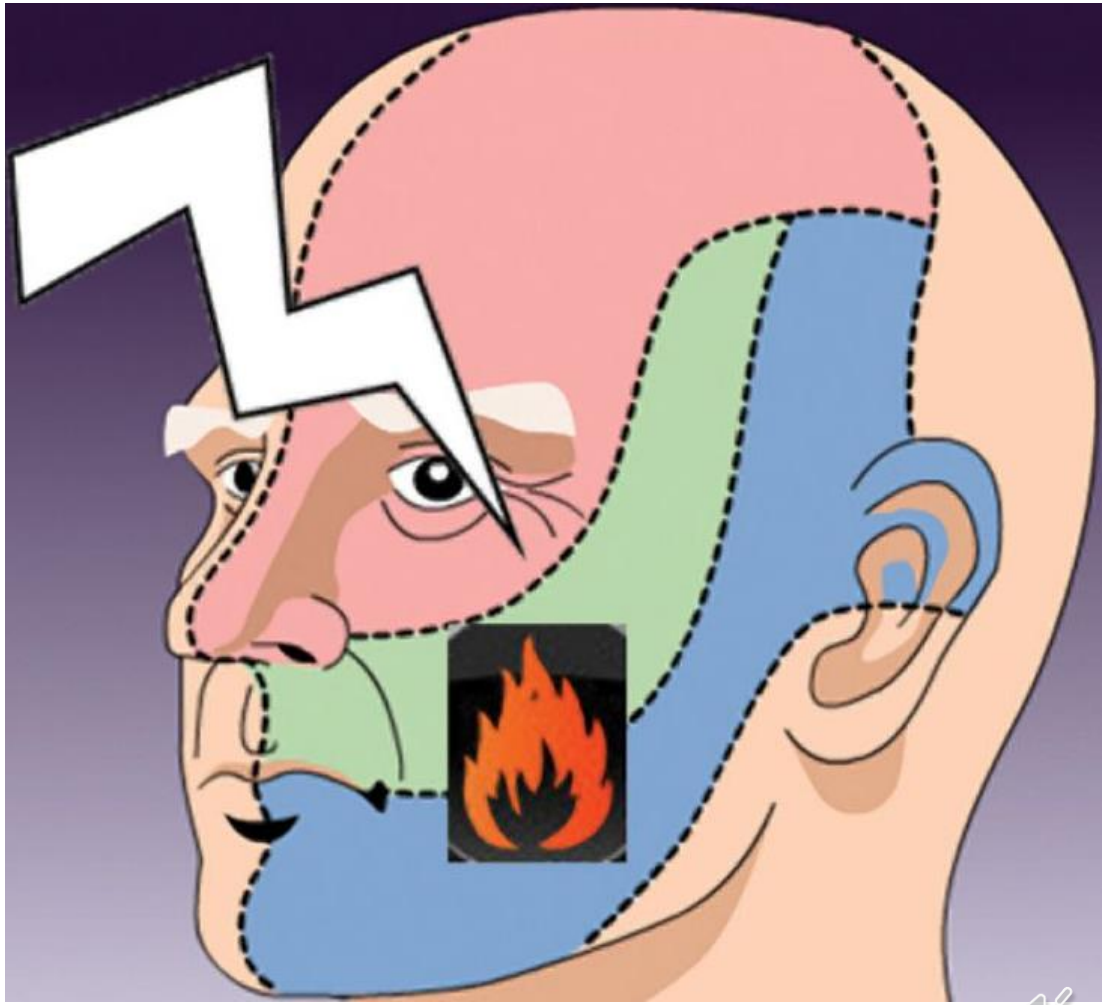
- Stimulation of **deep brain or brainstem structures**
- Technically difficult and risky = rarely used





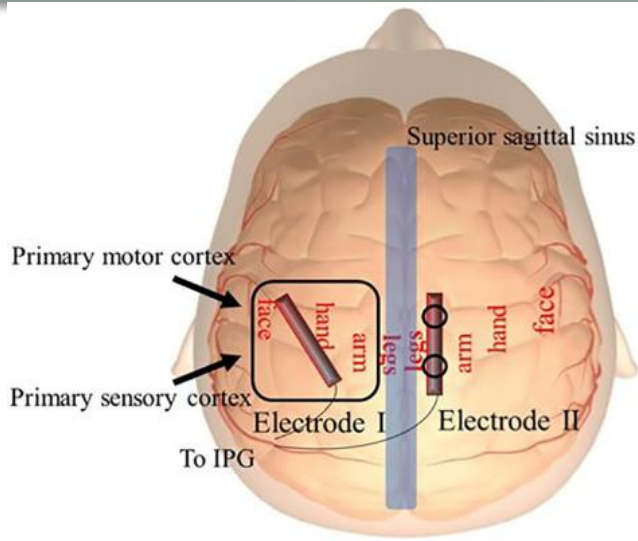
Deep brain stimulation: indications

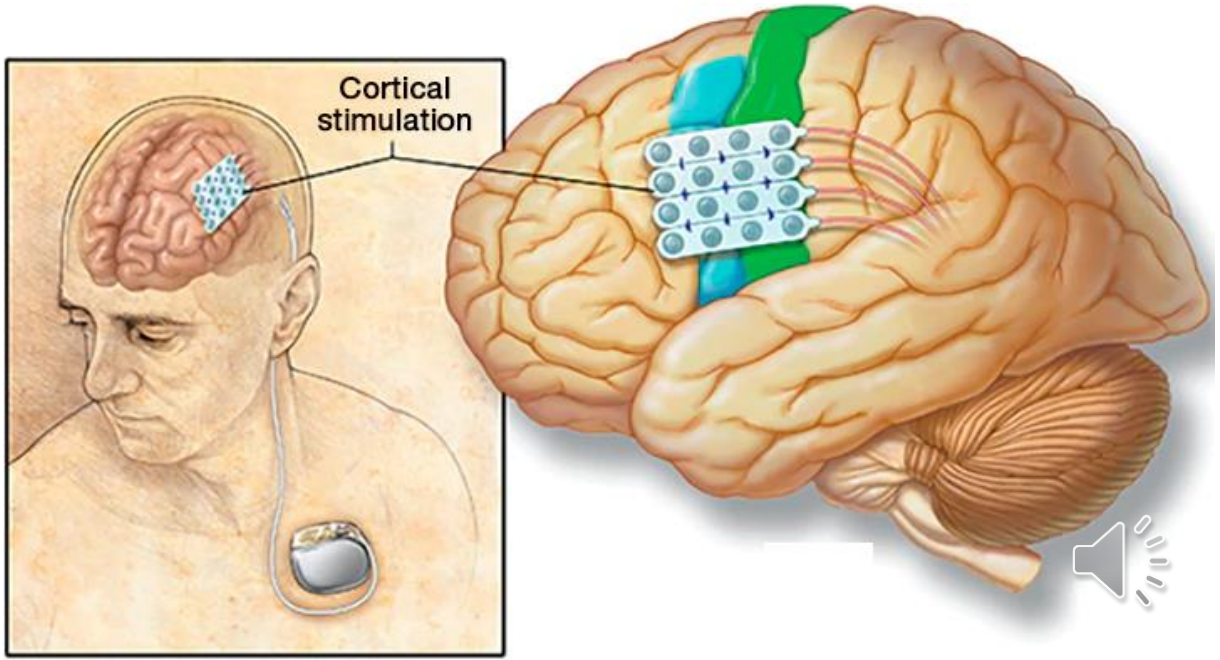
- Indications
  - **Deafferentation pain** (stimulation of thalamus nuclei, somatosensory subcortical areas, or posterior arm internal capsule)
    - Failed back syndrome, neuropathic pain after central or peripheral nervous system injury, trigeminal pain
  - **Pain due to excess nociception** (periaqueductal and periventricular grey matter stimulation)



Motor cortex stimulation

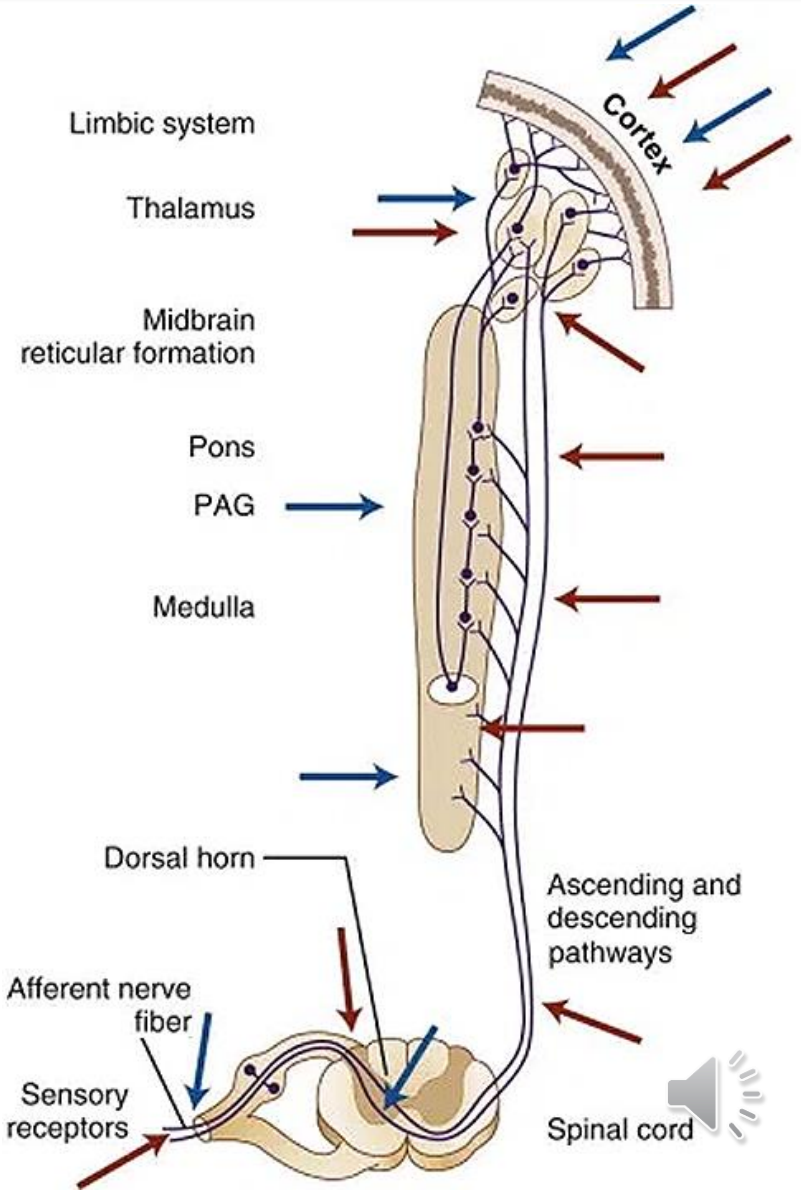
- Electrode placed **at the level of the motor cortex** in the subdural space
- **Indications**
  - **Facial neuralgia**
  - **Thalamic pain**
  - Nerve injuries
  - Brachial plexus injuries
  - Phantom limb pain





Pain surgery: ablative techniques

- **On peripheral nerves**
  - Sympathectomy
  - Neurectomy
  - Dorsal rhizotomy and ganglionectomy
  - **Radiofrequency**
    - Thermal
    - Pulsed
- **On the spinal cord**
  - **DREZ** lesion (dorsal root entry zone)
  - **Cordotomy** and myelotomy

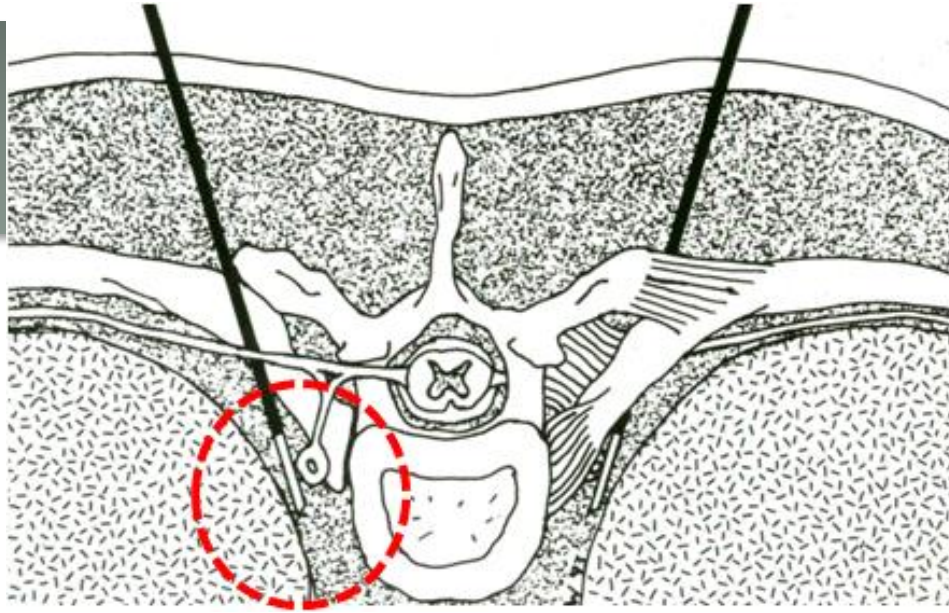


Ablative techniques on peripheral nerves

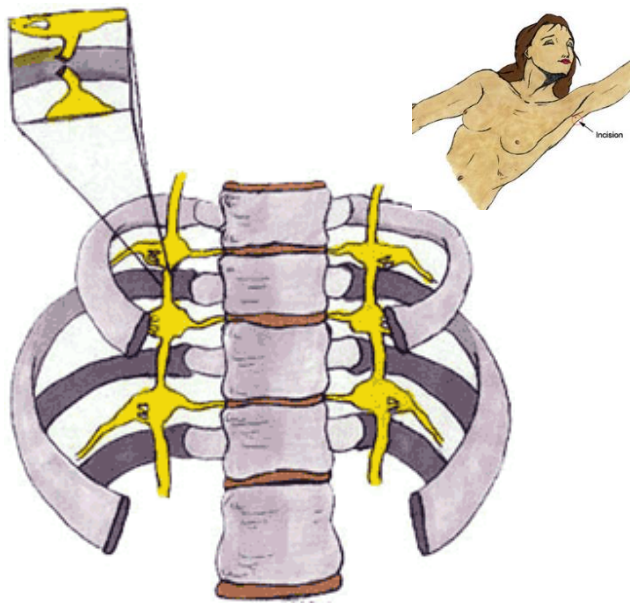
- **Sympathectomy**
  - Indication: **visceral pain** associated with cancer or vasospastic disorders
- **Neurectomy**
  - Indication: pain after a peripheral nerve injury (e. g. limb amputation)
- **Dorsal rhizotomy** and ganglionectomy
  - Indication: trunk or abdomen cancer pain
- **Radiofrequency**
  - Types
    - **Thermal**: irreversible nerve lesion
    - **Pulsed**: modulates nerve transmission without nerve damage
  - Those that transmit the sensation from certain structures, especially joints, are used for sensory nerve lesion
    - Indications: **low back, cervical, hip, and knee chronic pain**

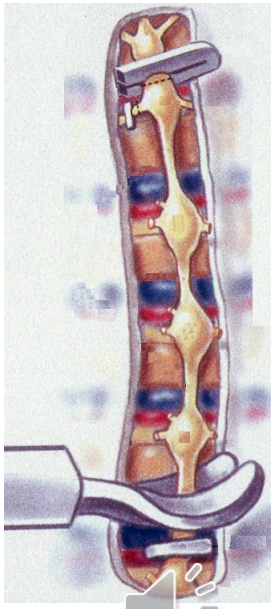
Sympathectomy

- Sympathetic chain block
- **Indications**
  - **Reflex sympathetic dystrophy**
  - ***Angor pectoris***
  - **Lower limb vascular disorders**
  - **Visceral cancer pain**
- Sympathetic chain interruption techniques
  - Ethyl alcohol infiltration
  - Radiofrequency
  - Sympathetic chain surgical removal



Radiofrequency sympathectomy

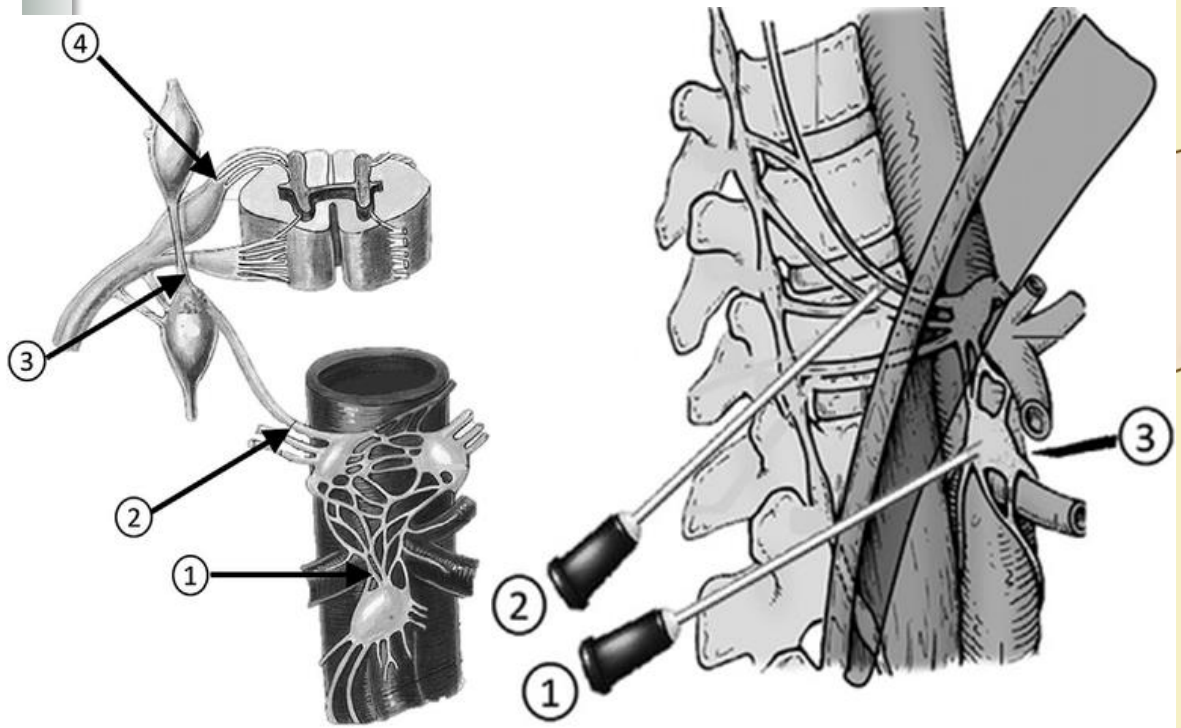


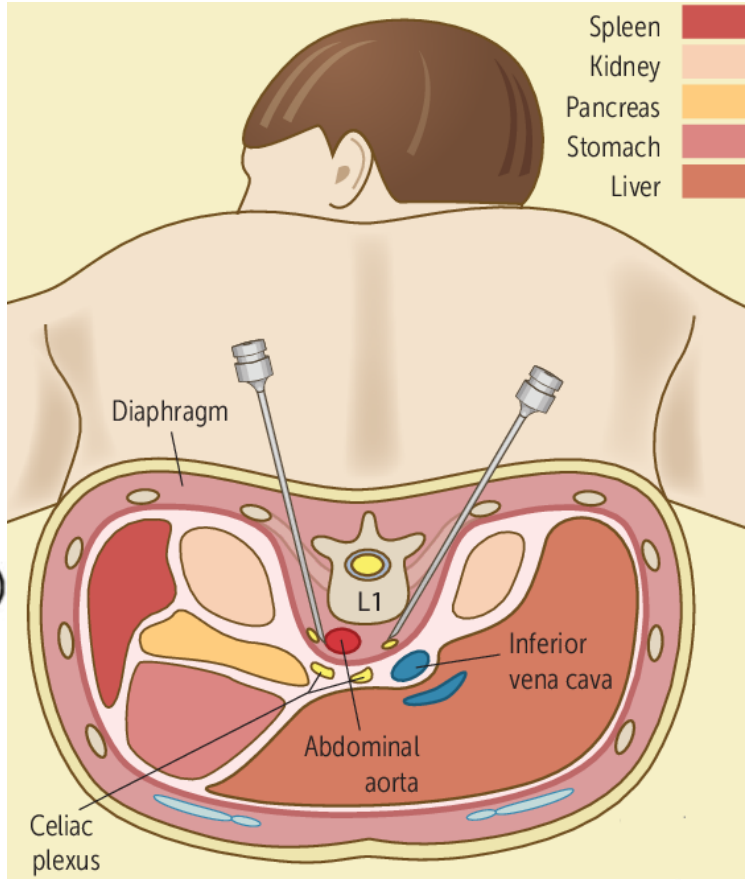


Endoscopic sympathectomy

Sympathectomy for visceral pain

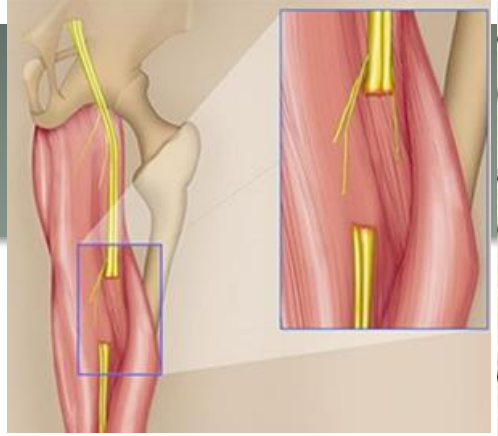
- Used for pancreatic cancer pain
- Infiltrating ethyl alcohol or phenol into the celiac ganglion

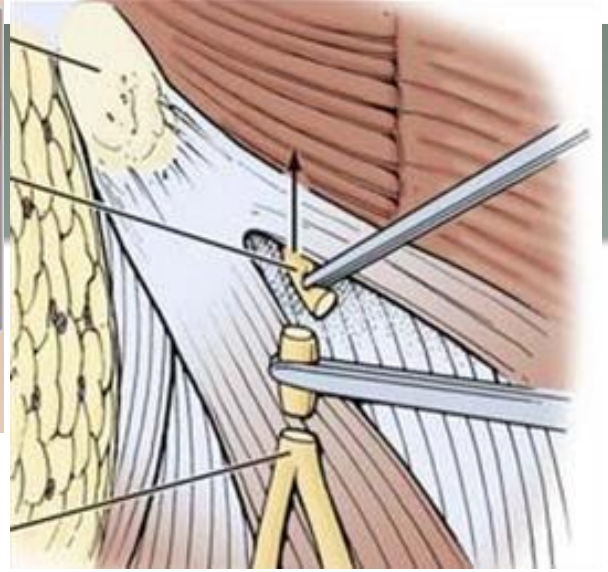




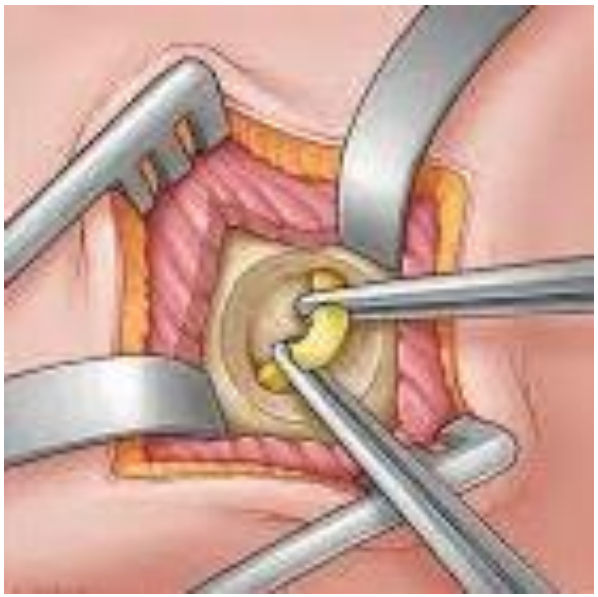
Neurectomy

- Nerve excision or avulsion
- **Disused** technique
- Indications
  - Meralgia paresthetica
  - Terminal branches fifth cranial nerve





Neurectomy femoral cutaneous nerve

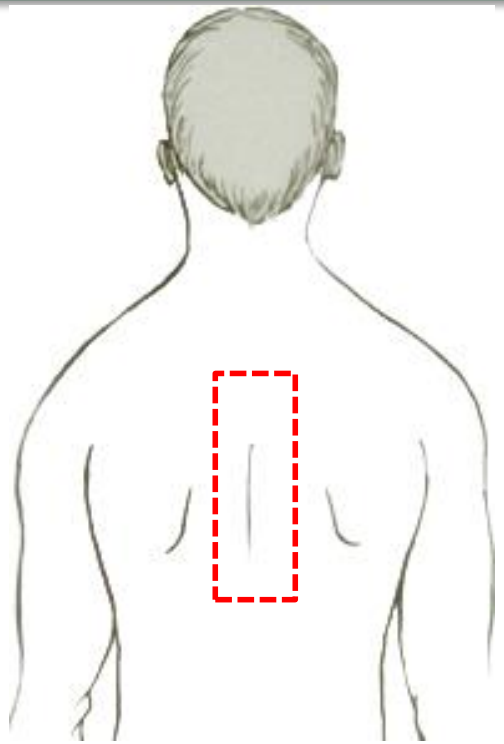


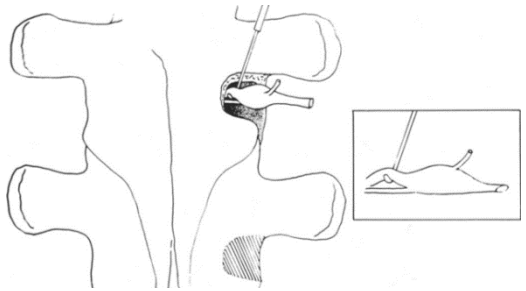
Trigeminal mandibular branch neurectomy

Neurectomy supraorbital nerve

Dorsal rhizotomy

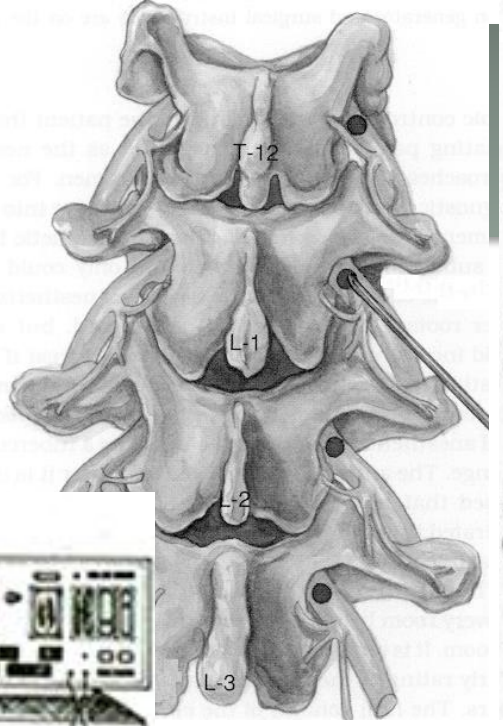
- **Section of spinal cord dorsal roots**
  - Section of three or more roots to achieve therapeutic effect
- Indications
  - **Intercostal cancer pain**

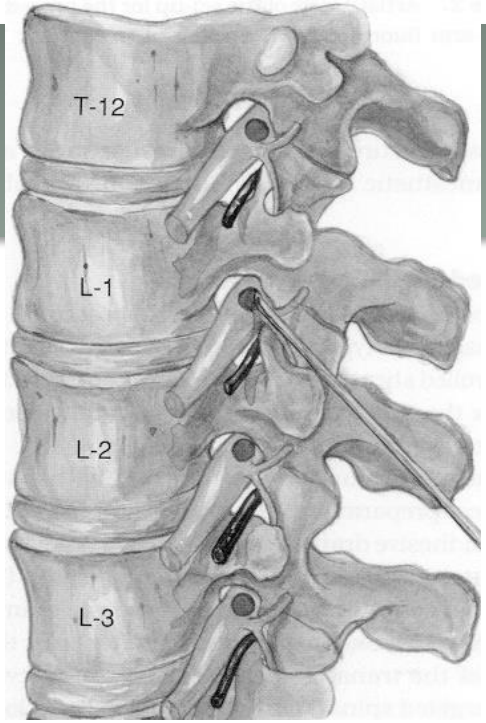


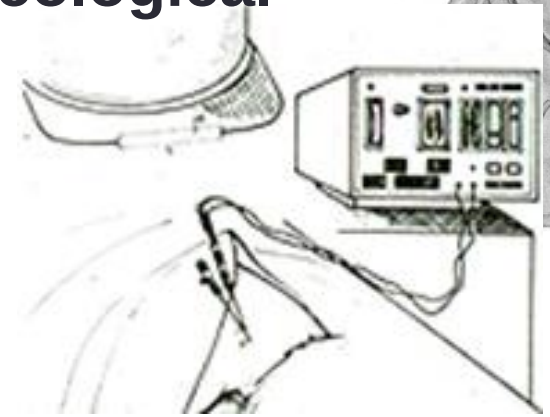


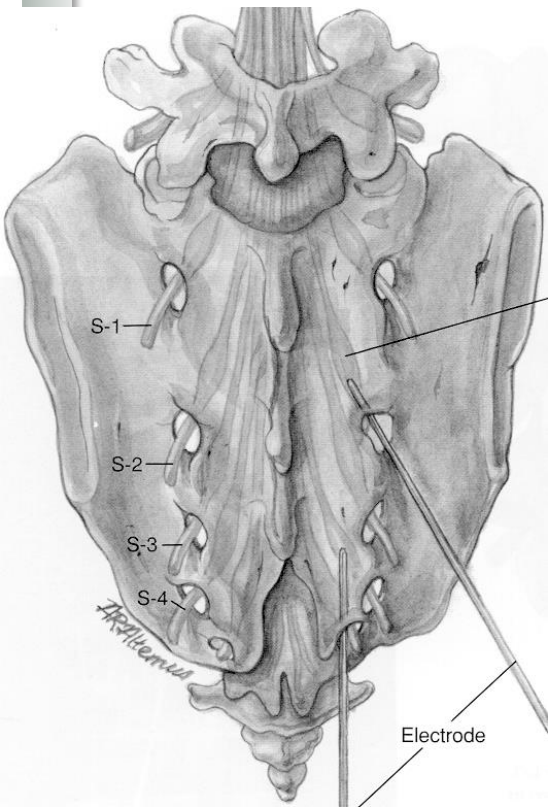
Gangliotomy

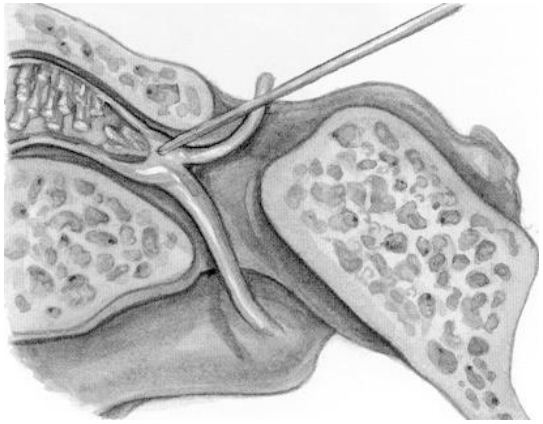
- Destruction of one or more spinal ganglia
- Indications: **oncological pain**

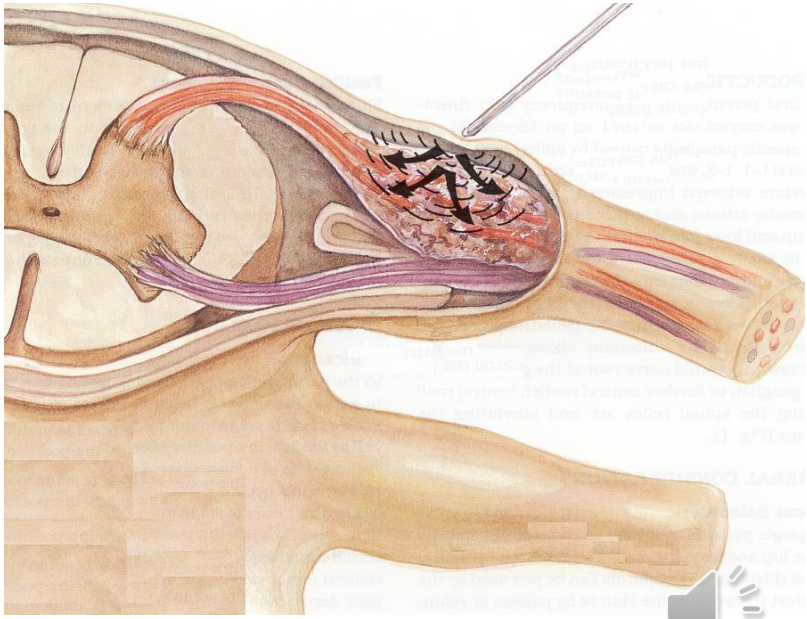








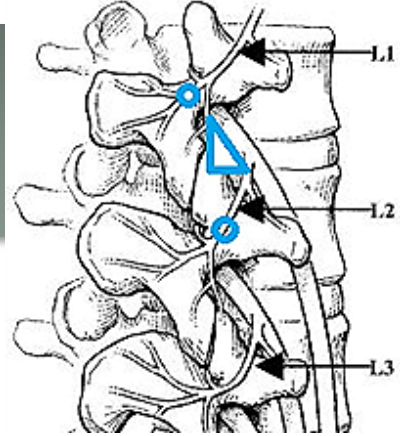


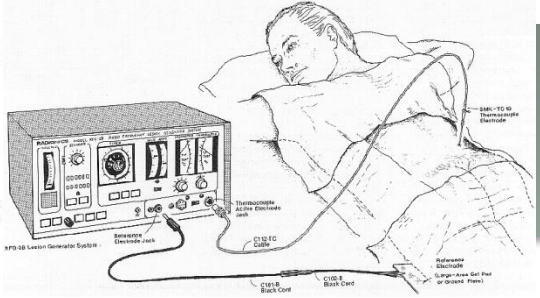


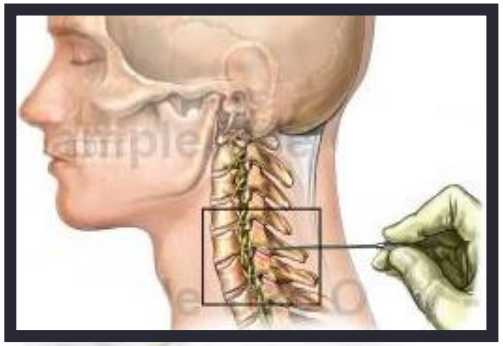
Radiofrequency gangliotomy

Radiofrequency lumbar / cervical rhizotomy

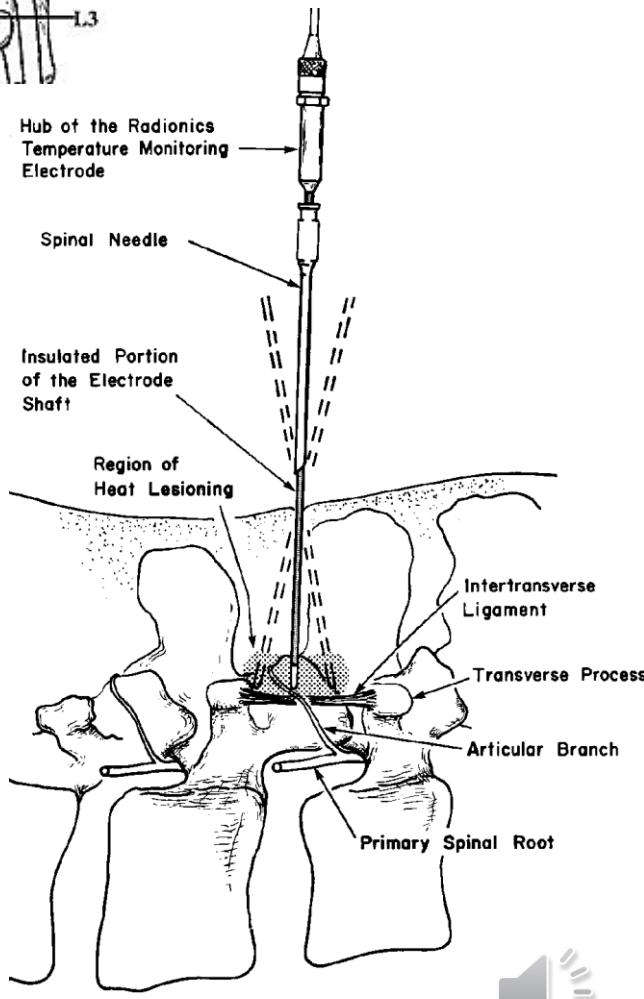
- Thermal radiofrequency lesion of the posterior spinal nerve branches
- Indication
  - **Chronic low back or cervical pain** of facet joint origin







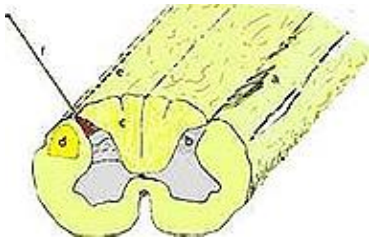
Cervical rhizotomy

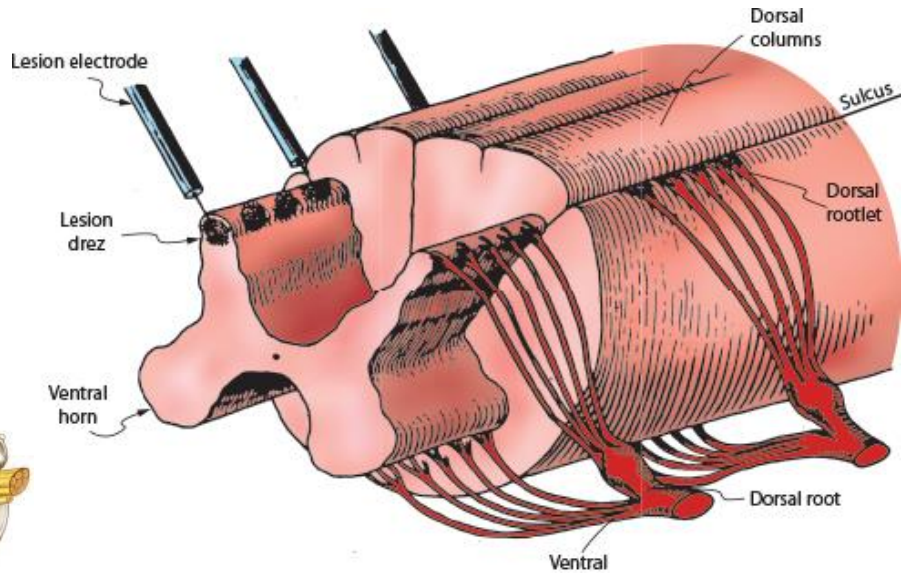


Lumbar rhizotomy

Spinal cord ablative techniques: DREZ lesion

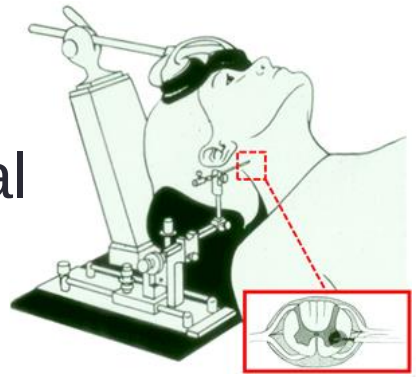
- Lesion to the posterior spinal cord dorsal root entry zone
- Indications: **brachial plexus avulsion, oncological pain**, phantom limb pain

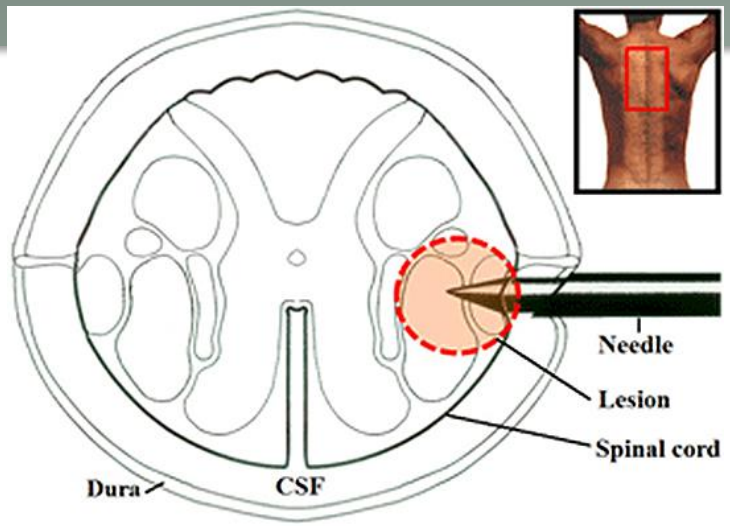




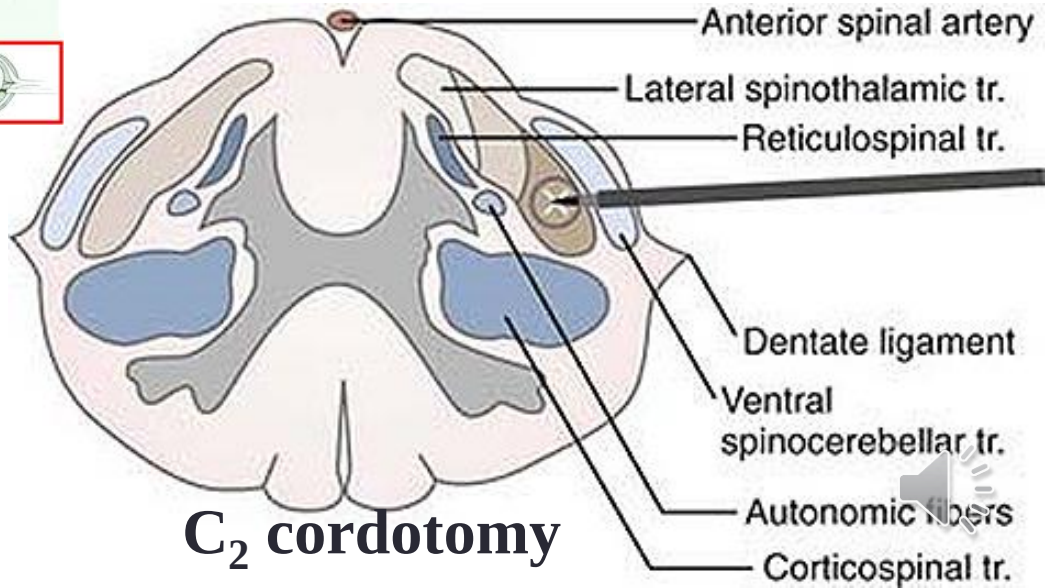
Spinal cord ablative techniques: cordotomy

- Spinothalamic tract lesion
  - Open or percutaneous
- Location: thoracic or cervical spinal cord (C_2)
- Indication: **cancer pain**





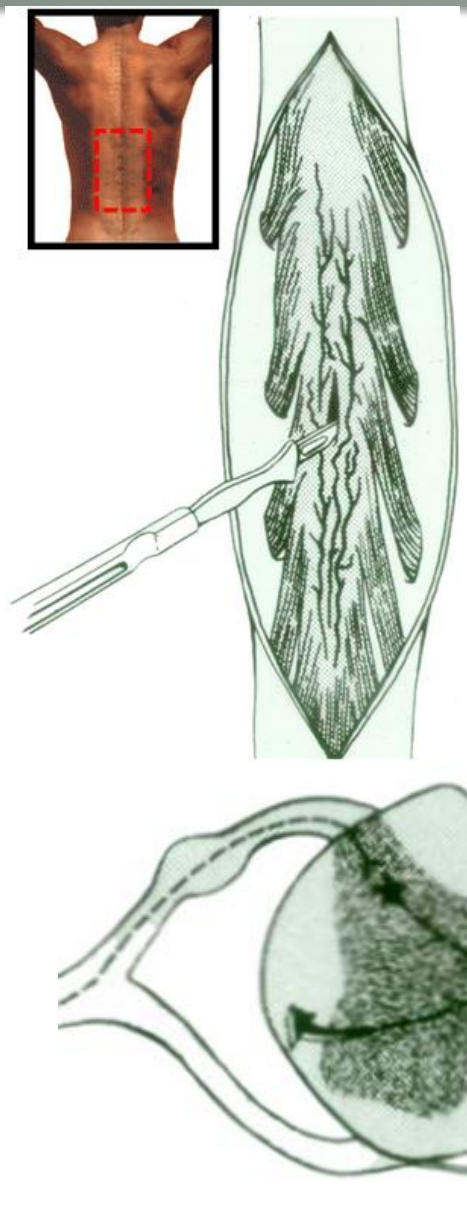
Thoracic cordotomy



C_2 cordotomy

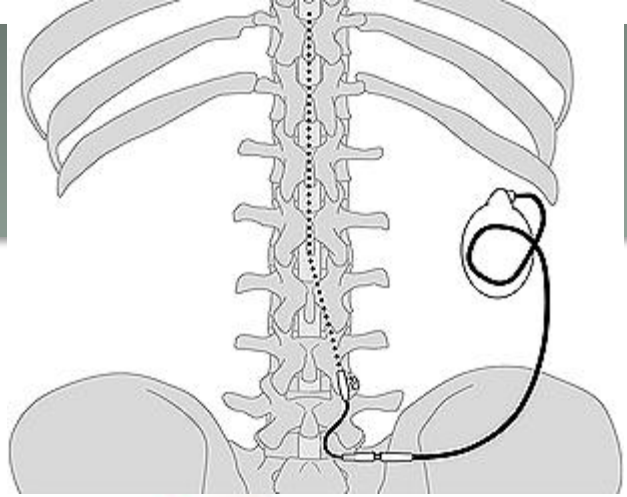
Longitudinal myelotomy

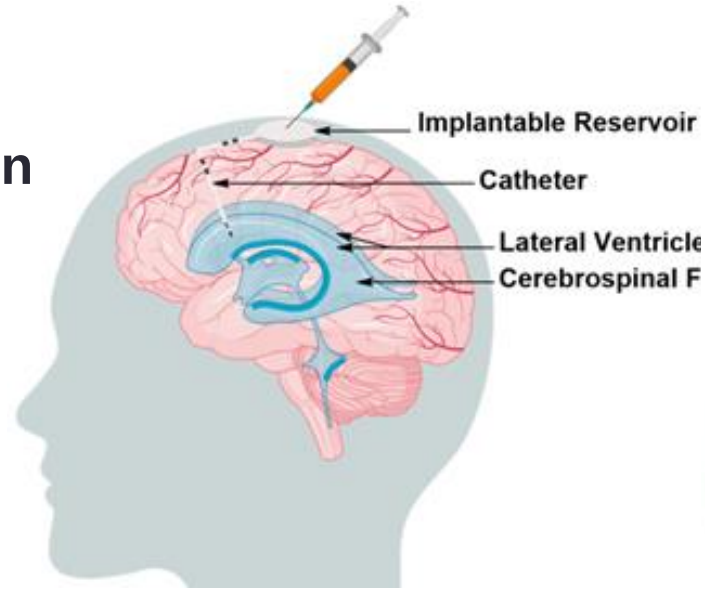
- Longitudinal incision midline spinal cord ⇨ bilateral section fibers thermoalgesic sensation
- Indications: **chest or abdomen midline cancer pain**
  - If it involves the conus medullaris there must be previous loss of sphincter control

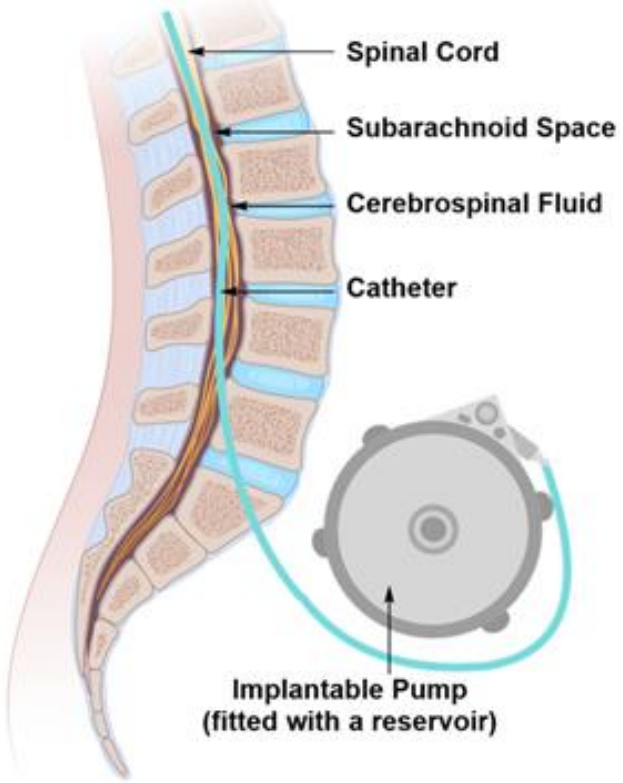


Pain surgery: drug delivery pumps

- **Drug administered at the intrathecal or intraventricular level**
- Indications
  - Especially for **nociceptive pain** (e. g. cancer)
  - Failed back syndrome

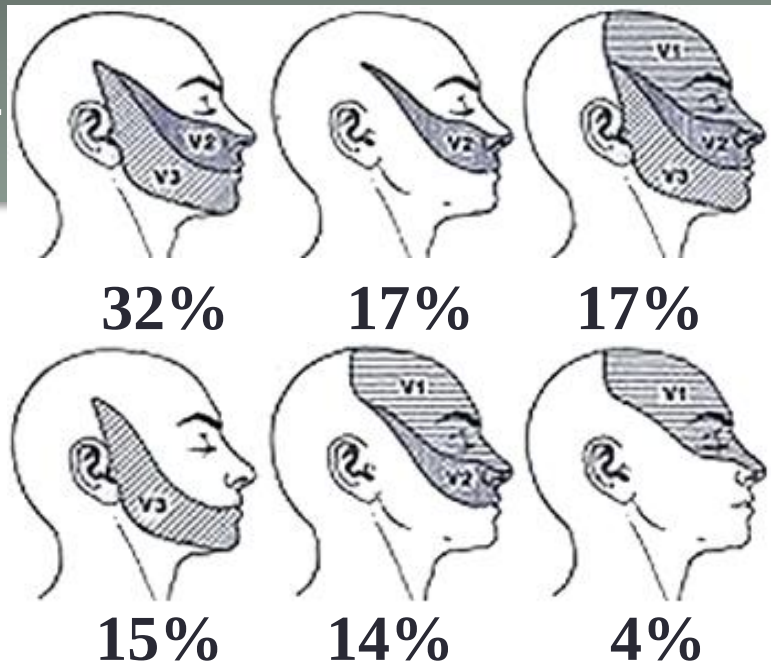






Intraventricular **Intrathecal**

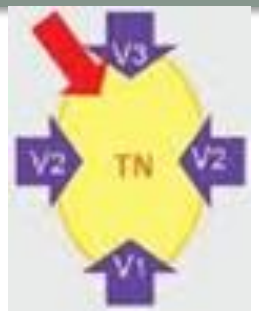
Trigeminal neuralgia

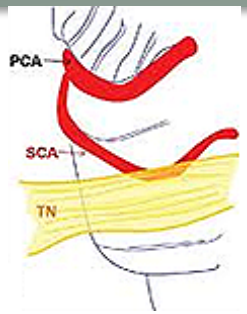


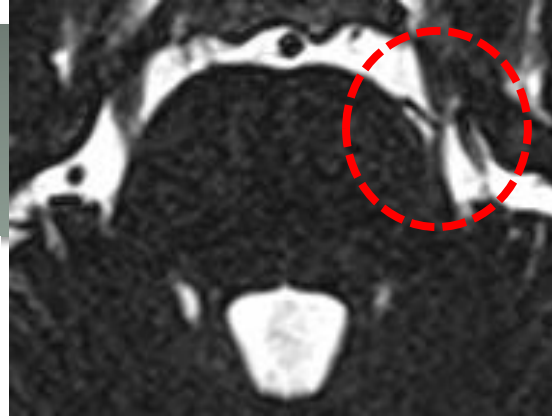
- **Painful syndrome of the face**
  - Usually unilateral
- Incidence 4/100,000 inhabitants/year
- Usually >50 years ♀/♂ 2/1
- Right side 60%
- It can affect one or more trigeminal branches
  - 2ª & 3ª more commonly affected (42%)
- **Neuropathic, episodic, and recurrent pain**
- Short duration and recurrent high intensity pain spells
  - Paroxysmal, lancinating, '**electric type shock'** pain
  - **Very severe pain** ⇨ sometimes suicidal ideation
  - Does NOT wake the patient up at night
  - May happen spontaneously or after sensory stimuli in '**trigger areas'**
    - Face rubbing, yawning, chewing, cleaning teeth, swallowing, talking,…
- **Types**: essential and secondary to different intracranial lesions (tumors, multiple sclerosis)
  - If there are neurological deficits or pain is continuous then likely to be secondary trigeminal neuralgia

Trigeminal neuralgia

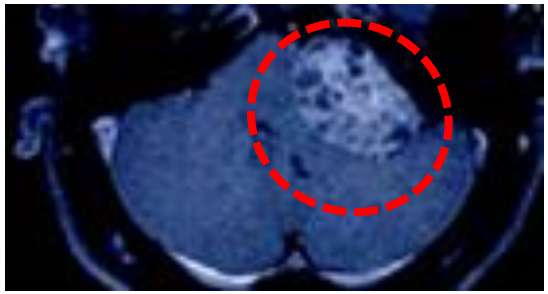
- **Types**
  - **Essential**
    - ⇑common
    - ♀ >50 years
    - Cause: vascular compression
  - **Secondary**
    - Inflammations, cerebellopontine angle tumors, infections, or demyelinating diseases (multiple sclerosis) that affect the nucleus fifth cranial nerve
- **Initial treatment: carbamazepine**
  - If ineffective there are other drugs
  - **If there is no response ⇨ surgical treatment**
    - Microvascular decompression
    - Percutaneous techniques (radiofrequency thermocoagulation, glycerol rhizolysis, Fogarty balloon compression)
    - Radiosurgery



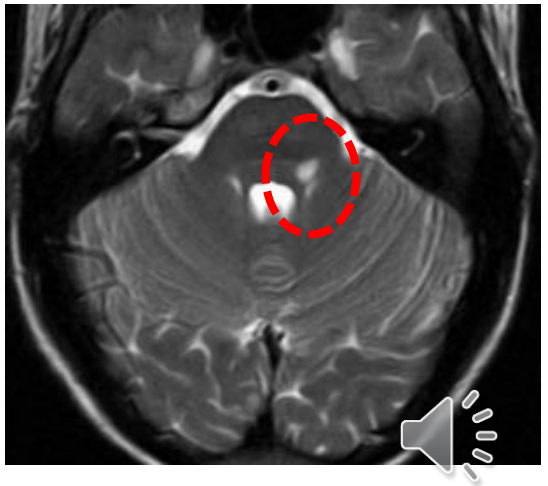




Vascular involvement



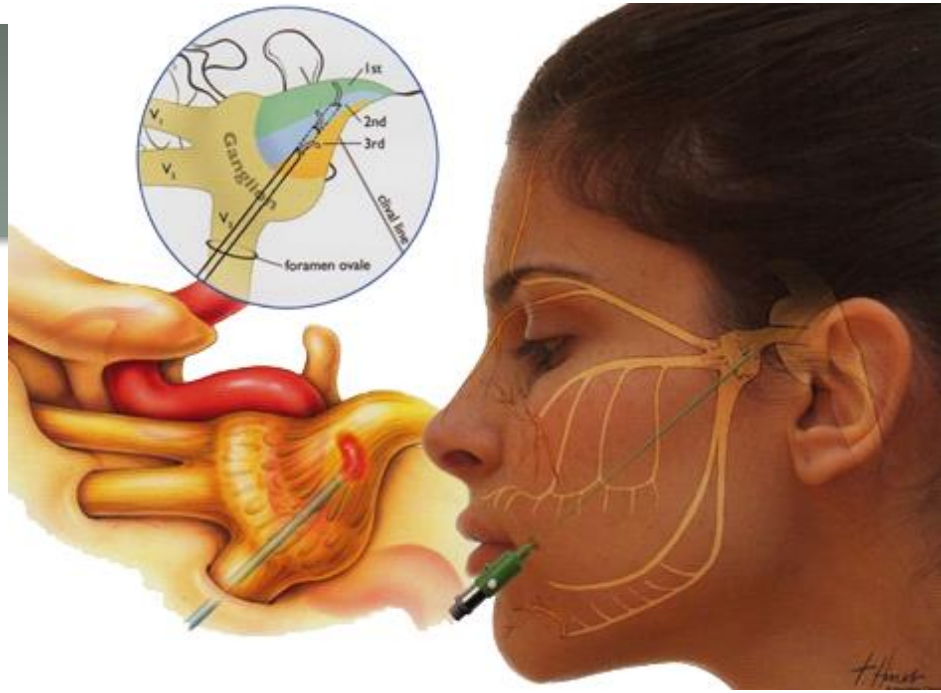
Cerebellopontine angle tumor



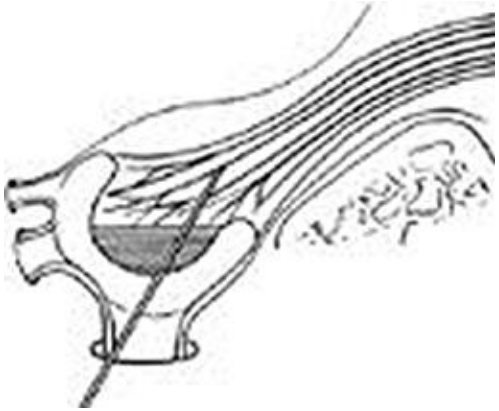
Multiple sclerosis plaque

Percutaneous procedures

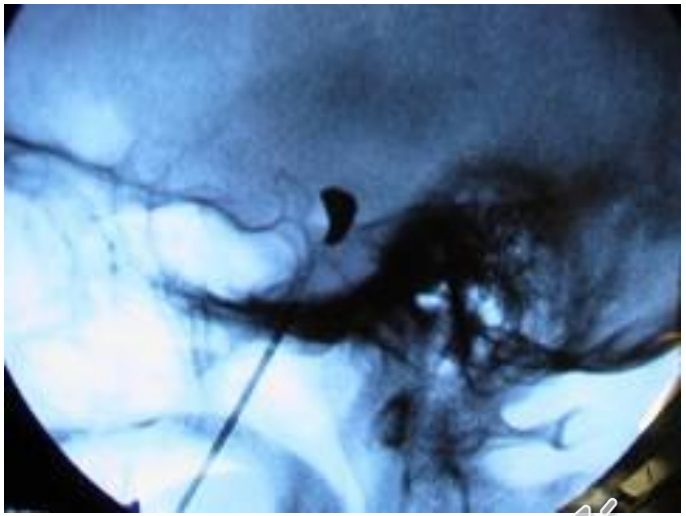
- Recommended in patients with ⇑anesthetic risk, if patient rejects craniotomy, unresectable intracranial tumors, multiple sclerosis, impaired hearing or life expectancy <5 years
- Options: radiofrequency, glycerol, percutaneous balloon compression (Mullan technique)
- Pain relief >90% but relapses in 2-5 years



Radiofrequency thermocoagulation



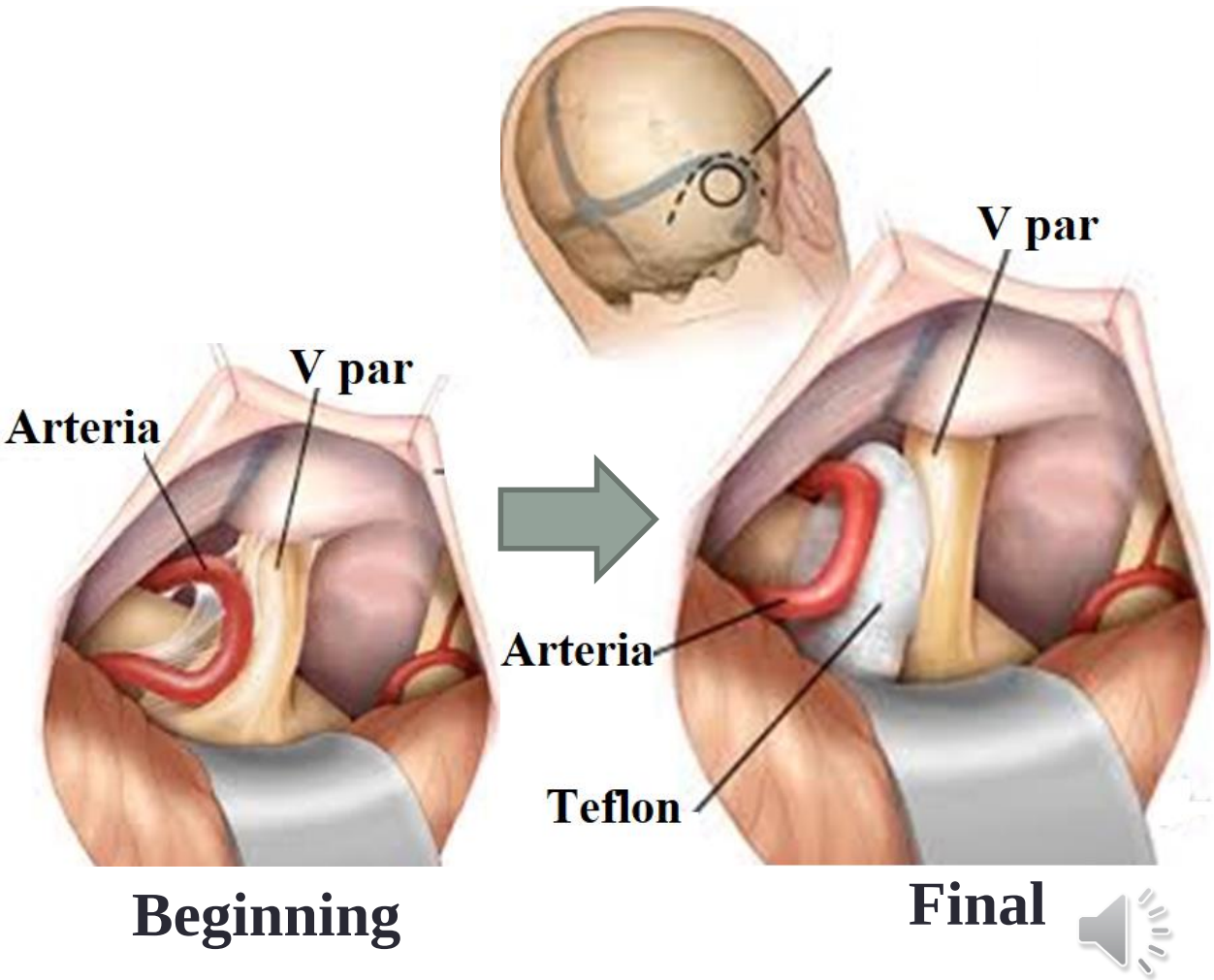
Glycerol



Percutaneous compression

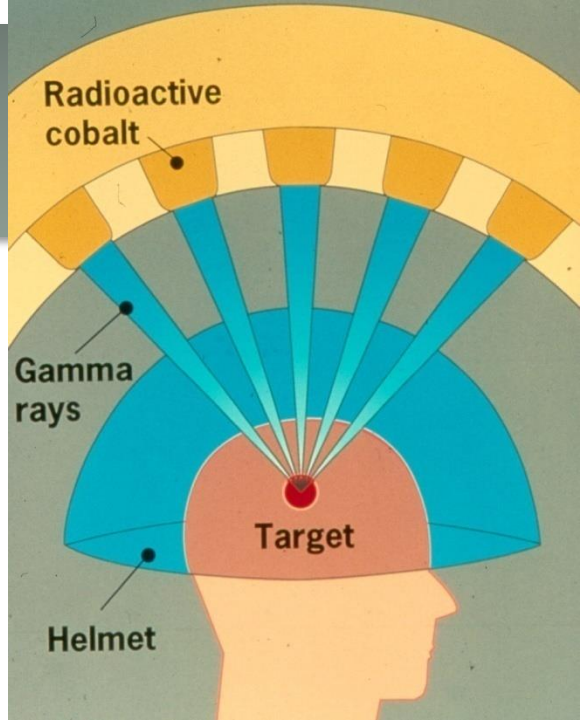
Posterior fossa trigeminal nerve microvascular decompression

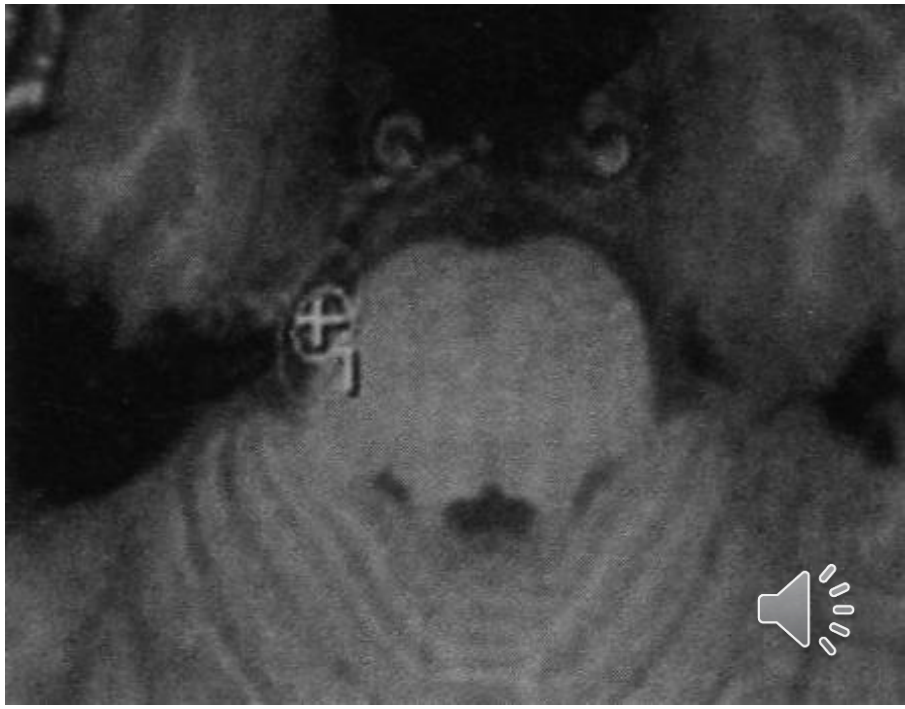
- Pain refractory to medical treatment, **life expectancy >5 years and patient able to withstand a craniotomy**
- **Long-lasting pain control** (70% patients >10 years)
- ⇓incidence of facial anesthesia
- Mortality ⇓1%



Radiosurgery

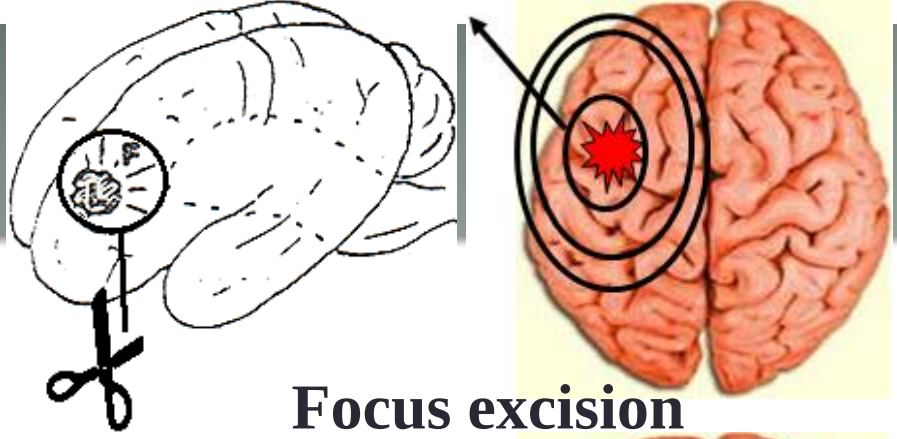
- ⇓invasive procedure
- Reserved for ⇑**risk** patients
- Results
  - Significant pain reduction in only 60% of cases
  - Pain relief needs three months to take place
  - Facial hypoesthesia in 20% patients
  - **Frequent relapses**
    - 32% patients with initial pain control need to repeat treatment



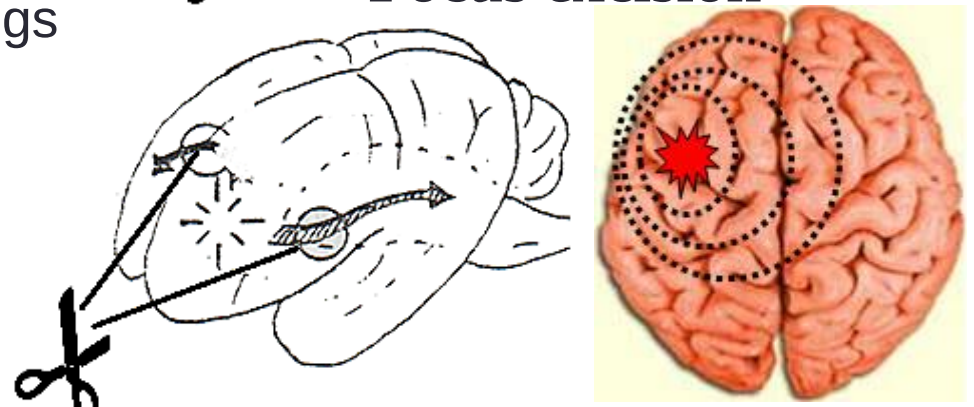


Epilepsy surgery

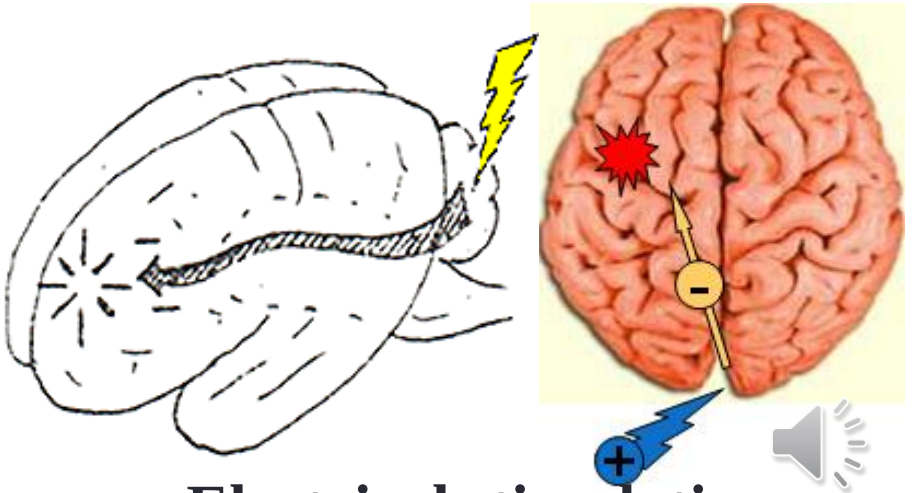
- **Requirements**
  - ≥1 crisis/month
  - No response to antiepileptic drugs
  - Intolerance to antiepileptics
- **Indications**
  - Poor epileptic seizure control
  - Possible removal of epilepsy-causing lesion
    - E. g.: cavernoma
- **Options**
  - Focus surgical excision
  - Disconnection spreading pathways
  - Epileptic activity inhibition by electrical stimulation



Focus excision



Disconnection spreading pathways



Electrical stimulation

1st step: hospital admission, medication withdrawal, and continuous EEG recording to localize epileptic focus

Epilepsy refractory to antiepileptic medication: indications for surgical techniques

- **Epilepsy with known epileptic focus and/or epileptogenic lesion**
  - Technique: focus and lesion removal (cavernoma, cortical dysplasia, etc.)
- **Temporal lobe epilepsy**
  - **Temporal lobectomy**
- **Epilepsy due to diffuse hemispheric disease**
  - Indicated only if only one hemisphere is affected and the other is healthy (e.g., Rasmussen encephalitis)
  - Technique: functional hemispherectomy ± callosotomy
- **Drop attacks**
  - Technique: callosotomy
- **Epilepsy with no known or non-removable focus**
  - Techniques: multiple subpial transections, vagal nerve stimulator

Refractory epilepsy: surgical techniques

Amígdalo-
Hipocampec-
tomía selectiva

Resección del
Lóbulo
Temporal

Topectomía

Hemisferectom
Funcional

Lobectomia
aislada

Multi-
lobectomia

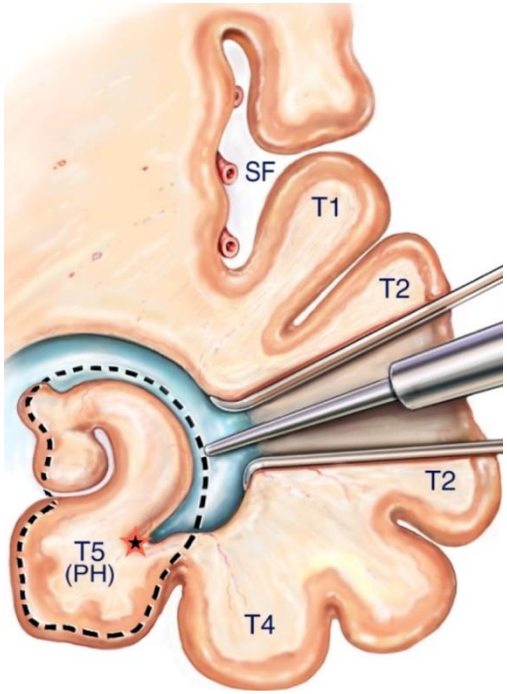
Transecciones
Subpiales
Múltiples

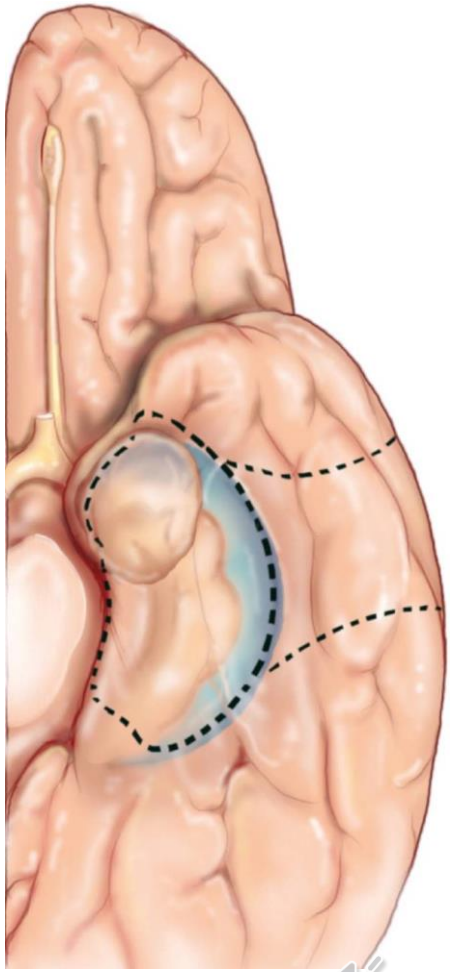
Transecciones
adicionales

Callosotomia
(2/3 - total)

Temporal lobe epilepsy surgical treatment

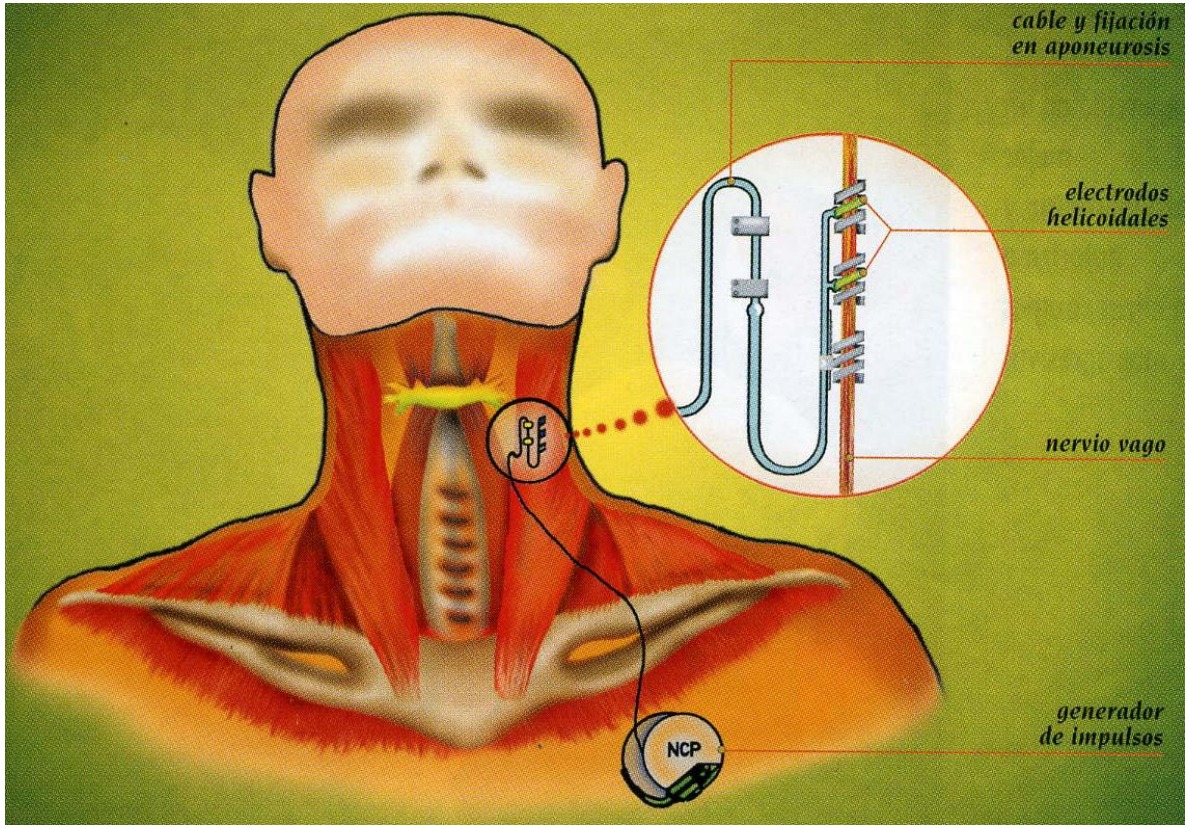
- Represents 55-90% epilepsies refractory to medical treatment
- ⇑⇑⇑**response to surgical treatment**
- Cause: **mesial temporal lobe sclerosis**
  - Amygdala and hippocampus neuronal loss
- Surgical treatment: **removal temporal lobe mesial part**
  - Amygdala, hippocampus, gyrus parahippocampalis ± temporal pole





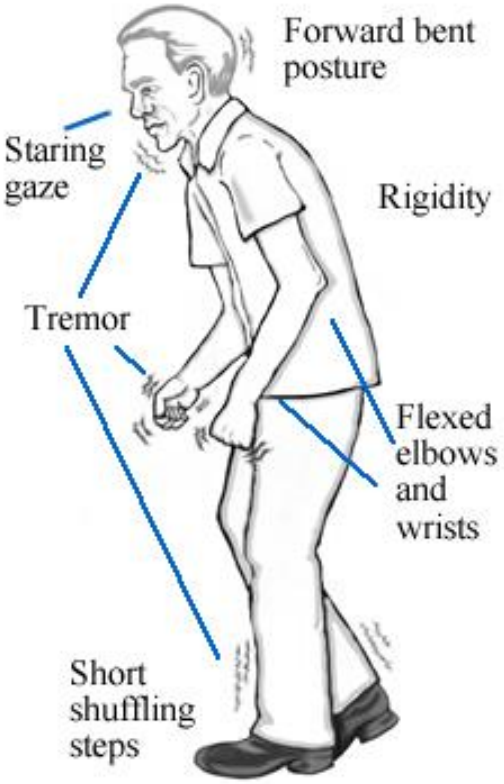
Vagal nerve stimulator

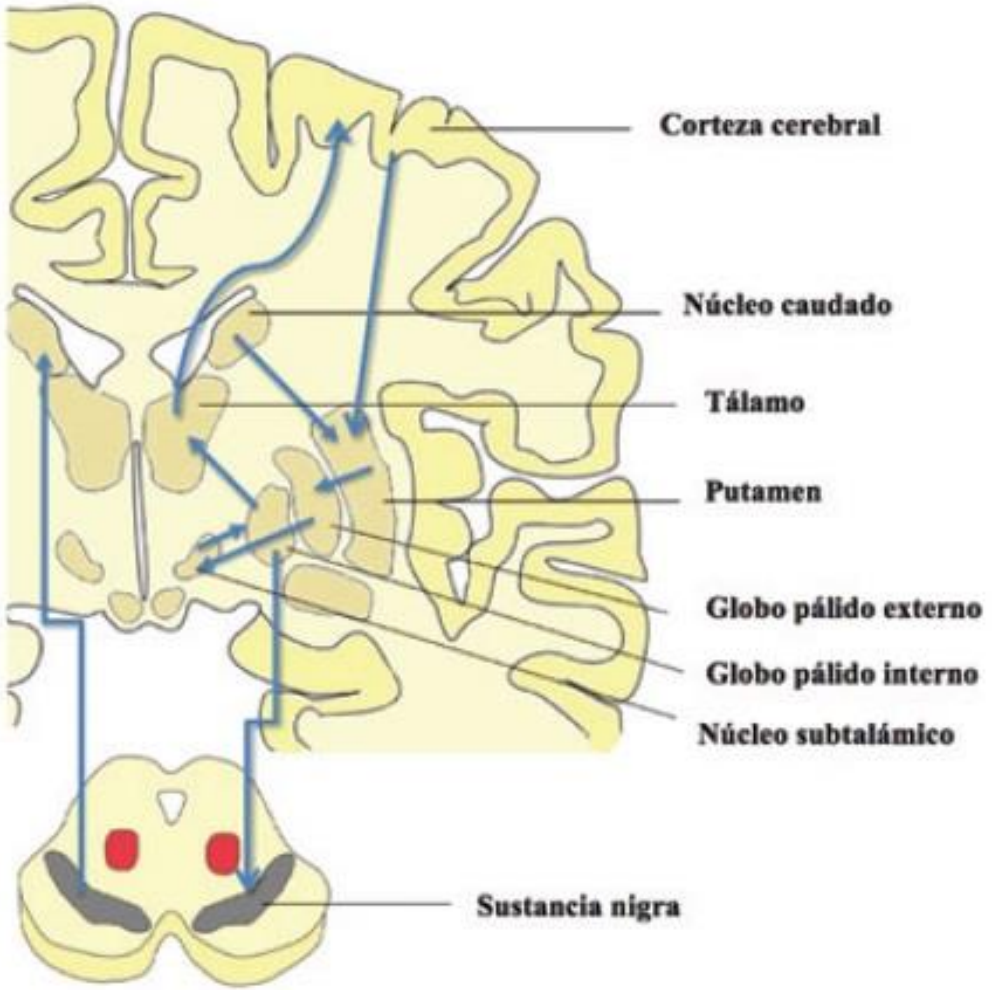
- Reduces epileptic seizure incidence, but does not make them disappear
- ⇓**surgically aggressive**
- **reversible**



Functional neurosurgery for movement disorders

- Parkinson's disease
- Dystonia
- Spasticity

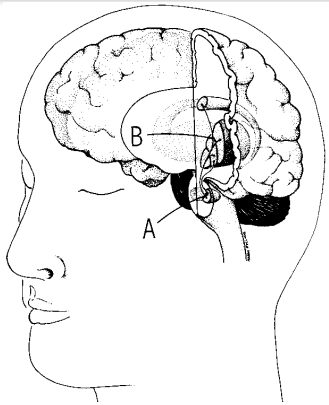


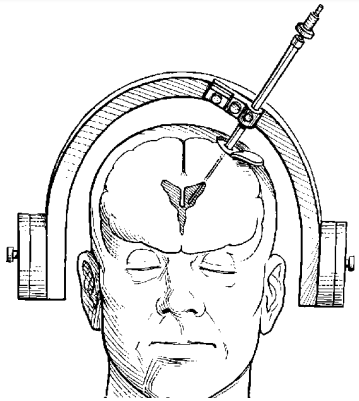


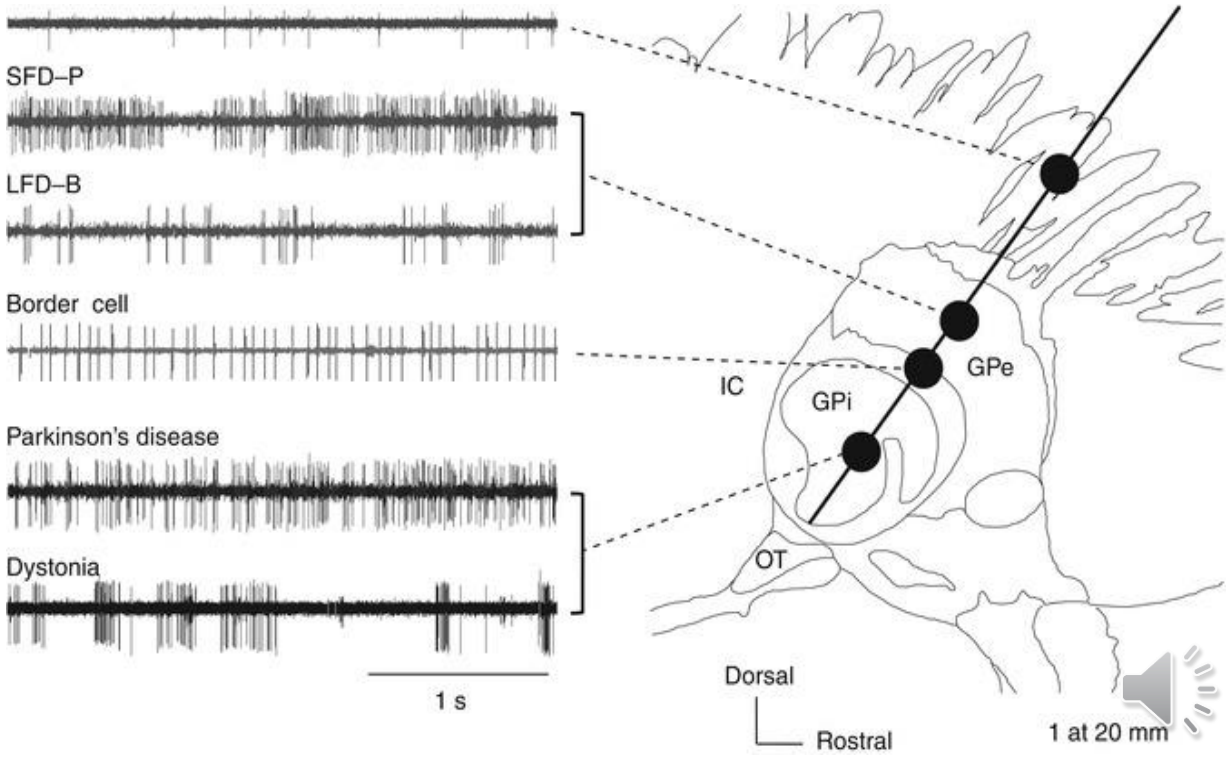
Circuits involved in movement control

Implantation of deep electrodes

- Target points <6mm ∅ = high precision required
- Intraoperative neurophysiological monitoring
- Risk of intracerebral hemorrhages
- Technical complexity = few cases/year

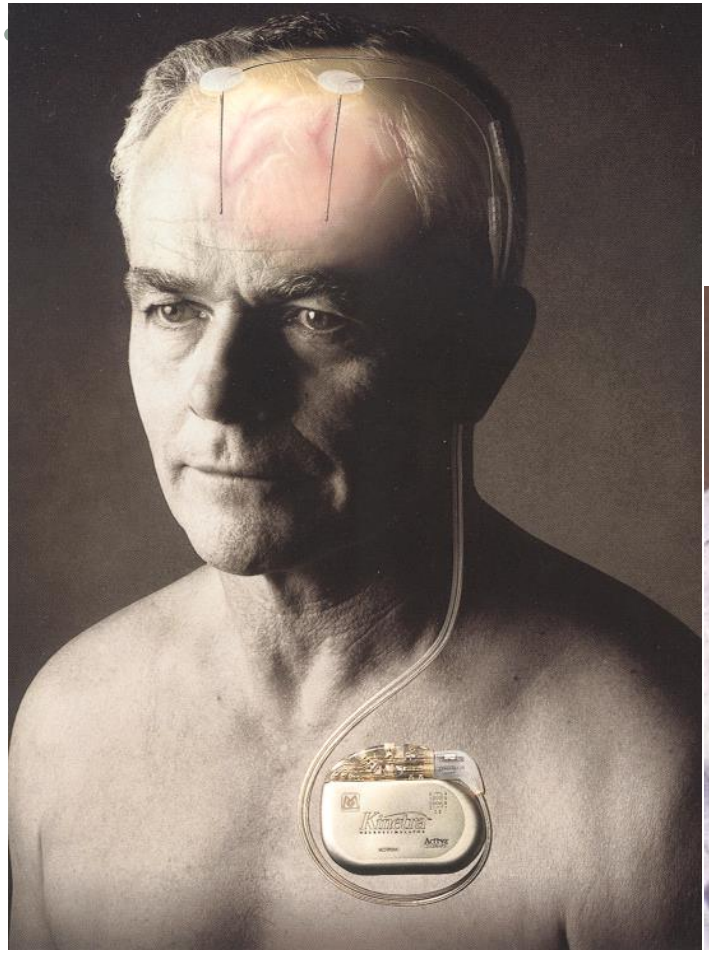


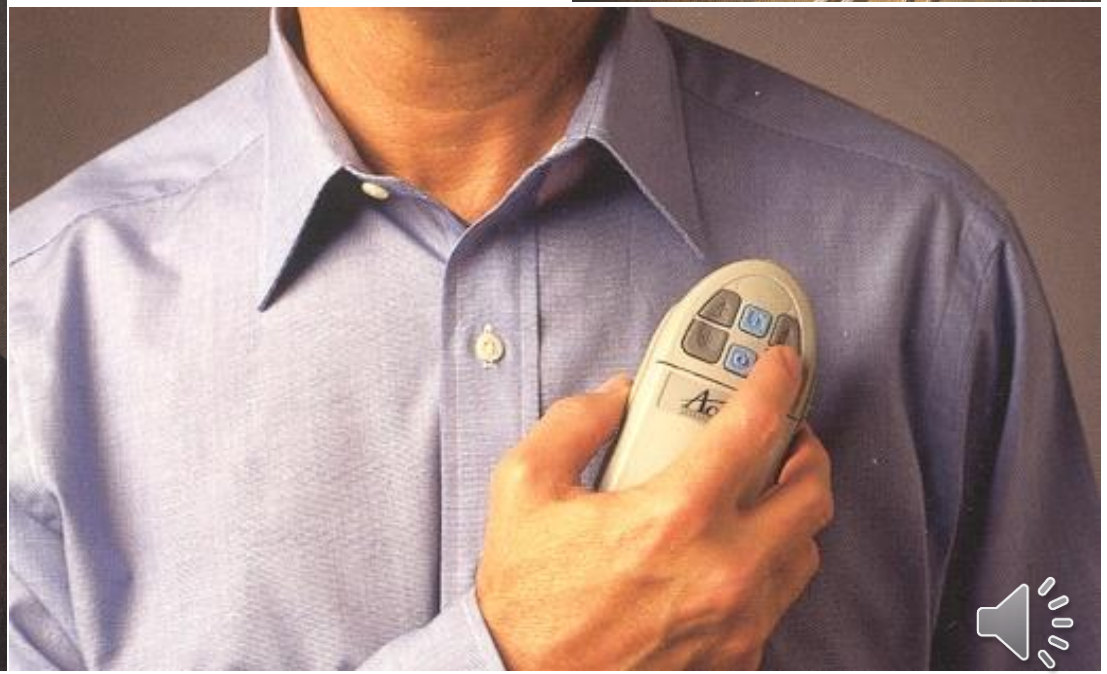




Deep brain stimulation

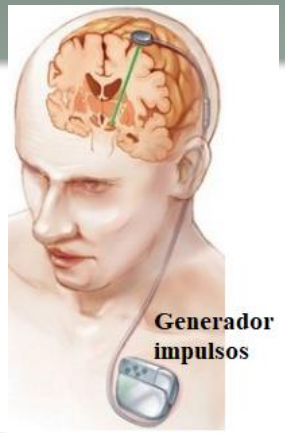
- Advantages: adjustable and controllable percutaneously

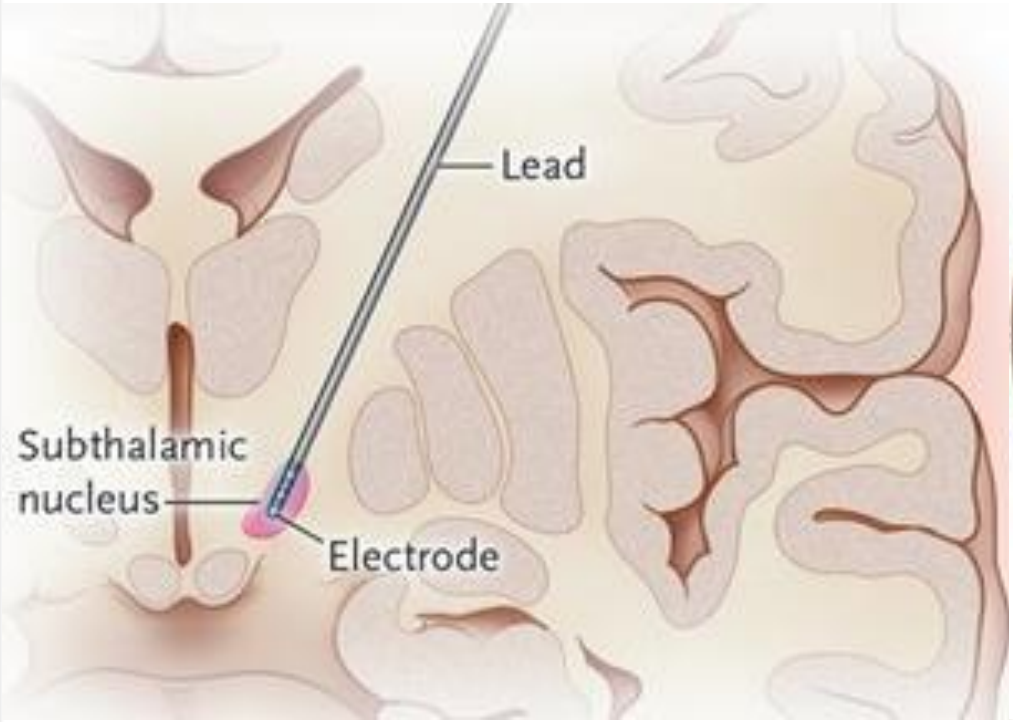


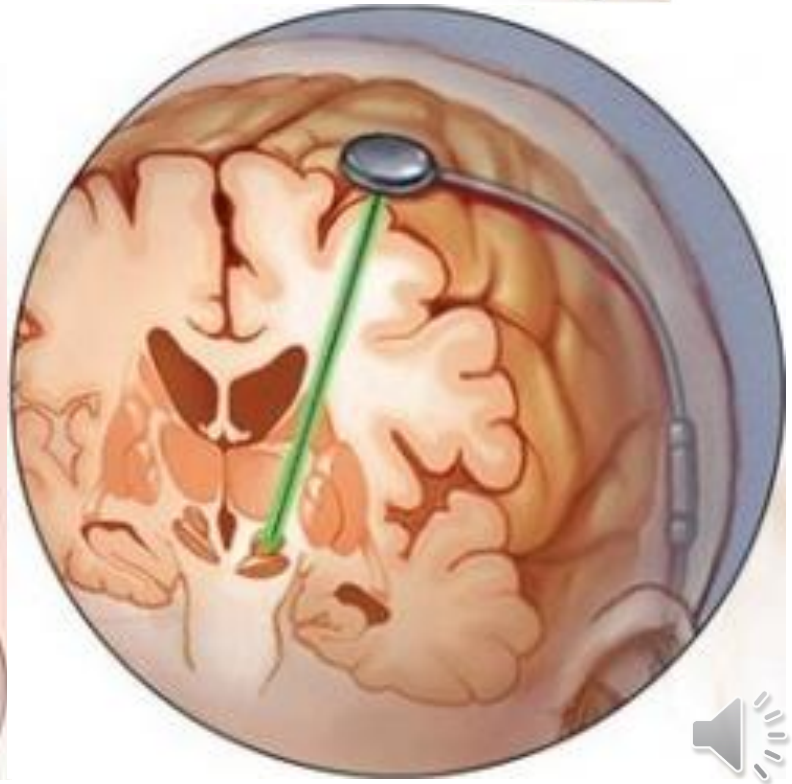


Functional neurosurgery for Parkinson's disease

- Indication: good response L-dopa, >5 evolution disease & NO cognitive impairment
- Technique: **subthalamic nucleus stimulation**

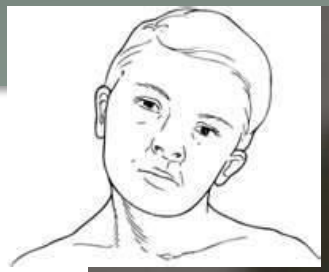


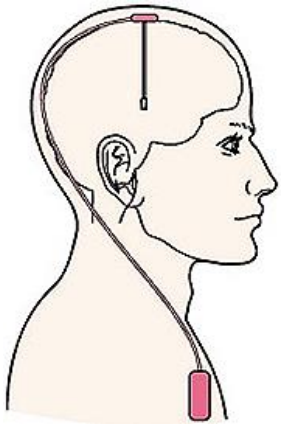


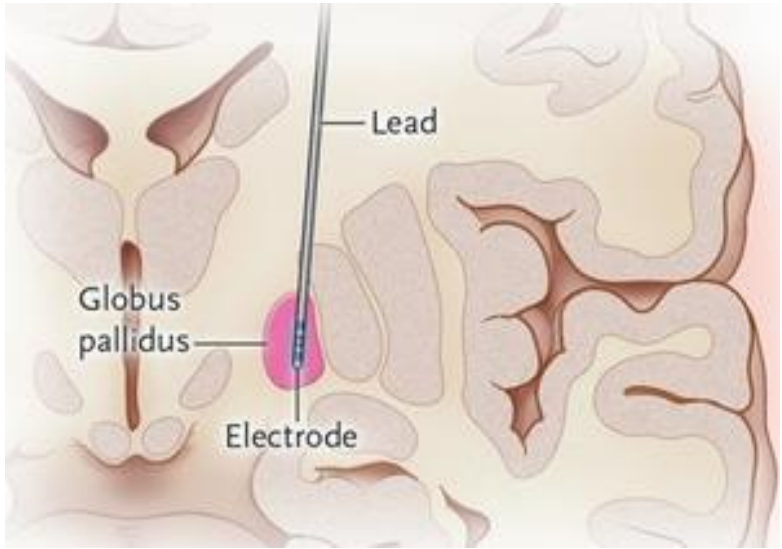


Dystonia

- Indication: severe pain or clinical symptoms refractory to medical treatment
- Technique: bilateral inner globus pallidus stimulation

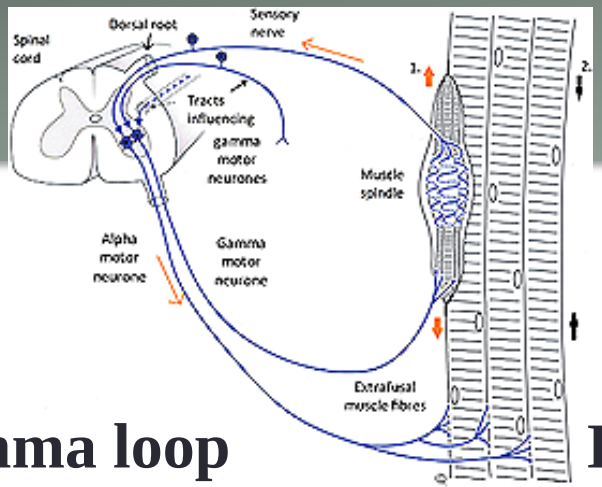




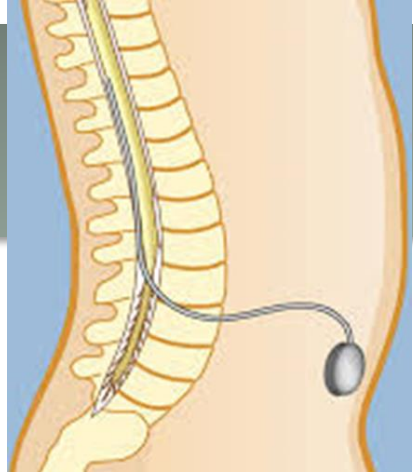


Spasticity

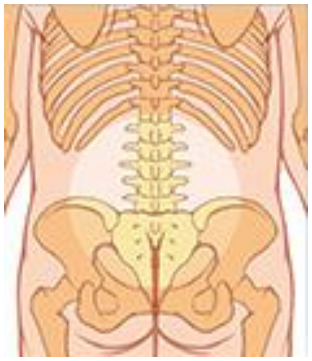
- Indication: spasticity refractory to medical treatment
- Techniques
  - Thecal sac **drug infusion pump** (baclofen)
  - **Selective posterior lumbar rhizotomy** (for spastic diplegia)
  - **Selective neurectomy** (section of some motor branches of the nerve/s causing painful muscle contractions)

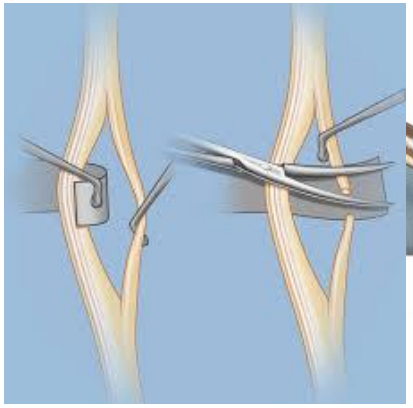


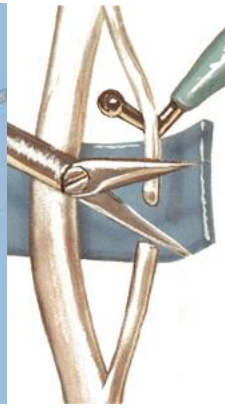
Gamma loop

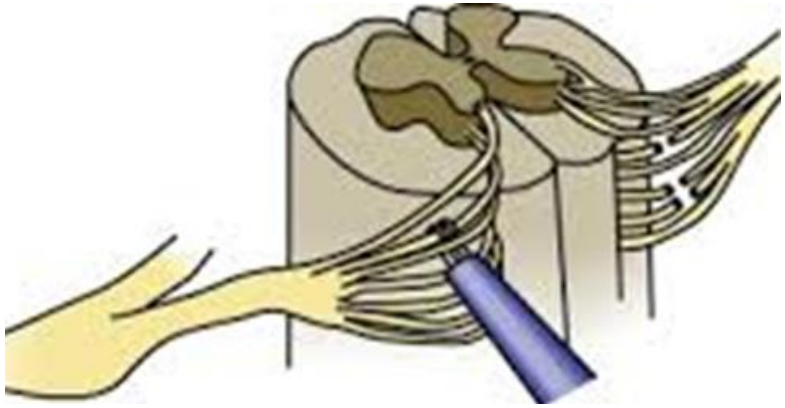


Baclofen pump



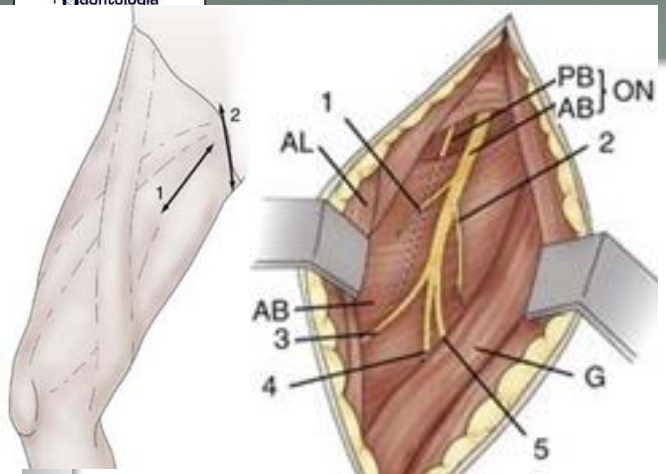




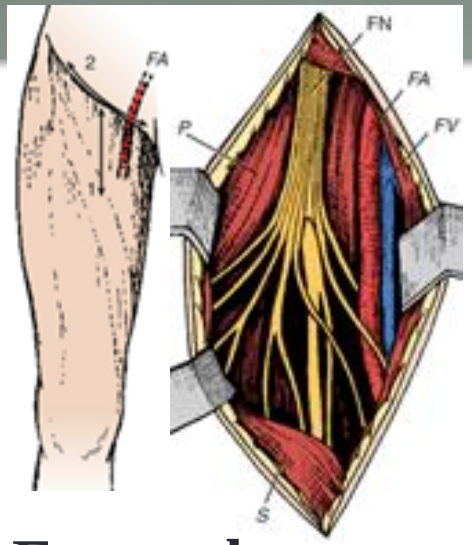


Selective posterior lumbar rhizotomy

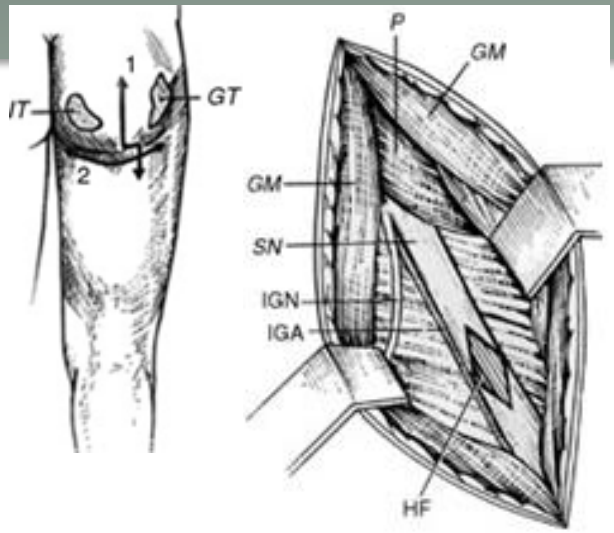
Spasticity: selective neurectomies



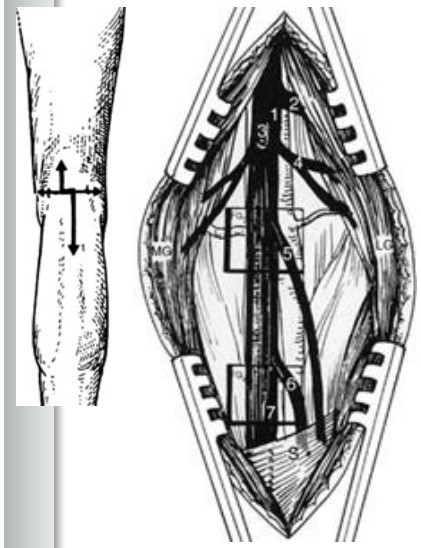
Obturator



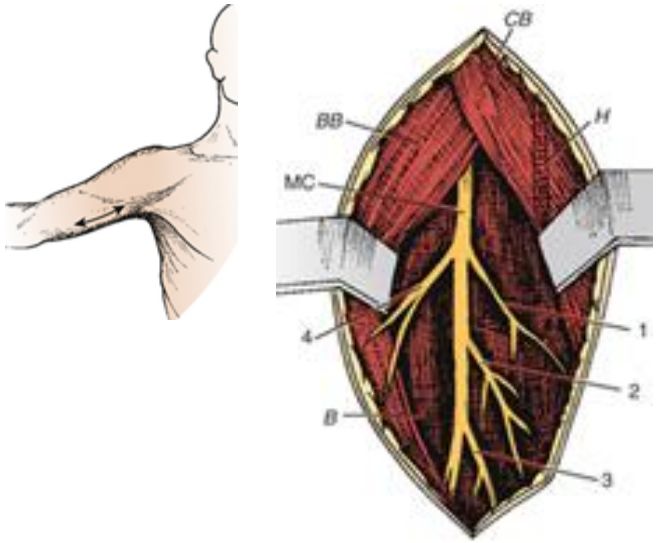
Femoral



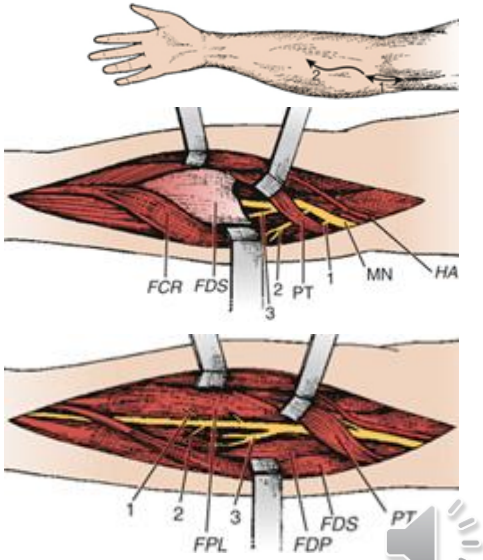
Sciatic



Posterior tibialis



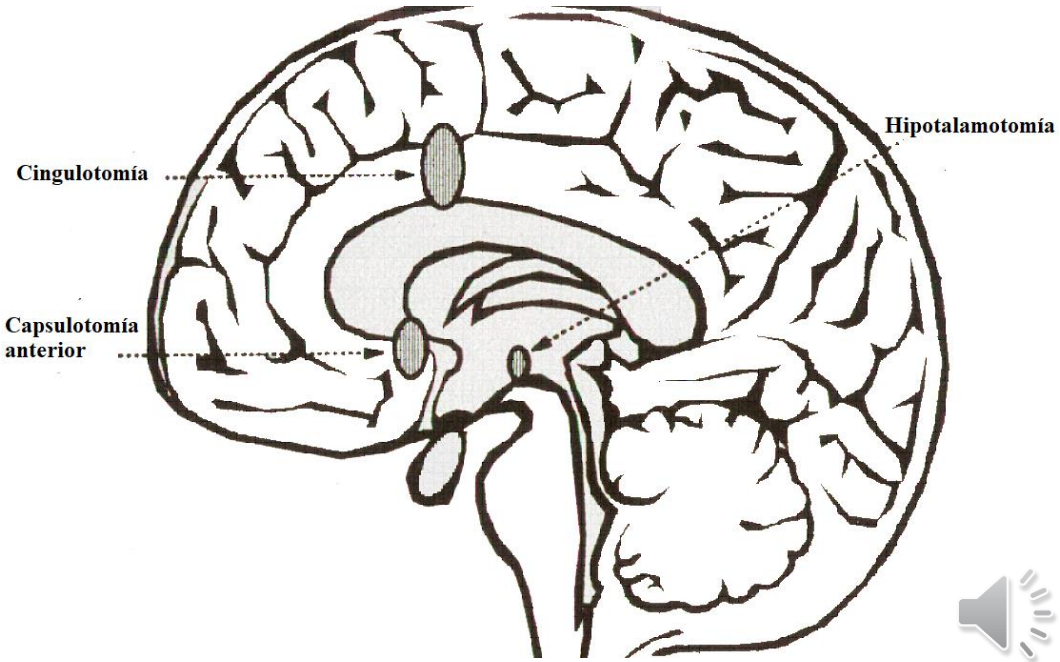
Muscle-cutaneous



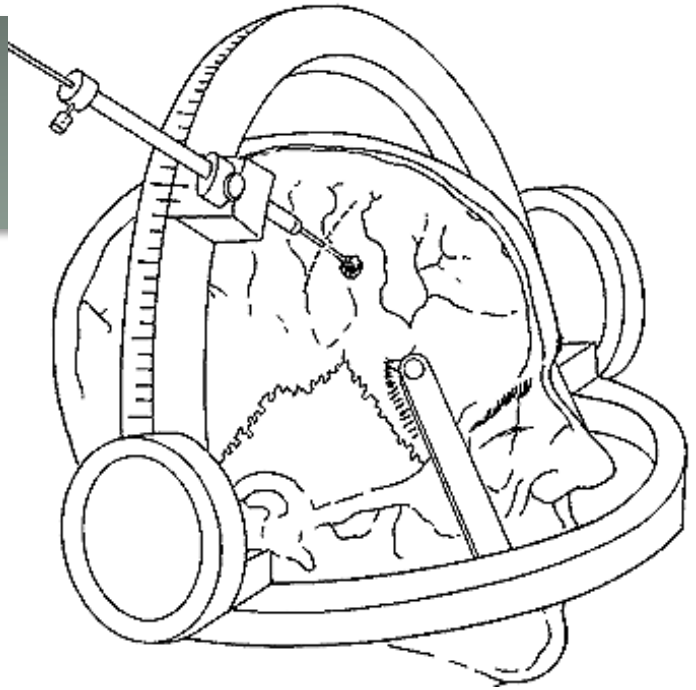
Median

Psychosurgery

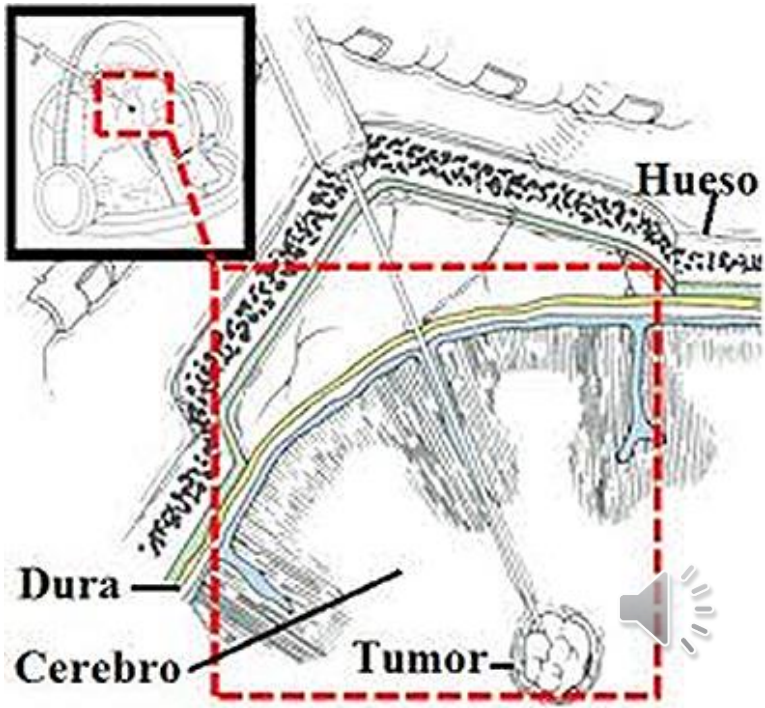
- **Indication: psychiatric patients** ⇓response to drugs + serious problem for patient, family, and caregivers & patient willing to continue psychiatric treatment after surgical procedure
- **Techniques** (maybe done by means of ablation or neurostimulation of same target points)



Stereotaxy

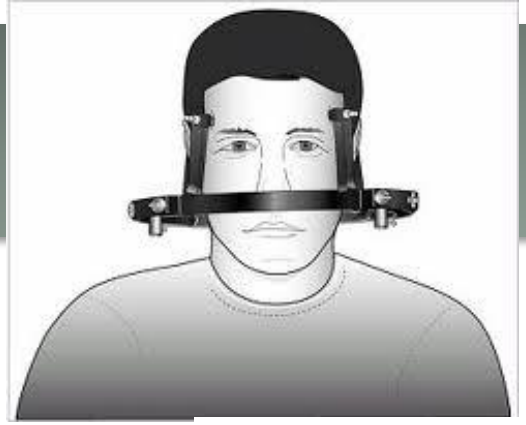


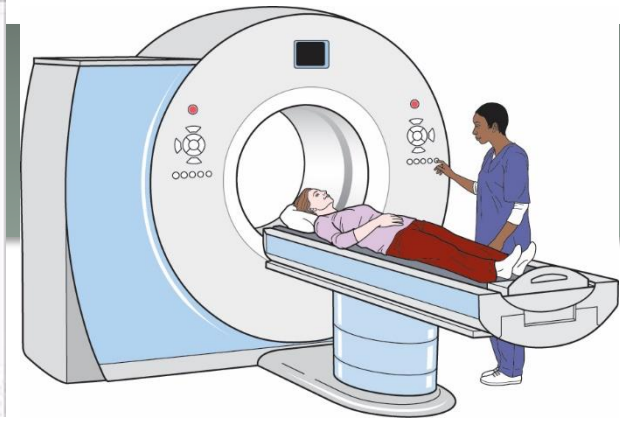
- From the Greek, stereo = space, taxos = nomenclature
- **Indications**
  - **Stereotactic biopsy**
    - Tumors, abscesses, inflammatory processes
  - **Implantation of deep electrodes**
    - Parkinson's, dystonia, pain, epilepsy
  - **Lesions located in deep brain areas**
    - Psychosurgery
  - **Localization of brain lesions**
    - Tumors in eloquent brain areas
- Options
  - Stereotaxic frame
  - Frameless stereotaxy systems

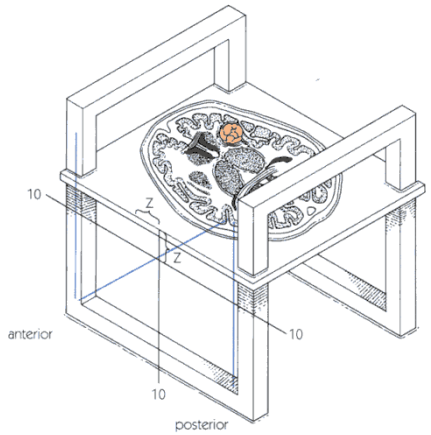


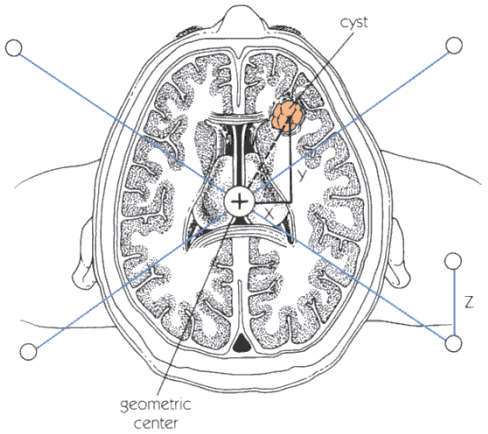
Stereotaxy

- Steps to follow
  - 1st - placement of stereotaxy frame
  - 2nd - CT/MRI studies to visualise lesion
  - 3rd - Coordinate calculation
  - 4th - Lesion removal, stimulating electrode insertion
- **Enables surgical technique precision** to minimise errors and complications

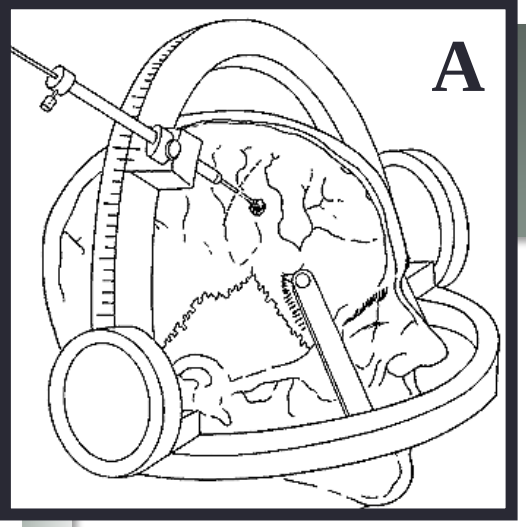


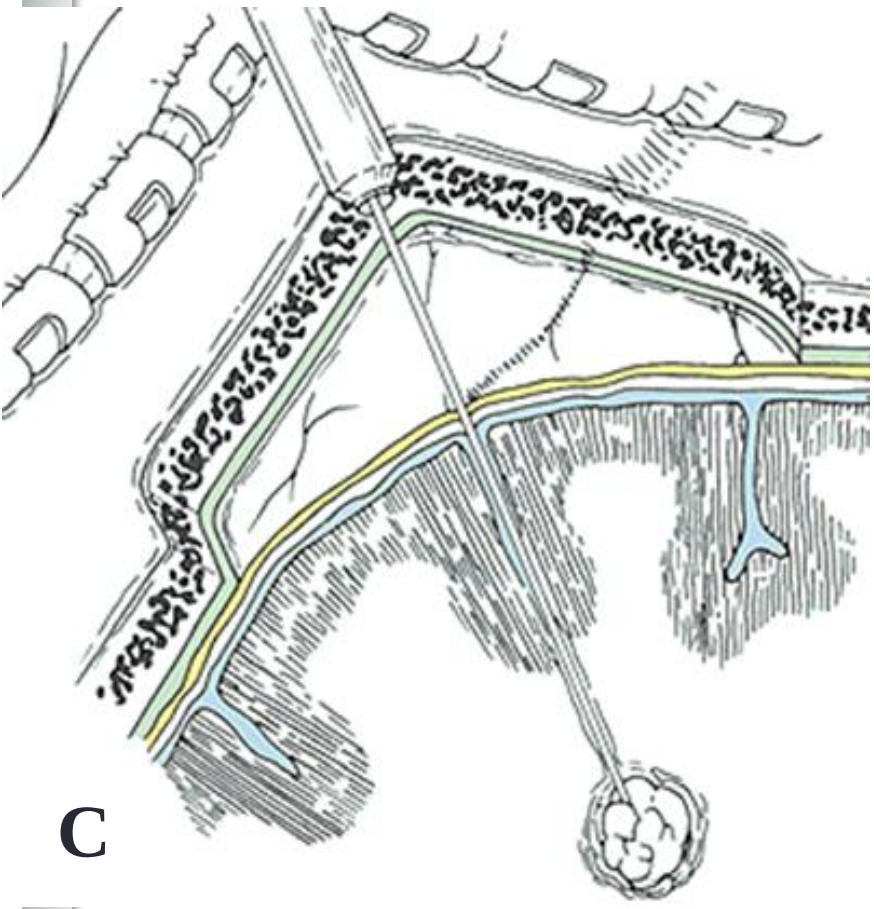


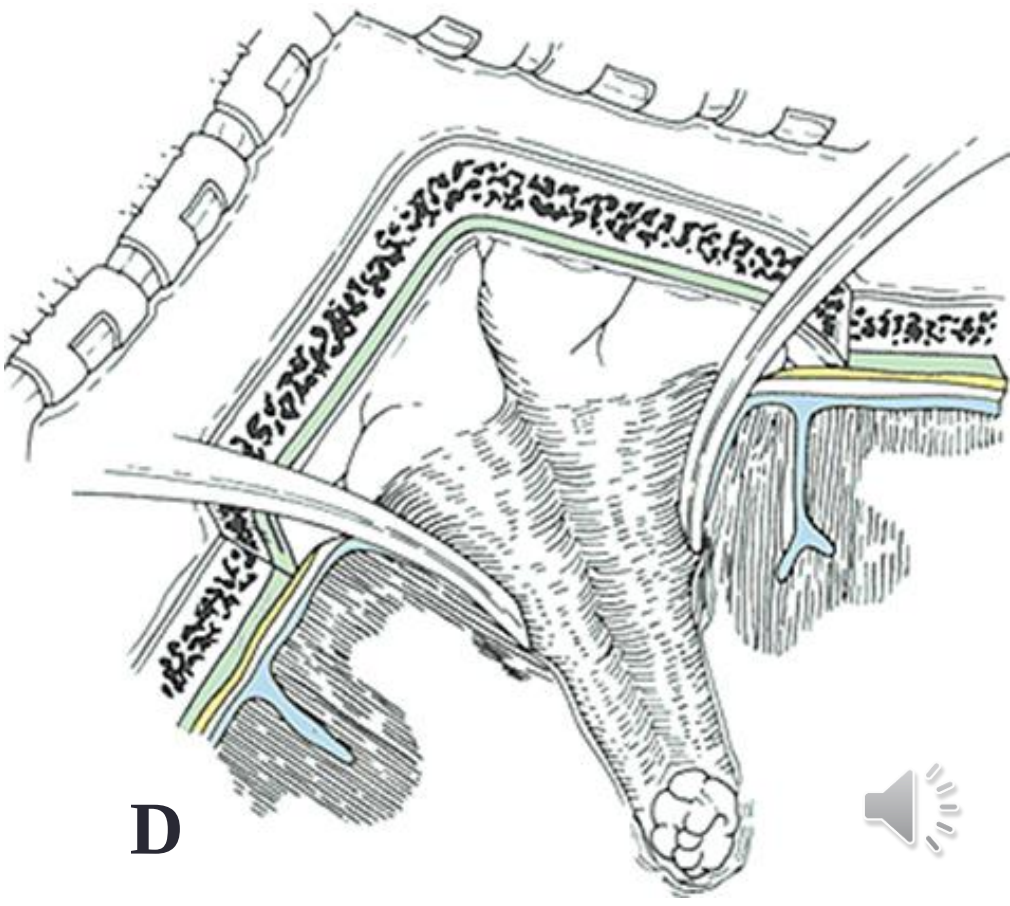




Steps in stereotactic craniotomy

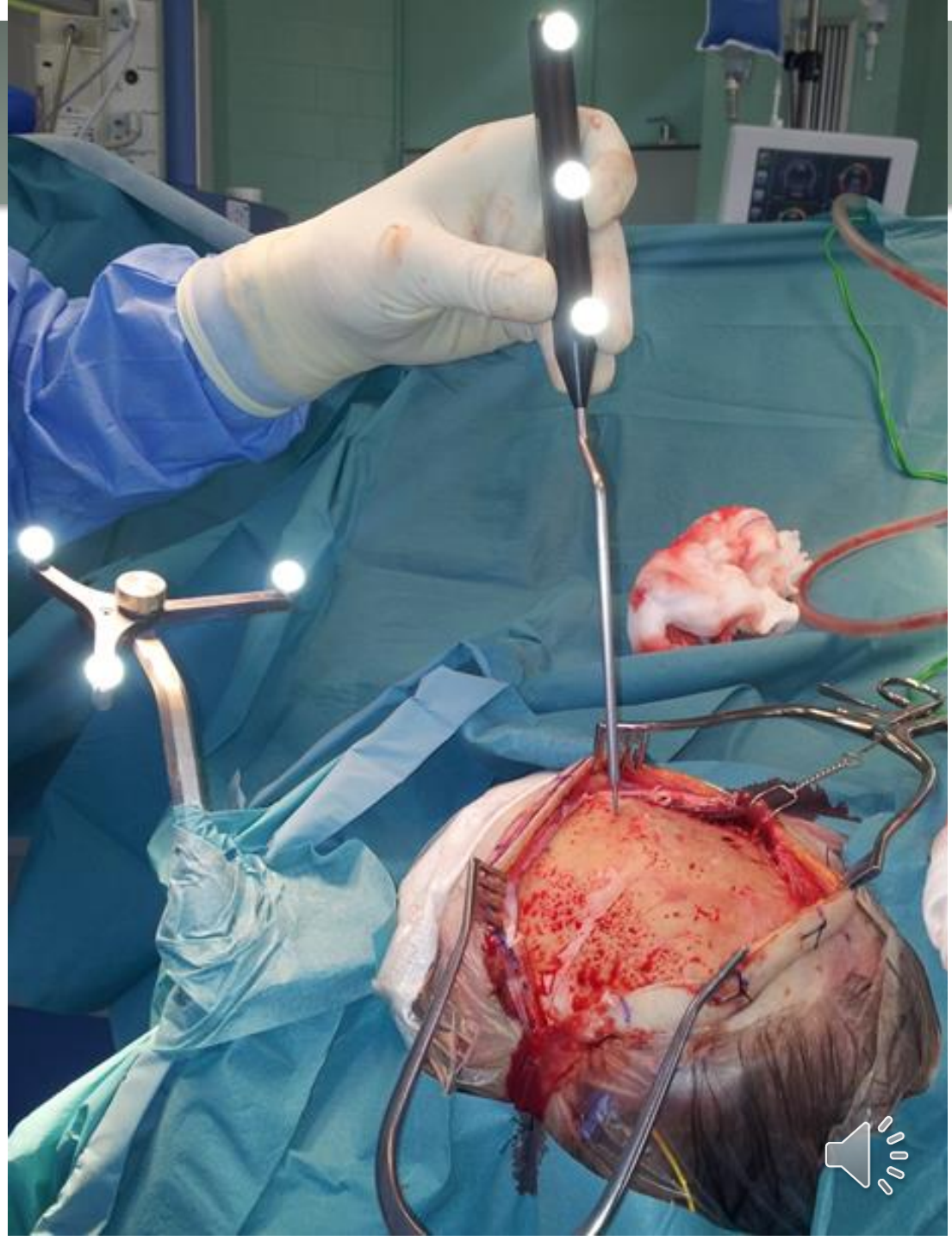






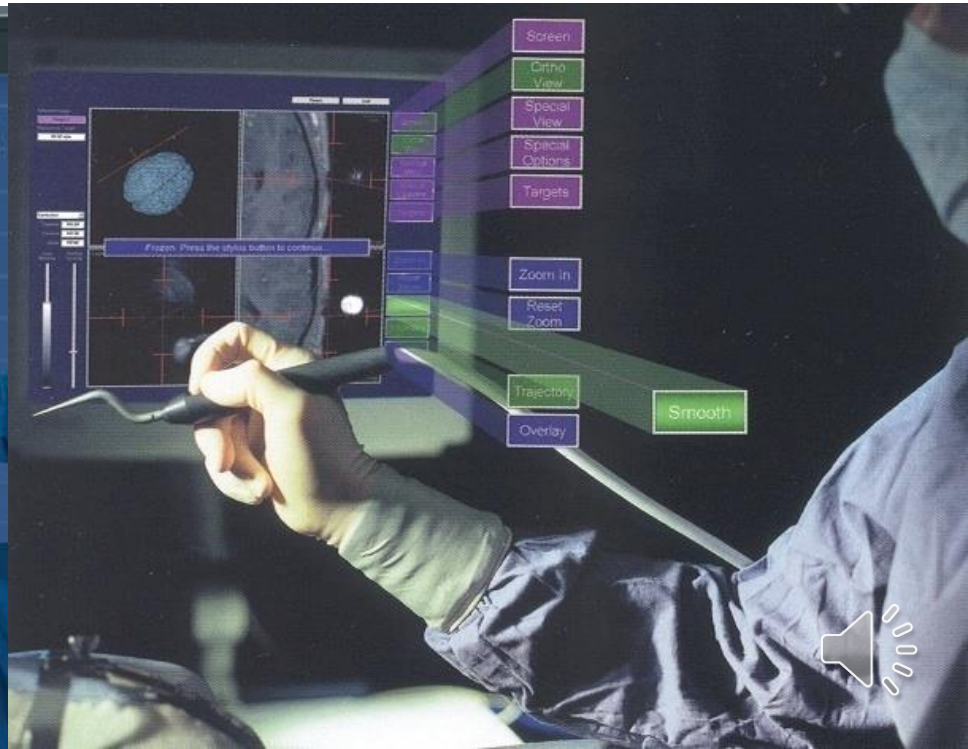
Neuronavigation

- Stereotactic system that does NOT use a helmet
- ⇓**precise than with helmet, but** ⇑**comfortable for patient**
- Integrates neuroimaging studies with surgical microscope movement

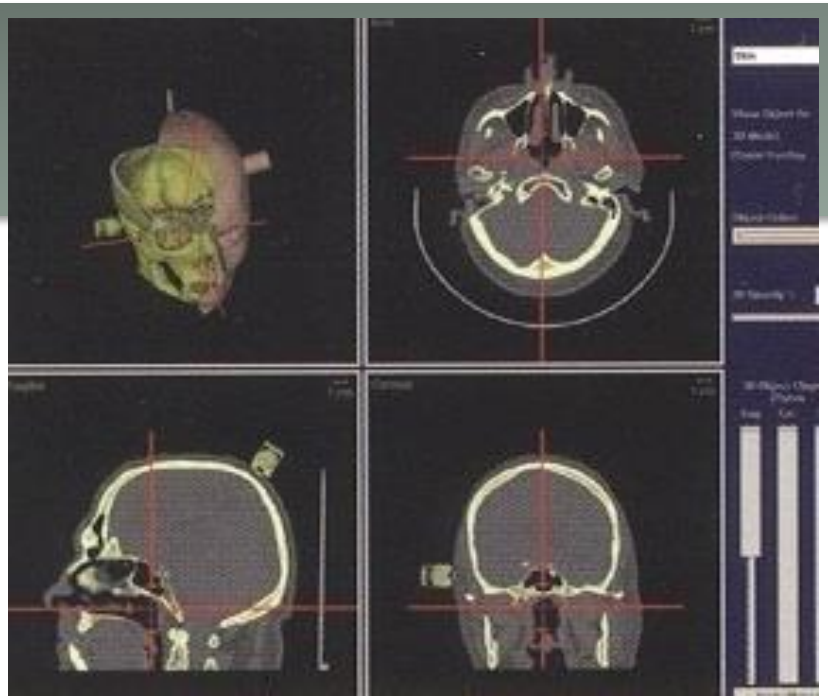


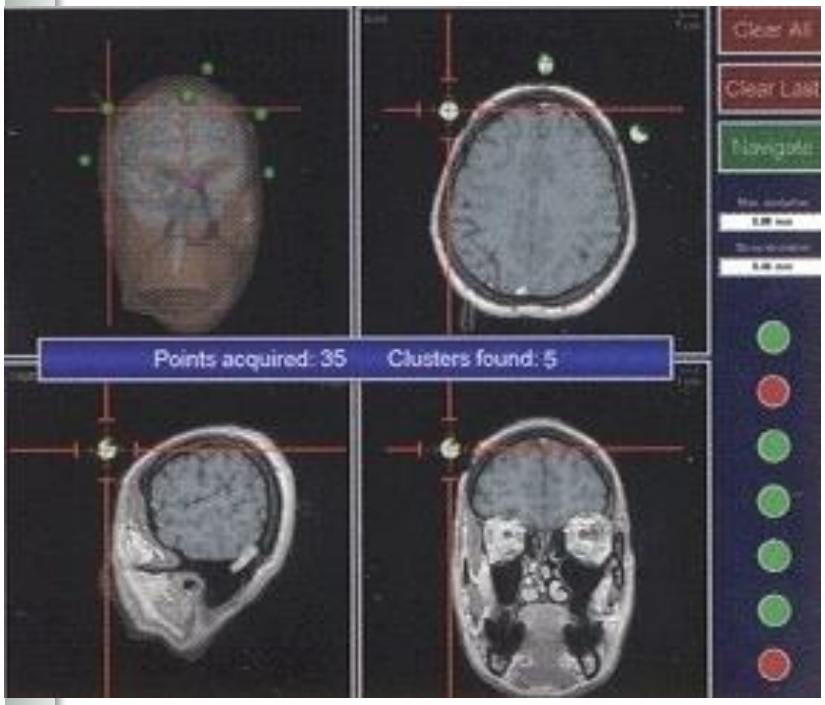
Neuronavigation:

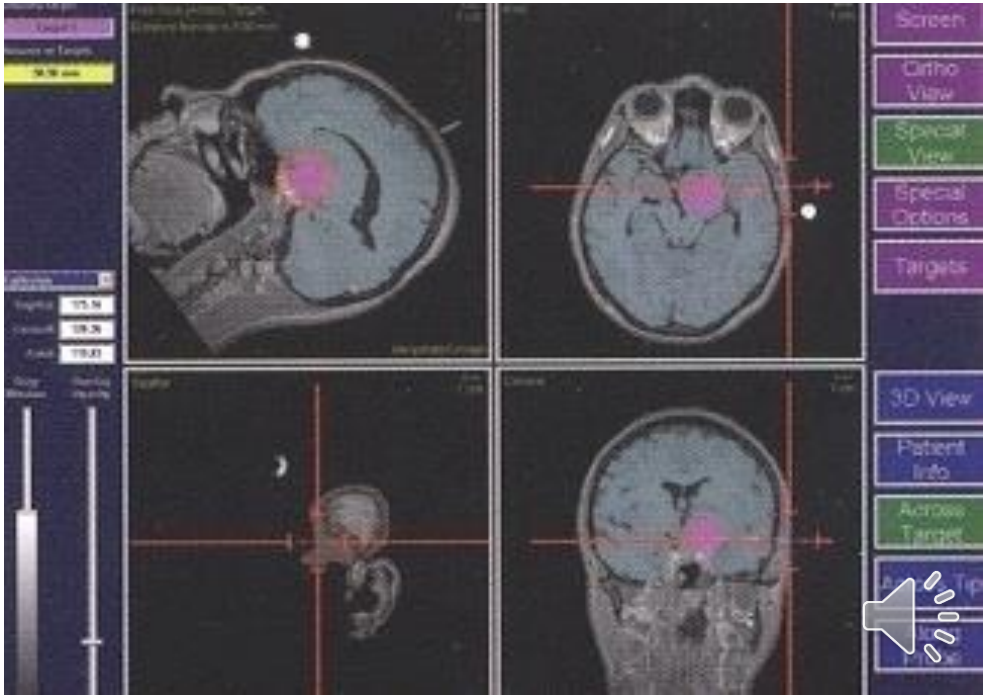
- Costly
- Requires specific training



Neuronavigation: usefulness

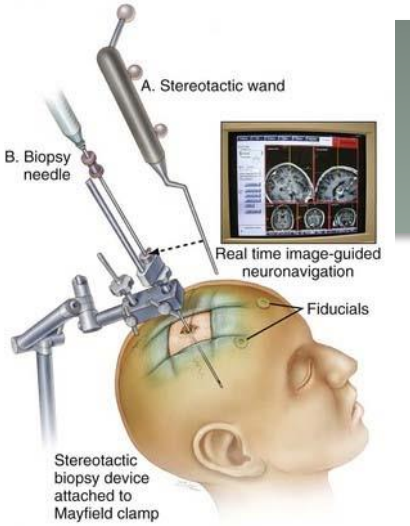




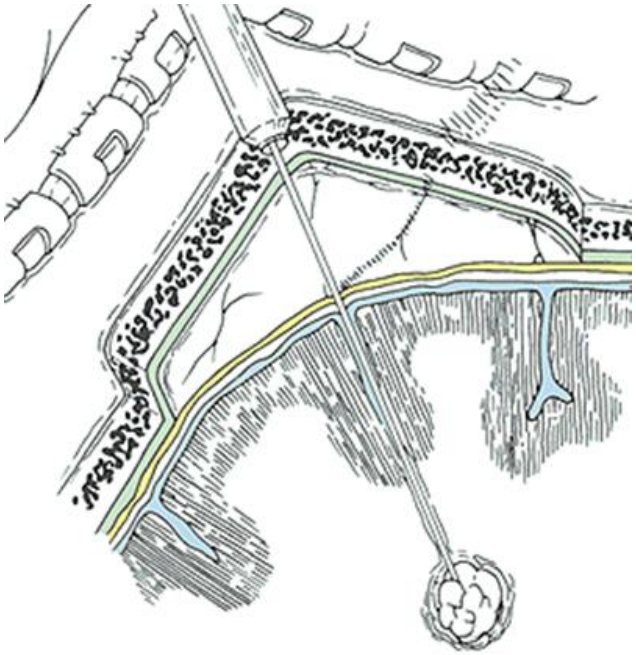


Stereotaxy WITHOUT frame

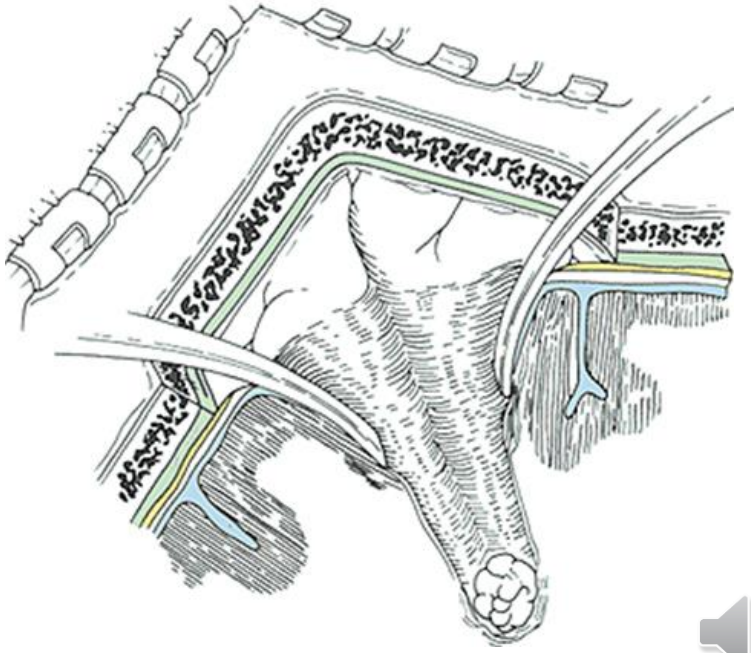
Lesion coordinate calculation



Coordinate use in operating room



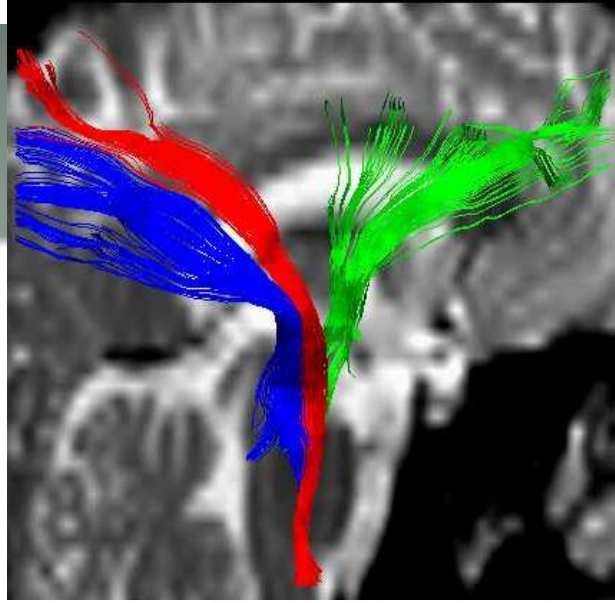
Lesion location

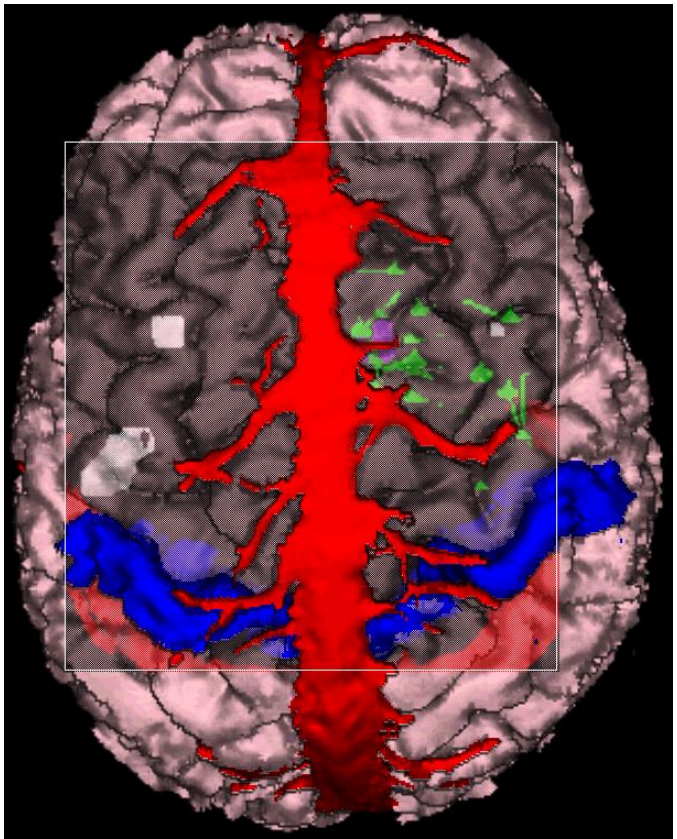


Lesion removal

Preoperative image-guided surgery

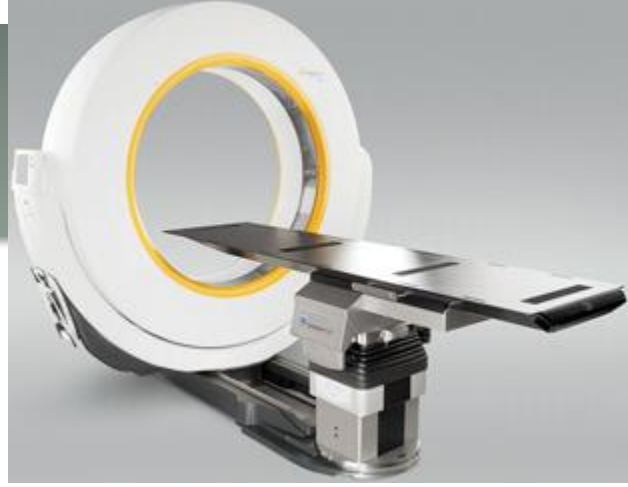
- Preoperative MRI studies
- **Allows visualisation of lesion, nervous pathways and tracts, and brain eloquent areas**
  - Enables precise preoperative surgical planning



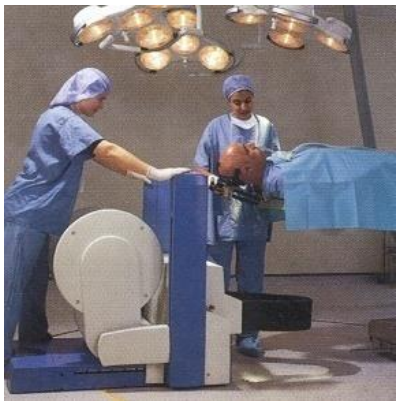


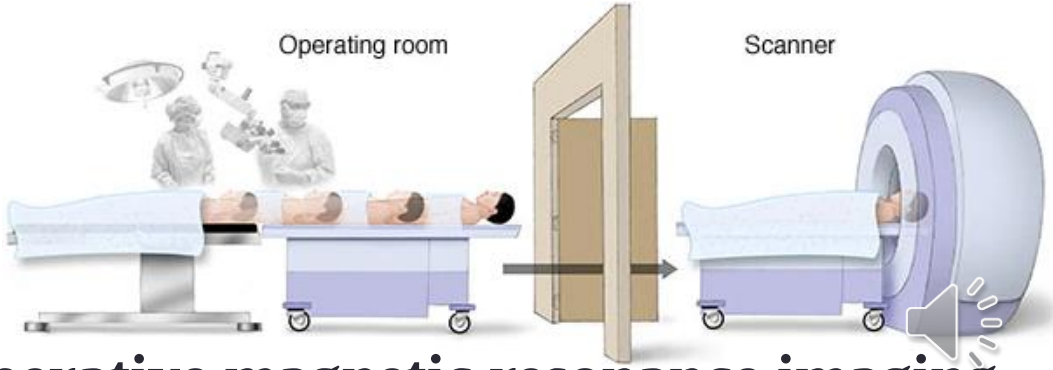
Intraoperative image-guided surgery

- **Uses intraoperative CT and/or RM imaging**
- **Enables intraoperative surgical performance control**
  - Reduces errors (e. g. misplaced screws)
  - ⇑degree tumor resection (gliomas, pituitary gland tumors)
    - ⇑tumor-free period & patient survival
- Requires costly equipment



Intraoperative CT





Intraoperative magnetic resonance imaging

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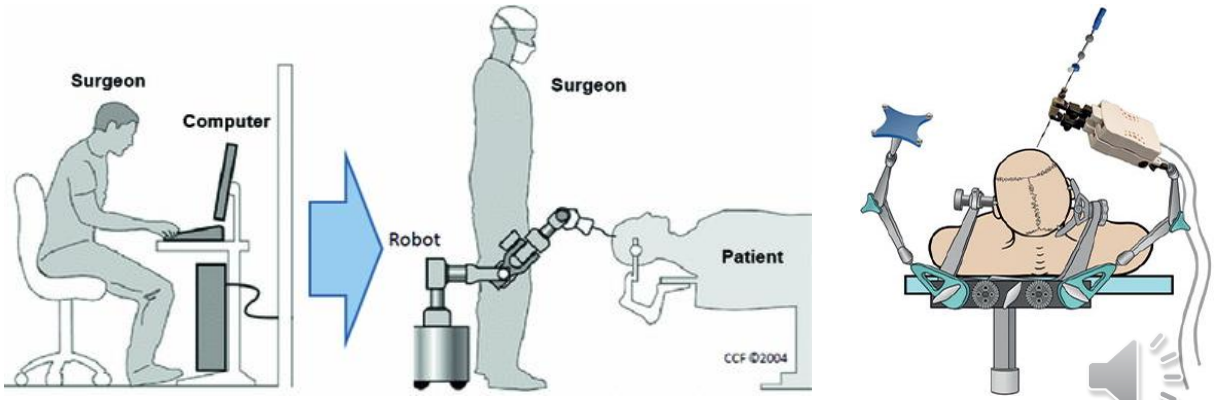
Robots in neurosurgery

Robots in neurosurgery

- Increase accuracy = reduce complications
- Limited usefulness
  - Epilepsy surgery
  - Abnormal movement surgery
- Very expensive

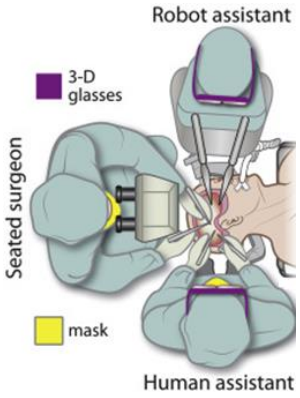
Robot to implant deep electrodes

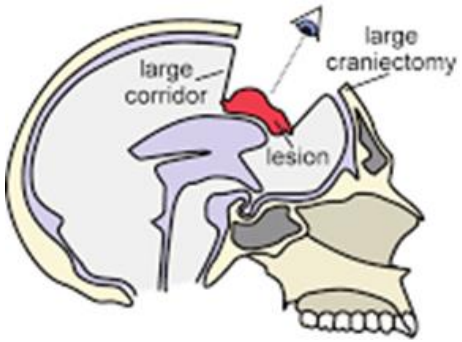


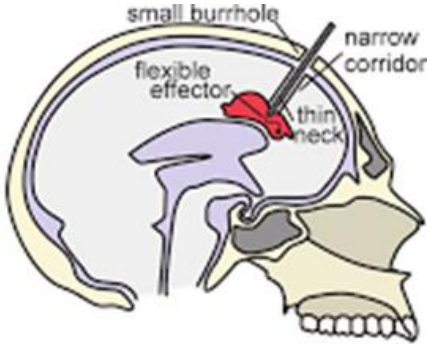
Robot for implanting electrodes in epilepsy

Robots in neurosurgery: future

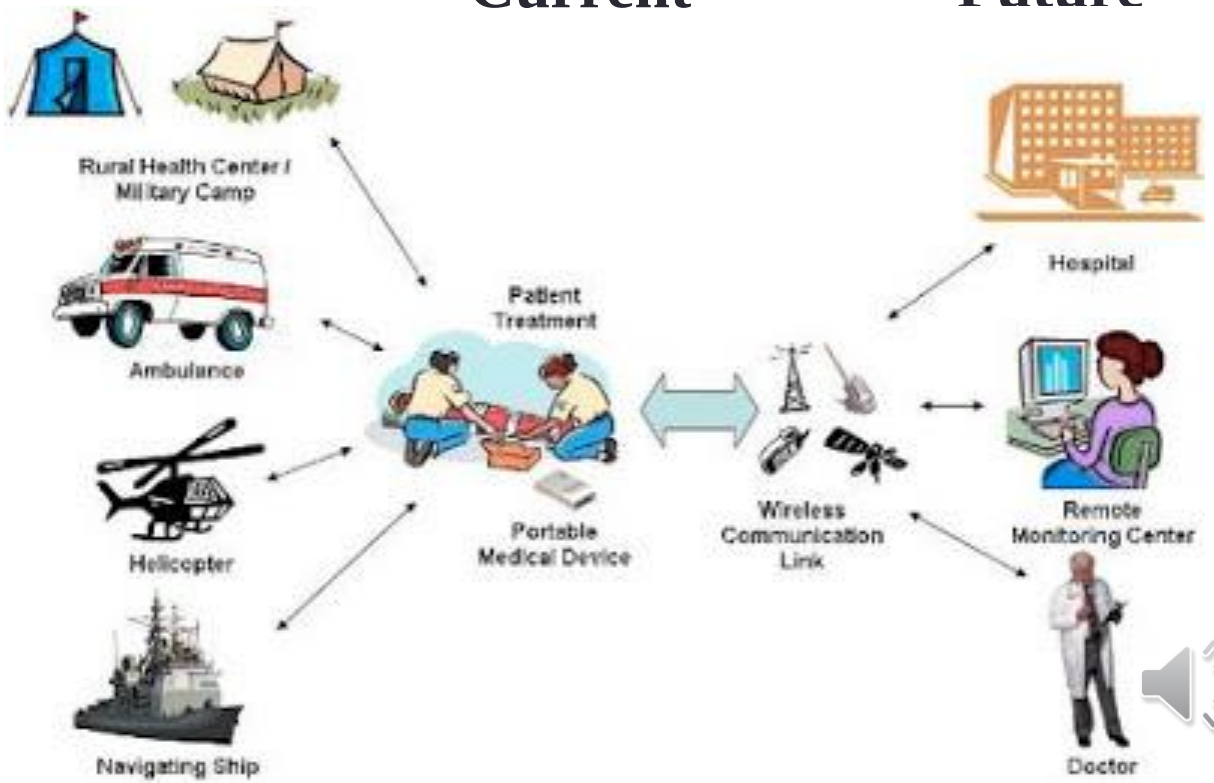
- Expanding options
- Telesurgery
  - Army
  - Unpopulated areas
  - Space travel





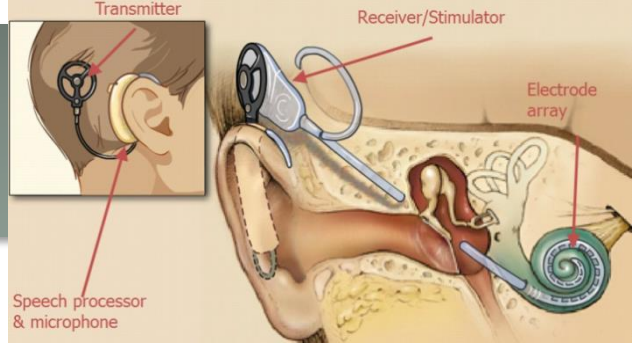


Current **Future**

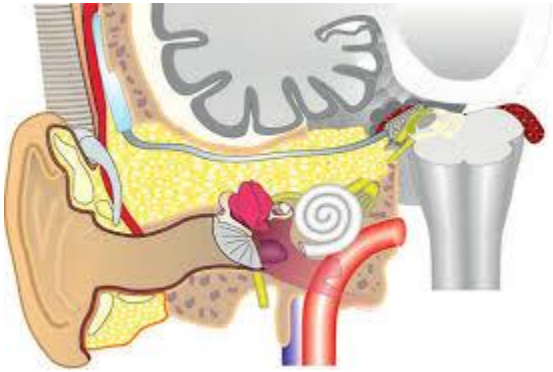


Neural prostheses

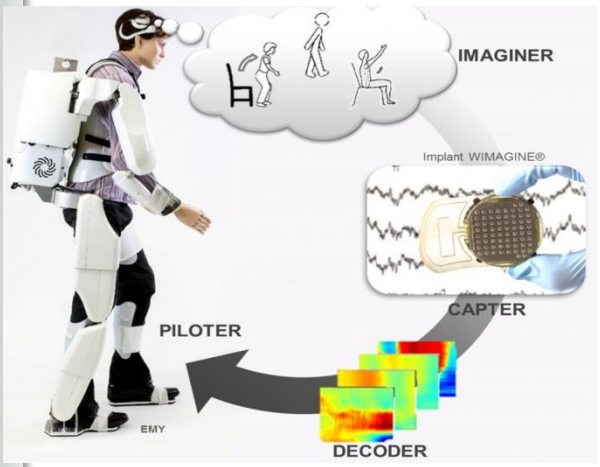
- Present: cochlear & brainstem auditory implants
- Under development
  - Visual prostheses
  - Motor prostheses
    - Connecting to prosthetic limbs for amputees
    - Tetra and paraplegia

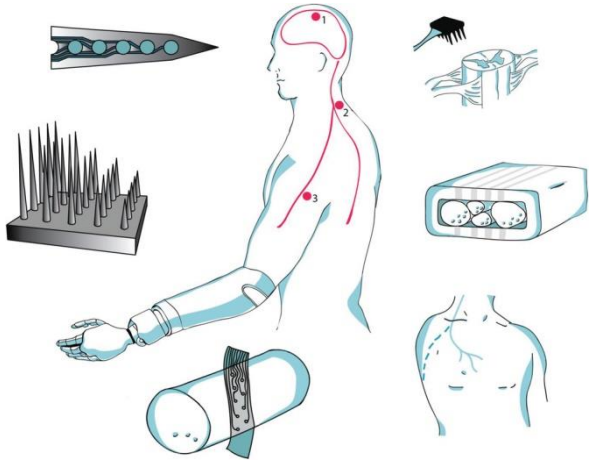


Cochlear implant

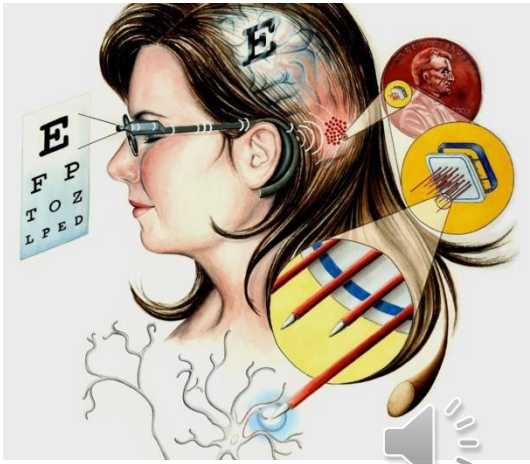


Brainstem auditory implant





Motor prostheses



Visual prosthesis

Concept summary: functional neurosurgery

- Chronic refractory pain
  - Multiple surgical treatment options, but neuromodulation is adjustable and reversible
  - Trigeminal neuralgia: surgical treatment ⇑successful
- Neurosurgical treatment of refractory epilepsy
  - Multiple options, mediocre results except in temporal lobe epilepsy
- Neurosurgical treatment of movement disorders
  - Parkinson's disease
    - Neurostimulation improves symptoms, but does NOT stop disease progression
  - Dyskinesias
    - Symptomatic relief and improves quality of life
  - Spasticity
    - Useful to facilitate patient rehabilitation and recovery (gait especially)
- Psychosurgery: only for desperate cases
- Stereotaxy: precision to reach deep located targets
- Neuronavigation: a guide for the surgeon and comfortable for patient
- Image-guided surgery
  - Very useful, but ⇑expensive= not all hospitals can afford this equipment
  - Vital for safe and effective neurosurgery
- Robots in neurosurgery: will enable telemedicine in wars and space travel
- Neural prostheses: possibility of restoring some lost neurological functions

ANY QUESTIONS?

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Bibliography

- Cataltepe O, and Jallo GI. Pediatric epilepsy surgery. Thieme. 2019.