

Neural Interfaces

NX-422
Clinical interfaces

- Trauma



- Neurodegenerative conditions

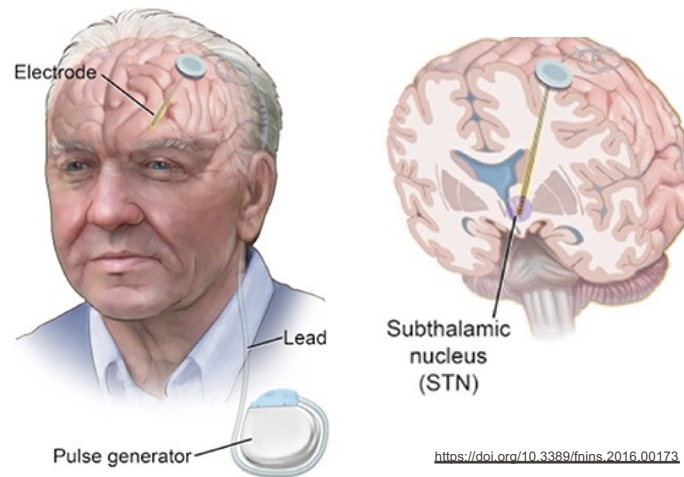


diagnostic



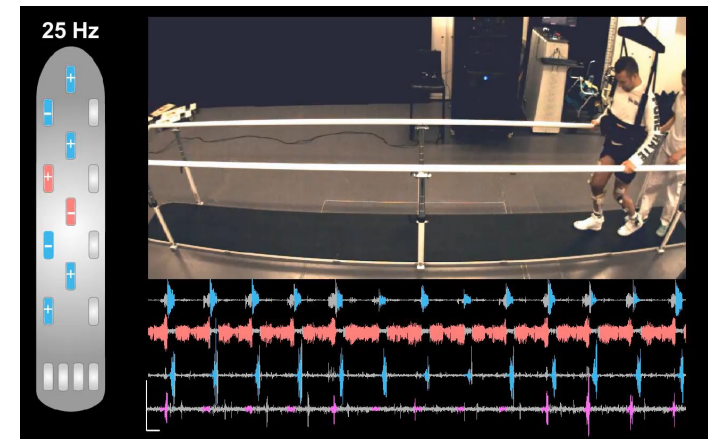
MRI

intervention



deep brain stimulation

rehabilitation



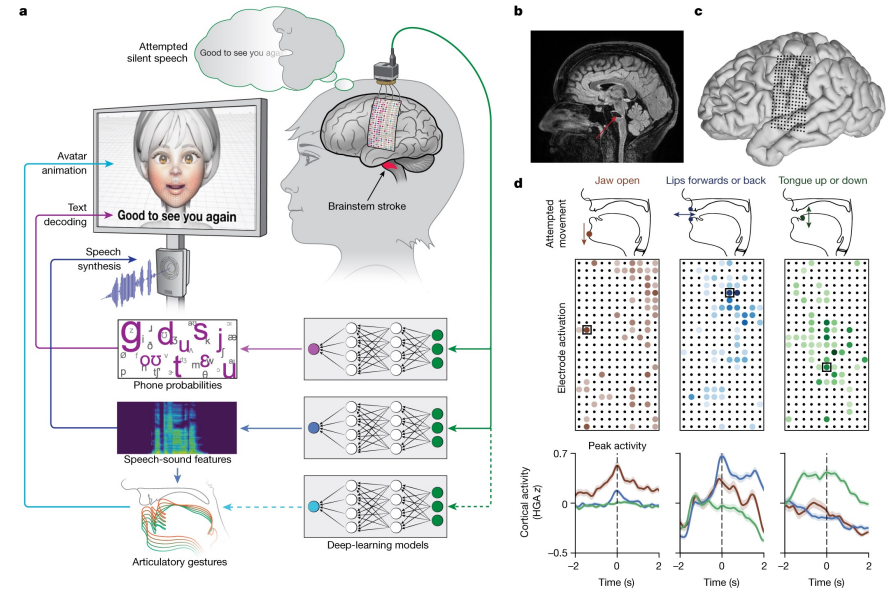
robotic assistance

Two classes of neurotechnology

- Non invasive / wearable



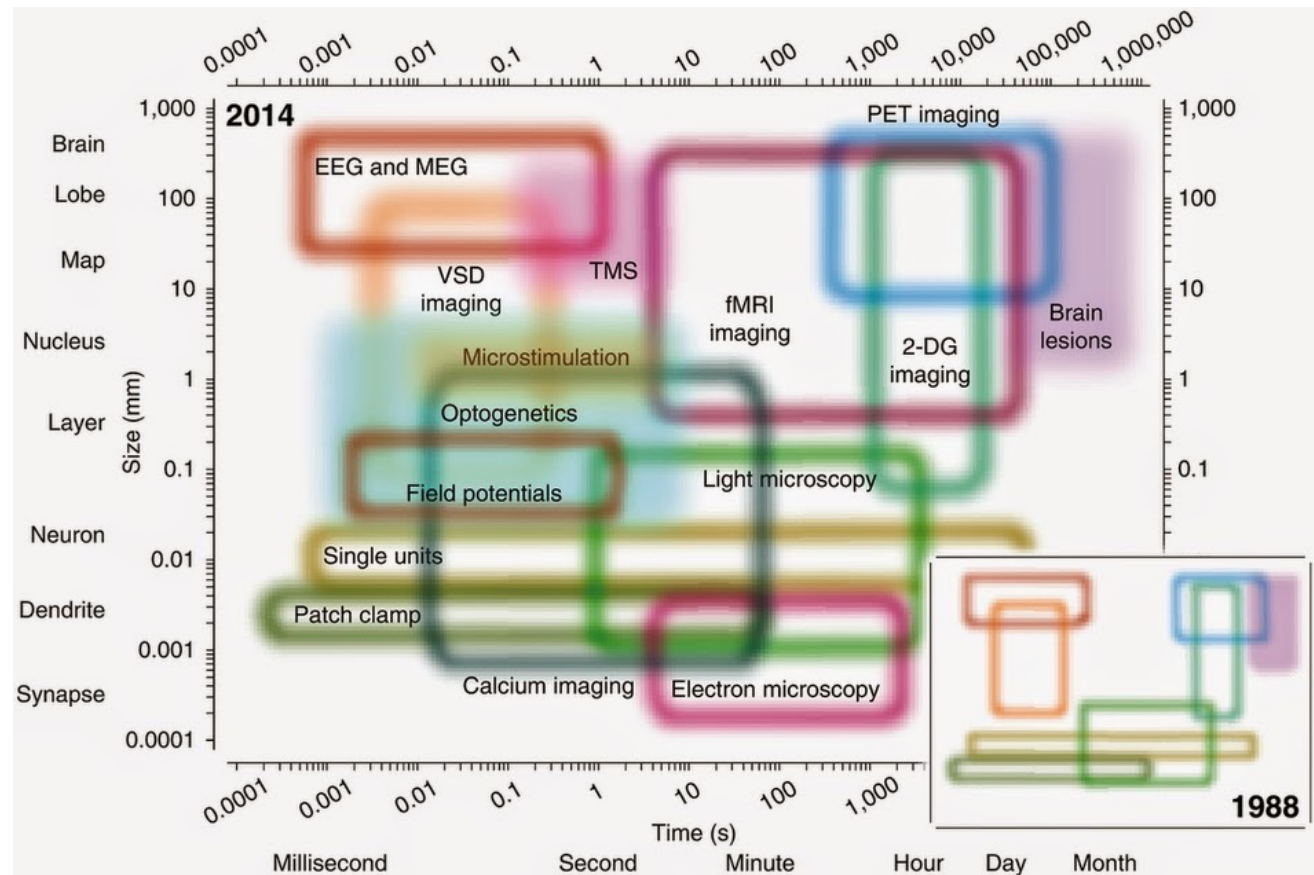
- Invasive



Nature 2023, UCSF

Functional representation of neural signals

- Spatial resolution
- Temporal resolution
- Invasiveness



[Nature Neuroscience. 2014 Nov; 17\(11\): 1440-1441.](#)

Magnetic resonance imaging - MRI

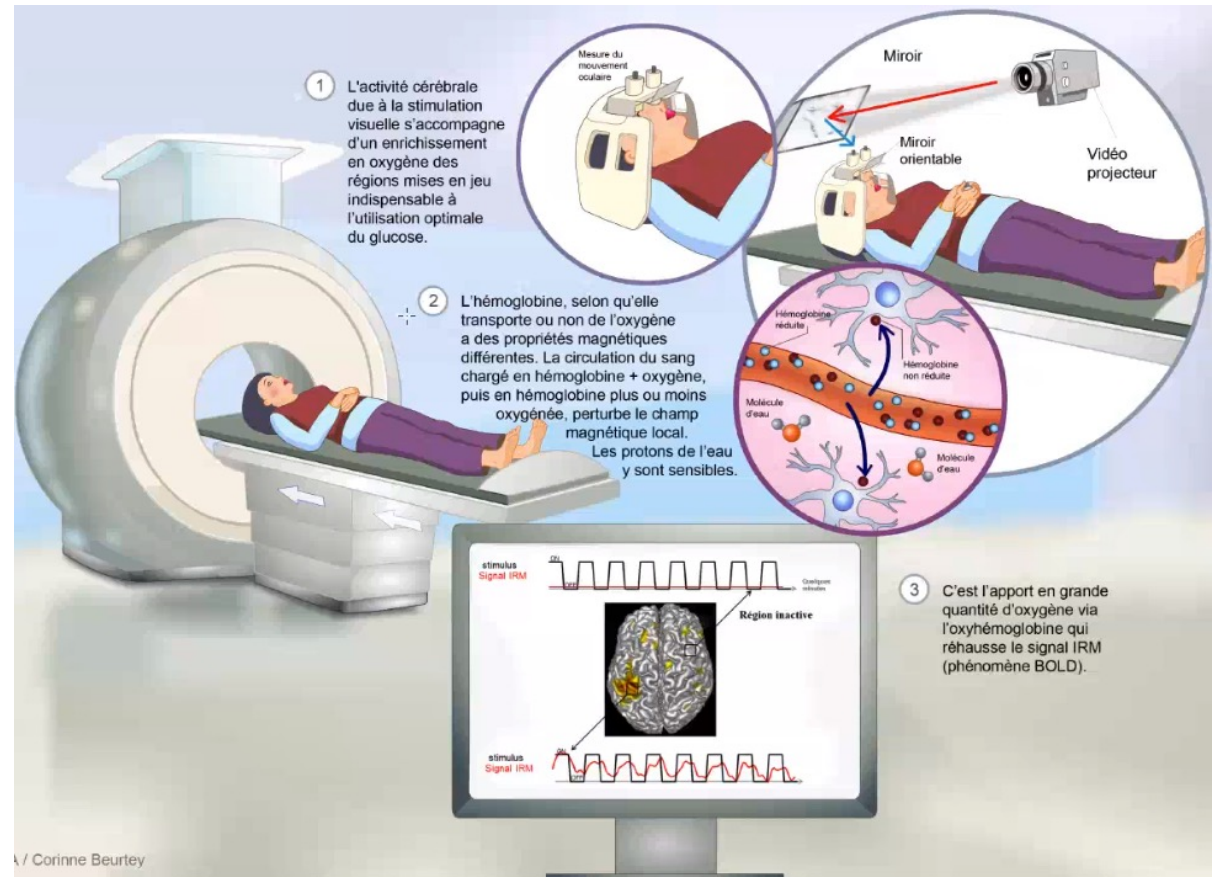
- Reference imaging

- **Magnet**
 - 1.5T
 - 3T
 - 7T
 - 11.5T / research



Siemens
Healthineers

- Anatomy
- Functional imaging
 - observation upon stimulation
 - **BOLD** (blood oxygen level dependence)

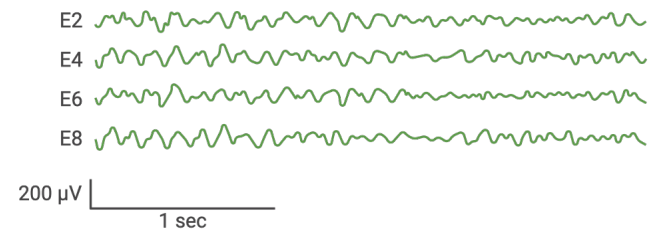




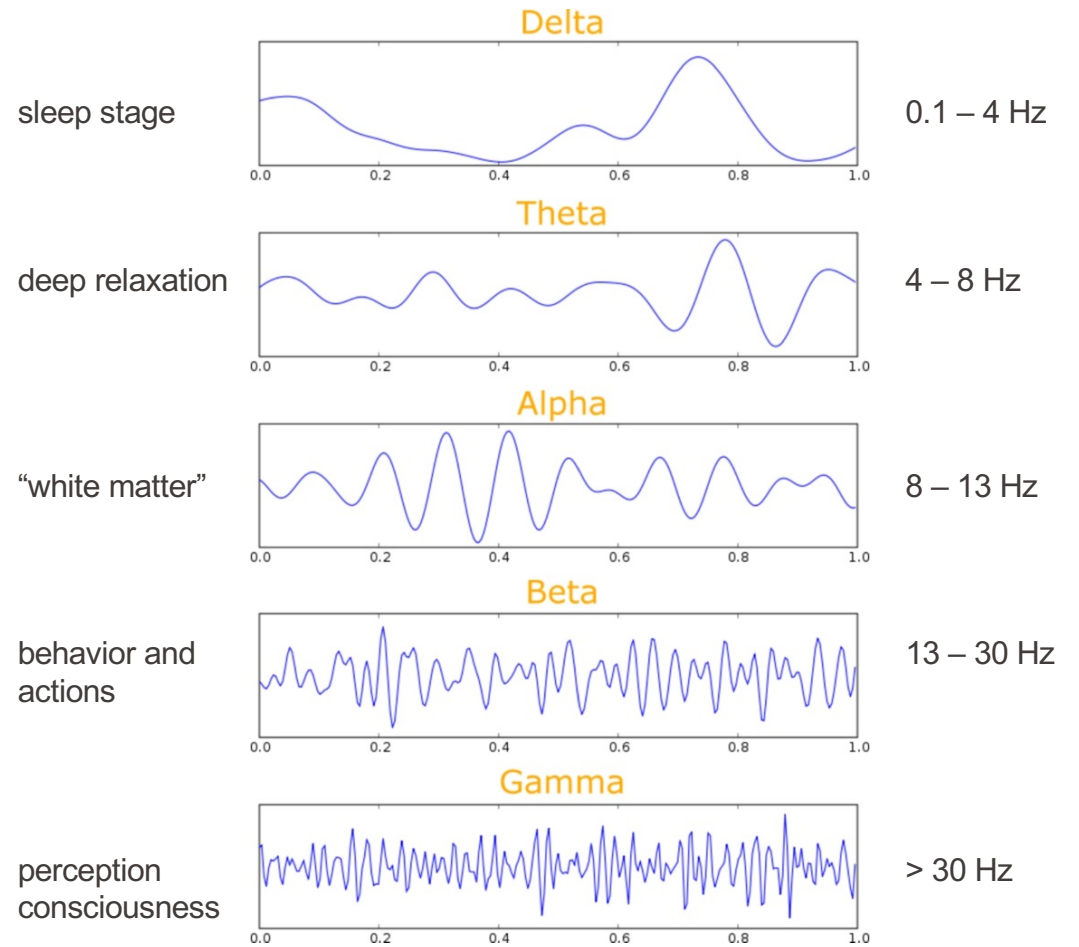
Brain Products

Electroencephalography **EEG**

5 – 300 μV , < 100 Hz

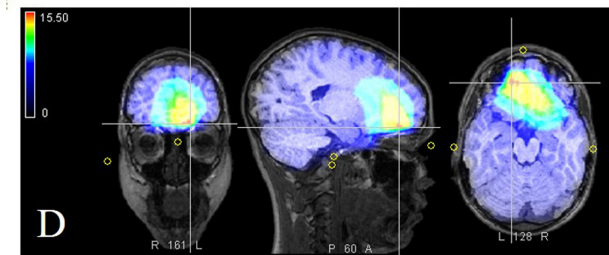
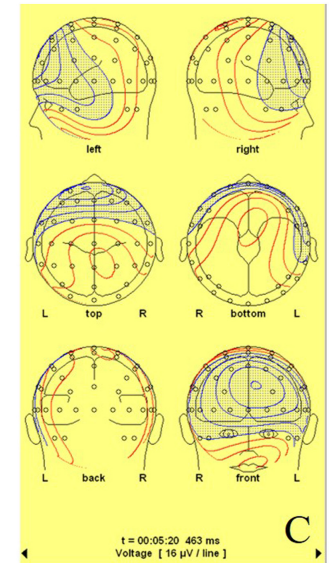
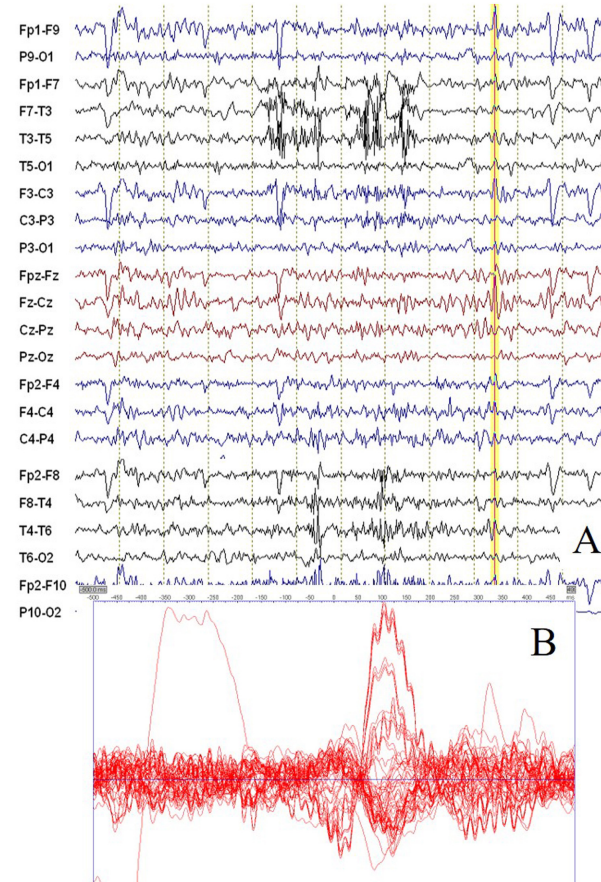


Brain waves



<https://doi.org/10.13140/RG.2.2.28622.82240>

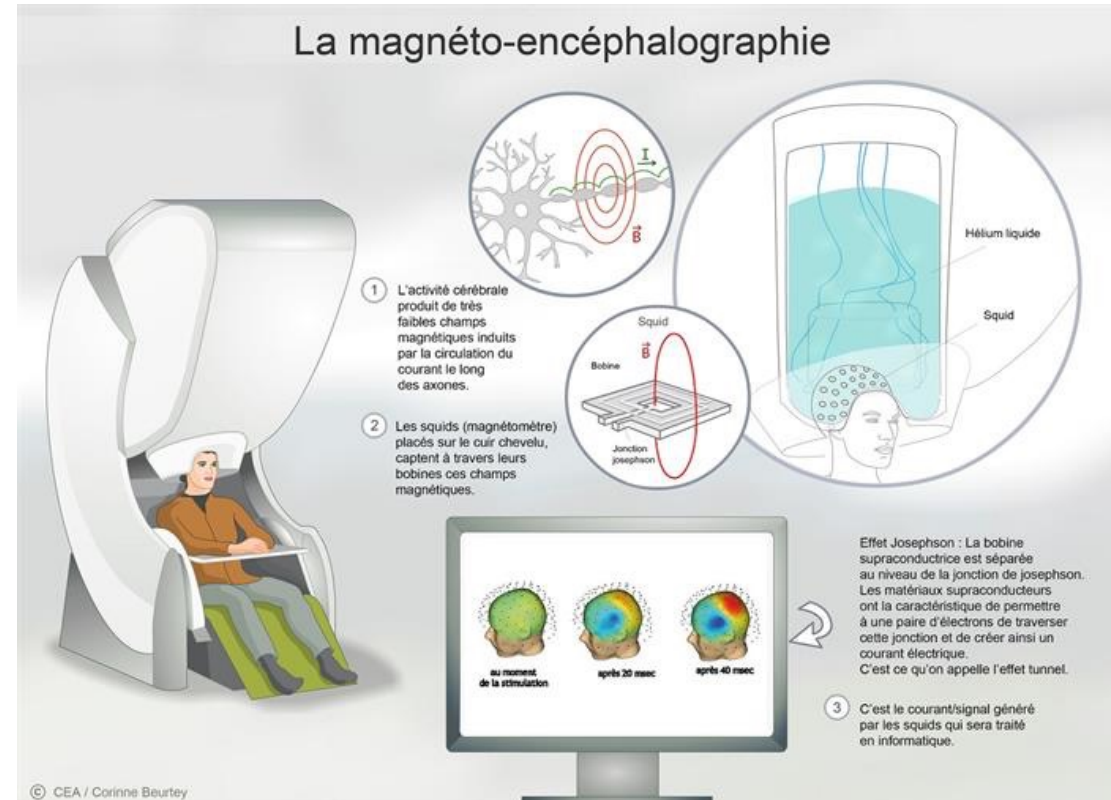
- A. High resolution EEG data
- B. Interictal event with the 64 channels superimposed
- C. Surface amplitude cartography
- D. Epileptic source localisation



<https://doi.org/10.1016/j.neurol.2022.12.008>

Magnetoencephalography MEG

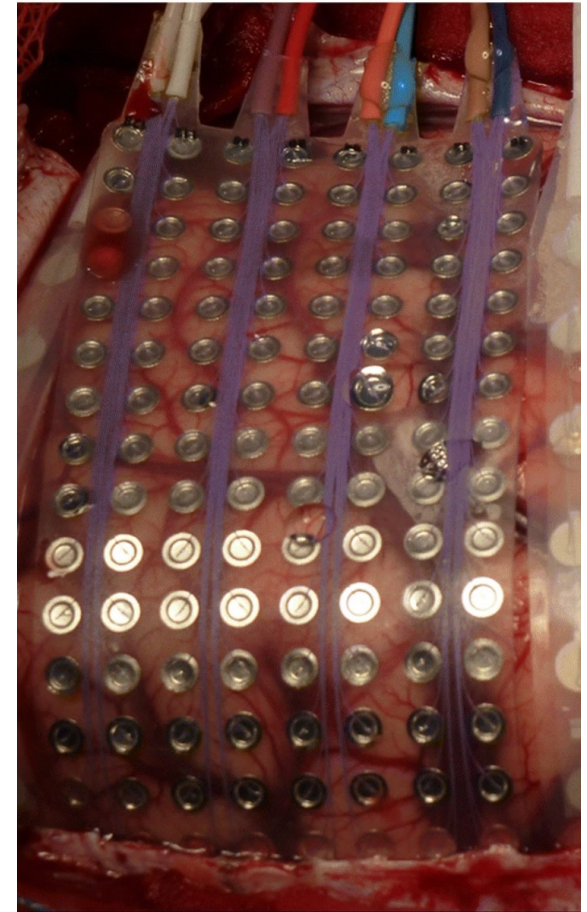
- monitoring magnetic field generated through brain activity



Electrocorticography ECoG

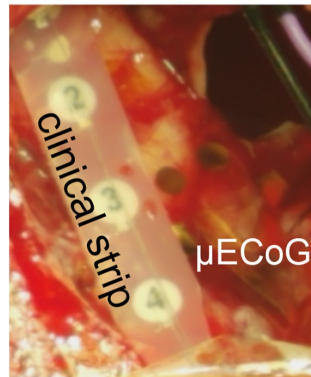
- Diagnostic:
 - Localisation of epileptic sources
 - Guide for tumor resection
 - Diagnostic for brain trauma

- Intraoperative or short-term (<30 days) monitoring



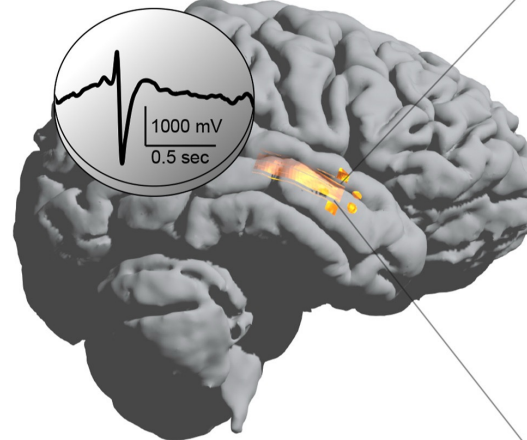
Signals vs electrode size

simultaneous
clinical and
thin film recordings

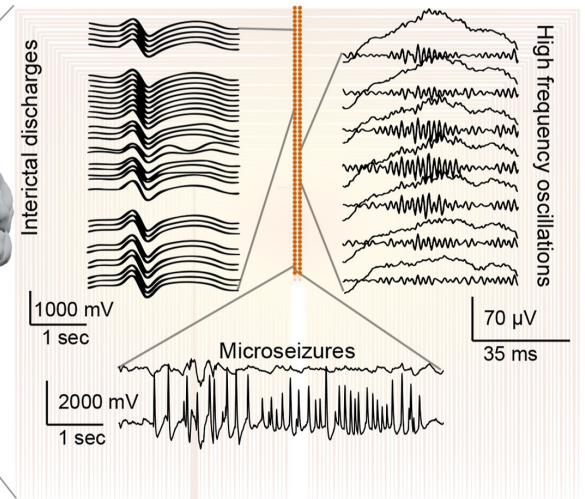


Clinical electrodes
Θ=1mm, 1cm inter-electrode

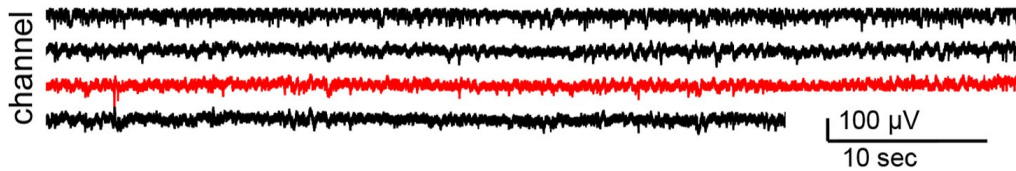
D clinical contact



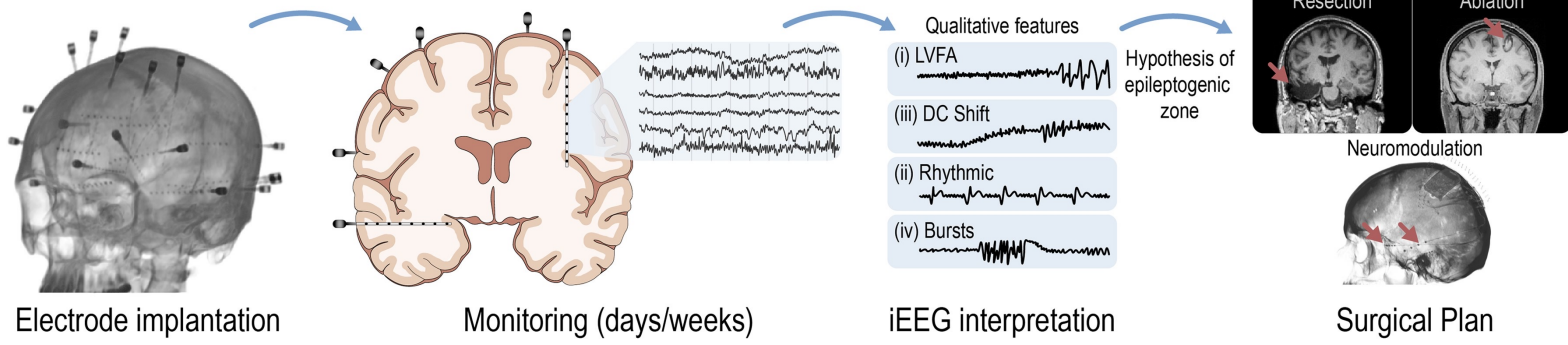
thin film microelectrodes



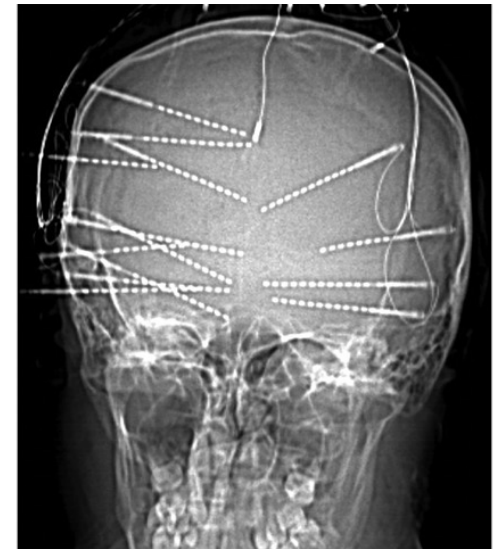
Micro-electrodes
Θ = 50μm, 1mm inter-electrode



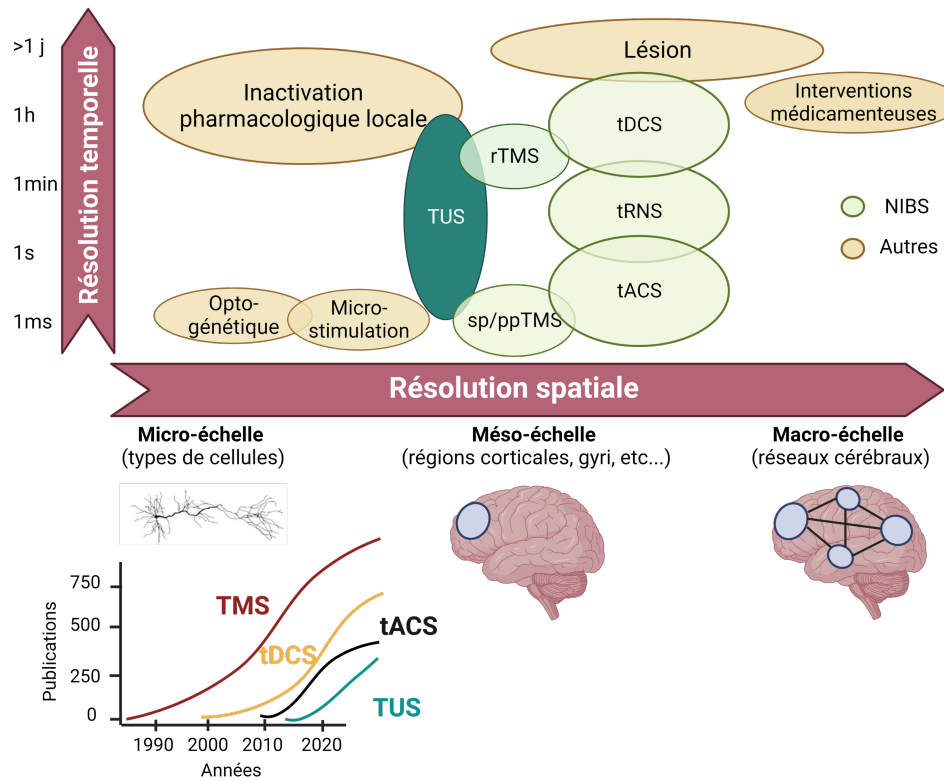
Clinical workflow of invasive monitoring



<https://doi.org/10.1093/brain/awad007>



J Neurosurg Pediatr vol 28 • 2021
404-15



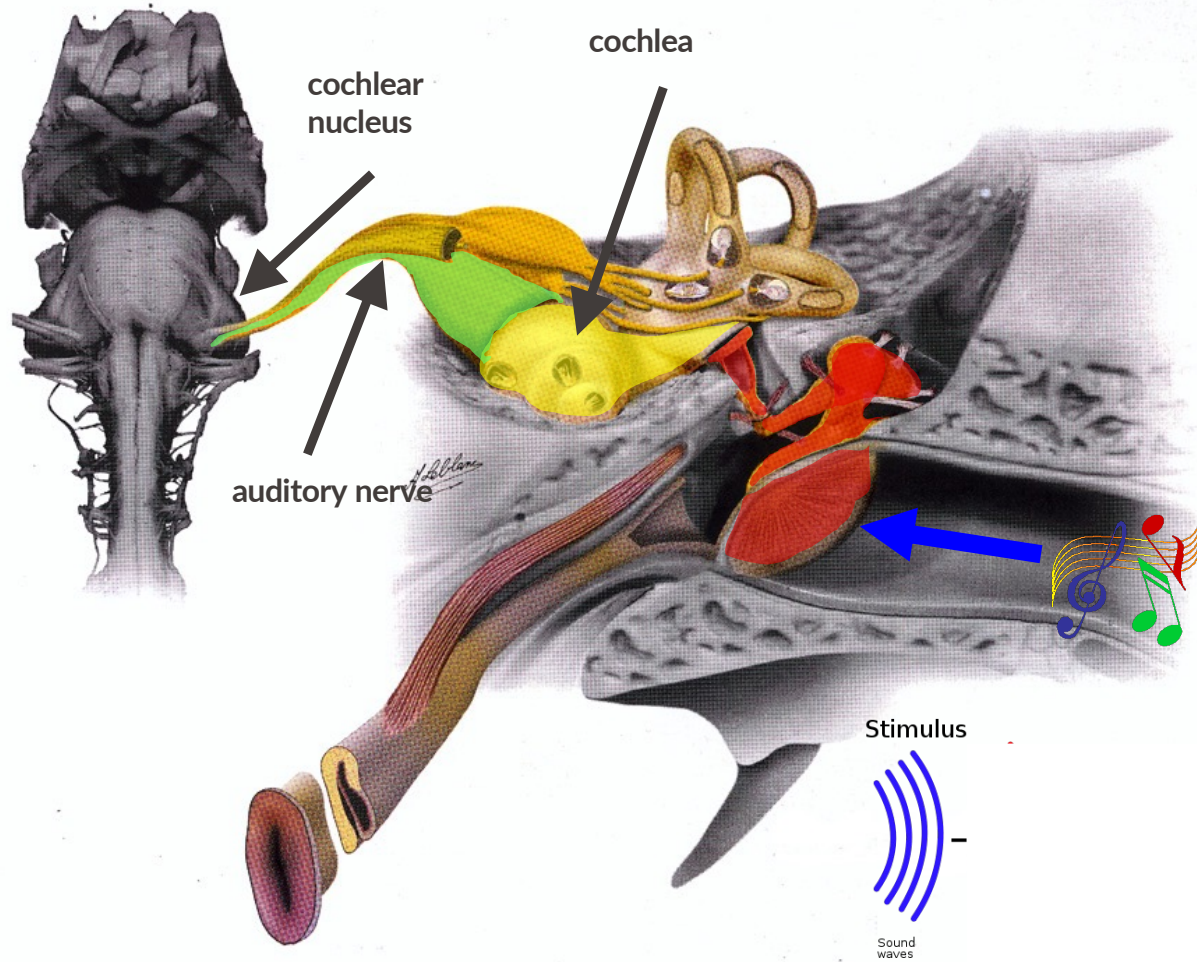
t-. transcranial

DCS: Direct Current Stimulation
 ACS: *Alternative Current Stimulation*
 RNS: random Noise Stimulation
 TMS: Transcranial Magnetic Stimulation

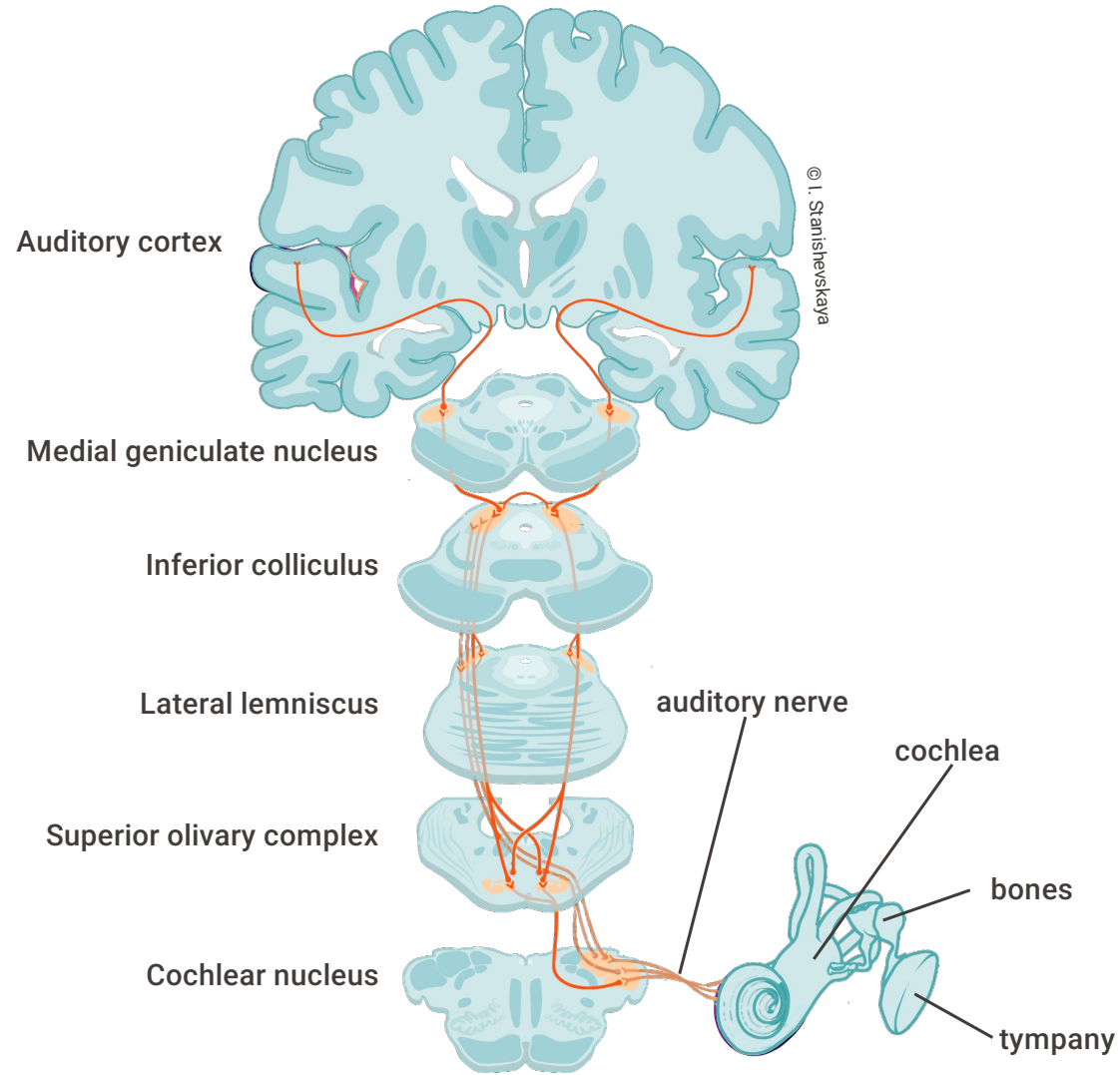
TUS: Transcranial Ultra-sound Stimulation

Invasive neurotechnologies

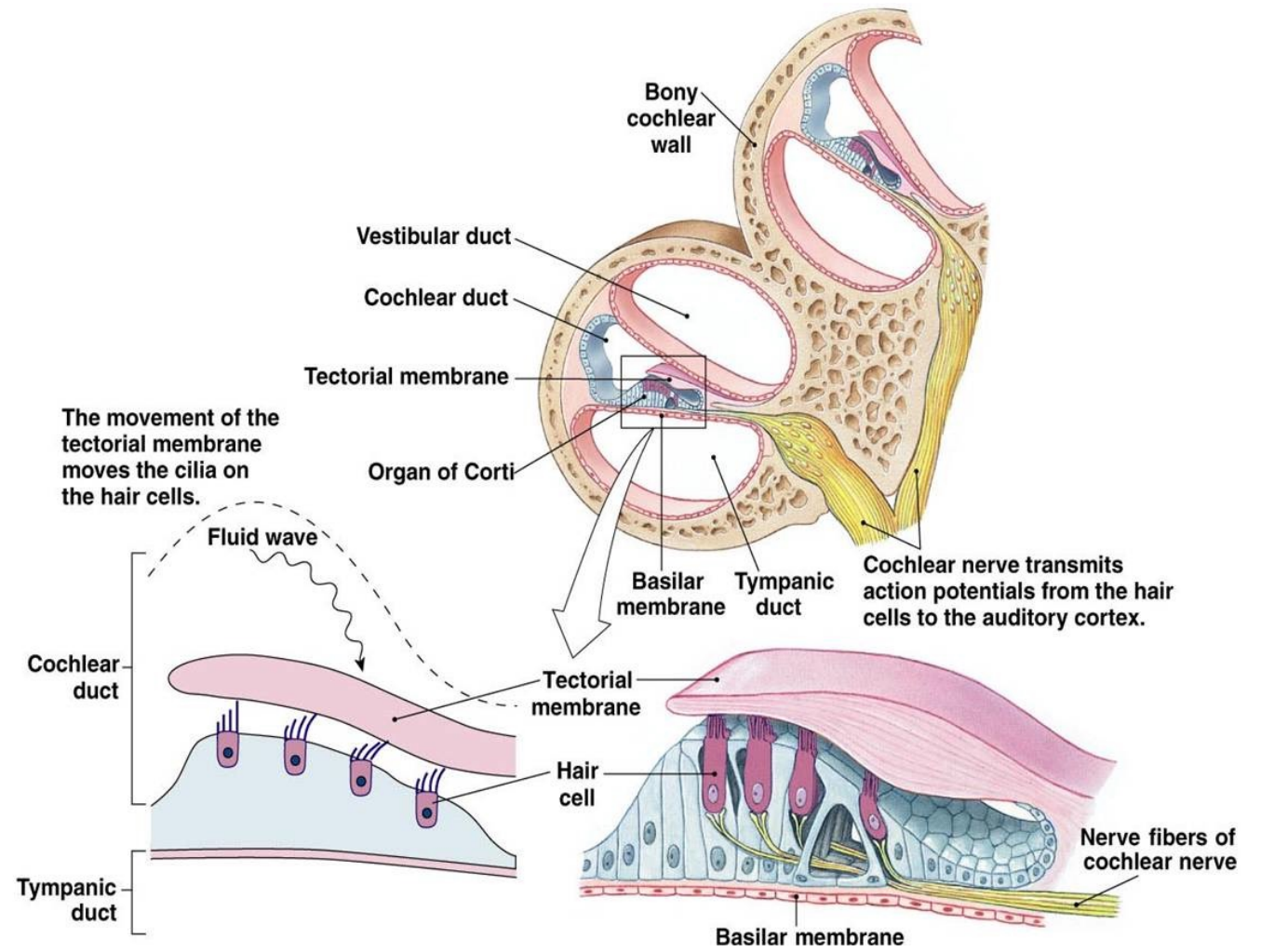
- Cochlear implants
- Deep brain stimulation
- Stimulation of the spinal cord



Auditory circuits



The cochlea



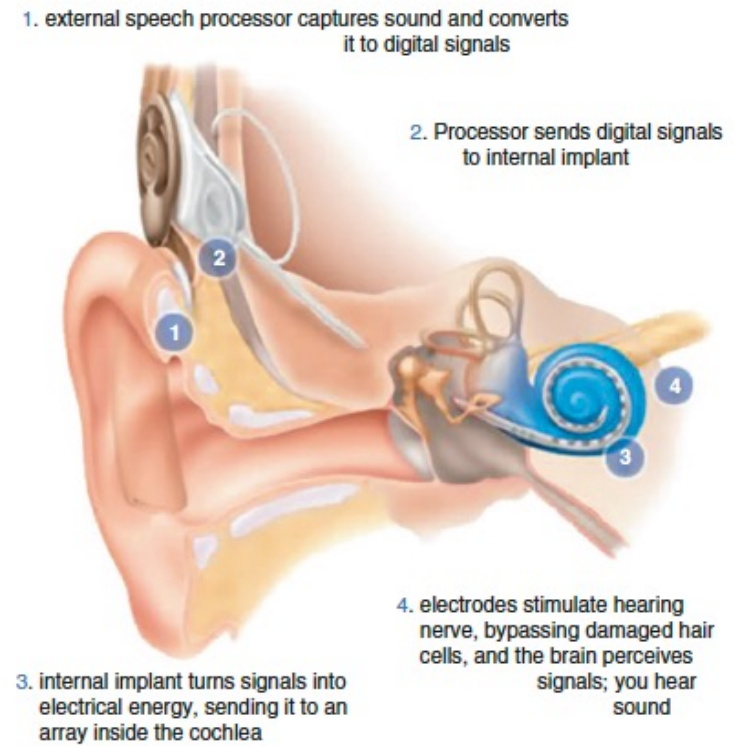
Cochlear implants

History

- First “experience”: Alessandro Volta (1800)
 - Electrical stimulation evoke auditory sensation in humans
- 1957 electrical stimulation of hearing in 2 deafened patients
- 1960s-1970s – multiplied efforts in the USA
- 1984: FDA approves the first cochlear implant (many others ensue)

- **Main players today:**
 - Med-El Corp., AU; Cochlear Corp., AUS; (Advanced Bionics) Sonova Holding, CH
 - audiological criteria for cochlear implantation:
 - from bilateral total deafness (<110 dB HL) in the early 1980s
 - to severe hearing loss (>70db HL) in the 1990s,
 - then to current suprathreshold speech based criteria (< 50% open-set sentence recognition with properly fitted hearing aids).

Cochlear implants



A long-term interface

- **Exceptional constraints on life-time**, reliability of the interface
 - Implantation in new-borns
- **Implantable electronics**: as simple as possible
 - Transmitter of signals received from external device to the electrodes
 - 12-22 channel electrode
 - “no upgrade” over time of the implanted hardware
- **External speech processor**
 - Complex signal processing
 - Positioned behind the ear
 - Energy source (battery)



Surgical positioning

- Difficulty due to configuration of bones around the cochlea
- Proximity of facial nerves
- Alignment of the external and internal coils
 - Implanted magnet (issue with MRI)



Implantable electronics

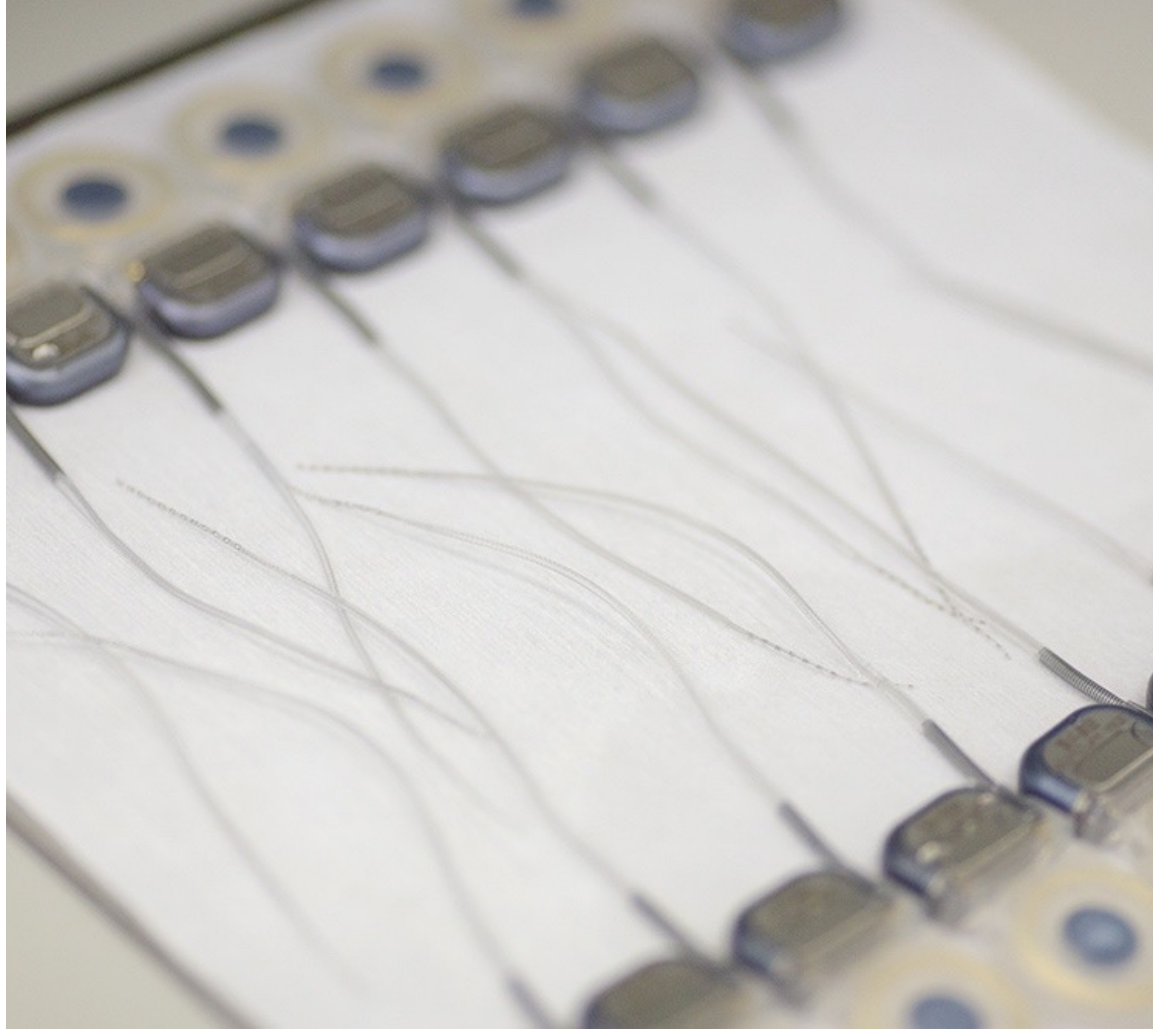
- **Titanium housing** providing hermetic seal to implantable electronics
 - Must be as thin as possible
 - Limited protrusion under the skin
 - Minimal skin erosion
 - Inductive coupling for power transfer
 - Induction coil outside of the casing
 - mm distance between coils
 - Alignment of coils
 - External batteries

- **Connectors**
 - Non detachable lead cable from housing
 - Challenges of number of contacts and hermeticity
 - One company : Bal Seal Engineering Inc.

Bal Spring® technology

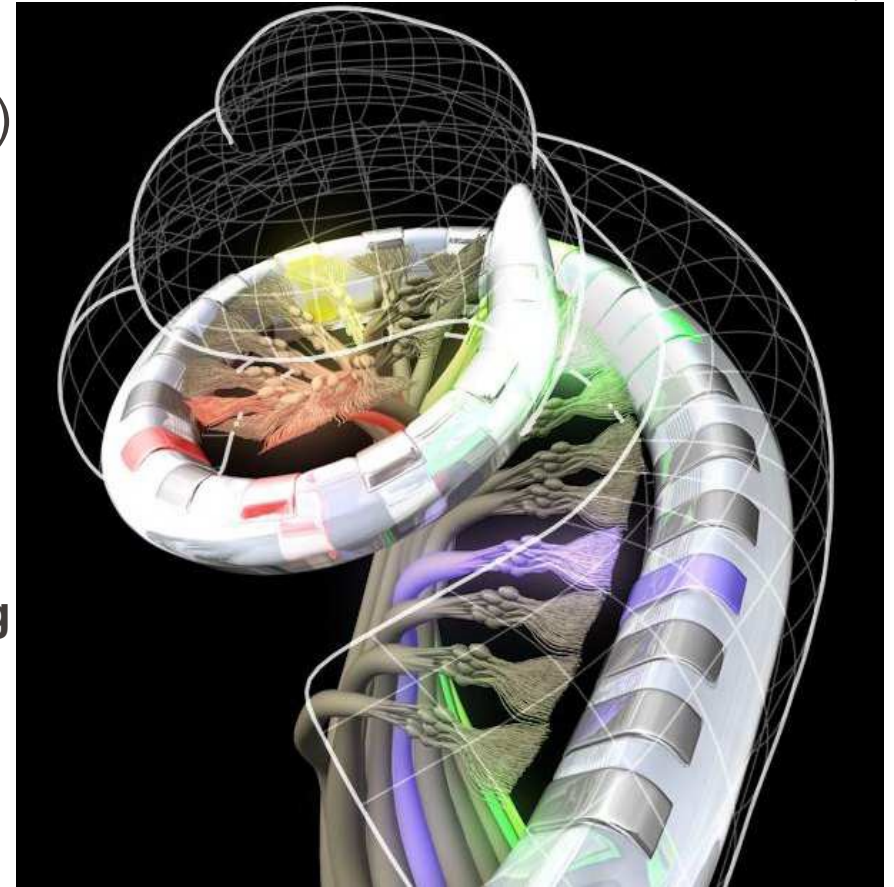


Implantable interface

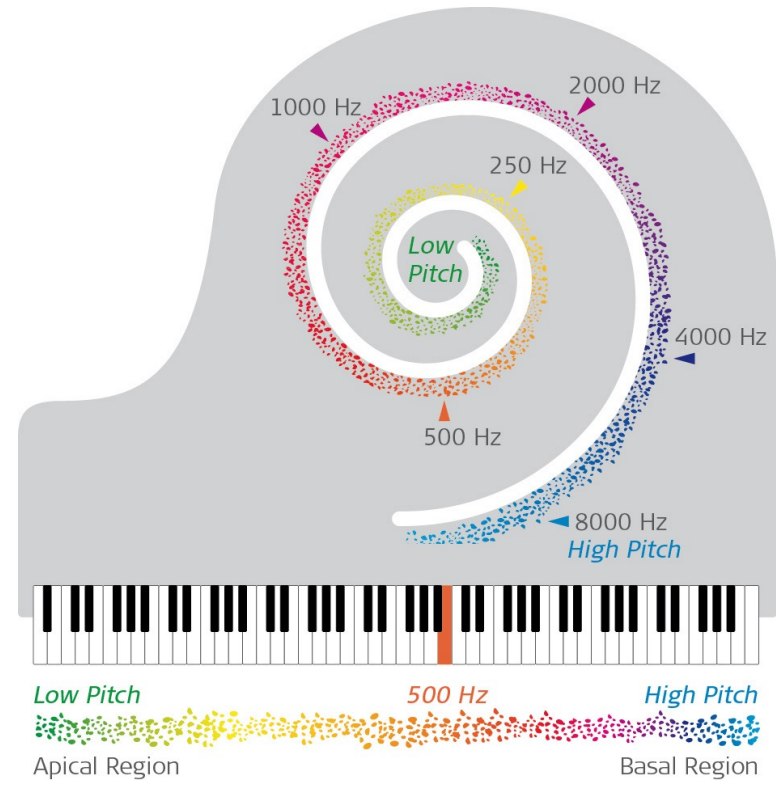
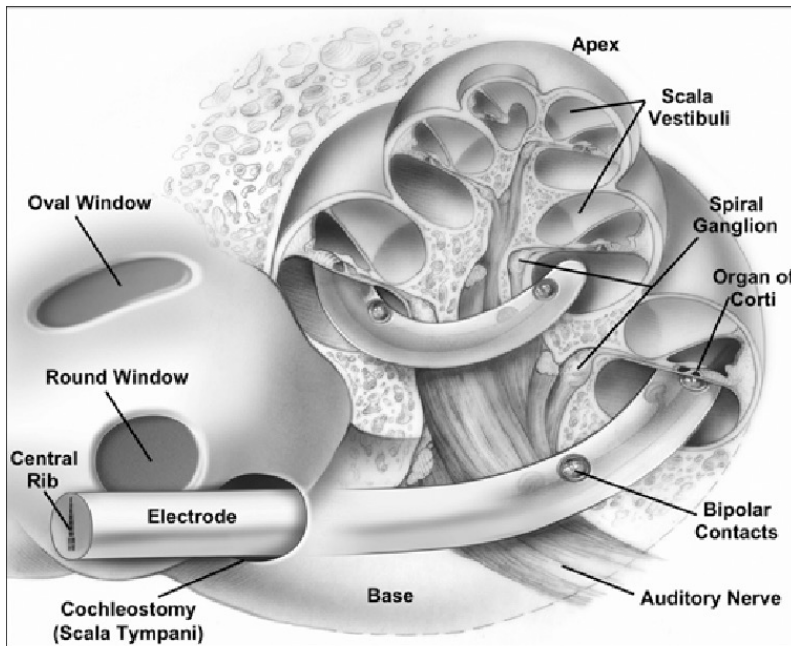


Cochlear Electrodes

- Invasive electrodes (surgical positioning)
- **Electrode contacts**
 - non-insulated surface
 - Metal: **Platinum**
- **Insulated wires**
 - gathered in a coiled cable or a flat ribbon
 - Materials: **Platinum-Iridium 90/10**
with Teflon insulating coating
- Embedded in **silicone** to form the lead

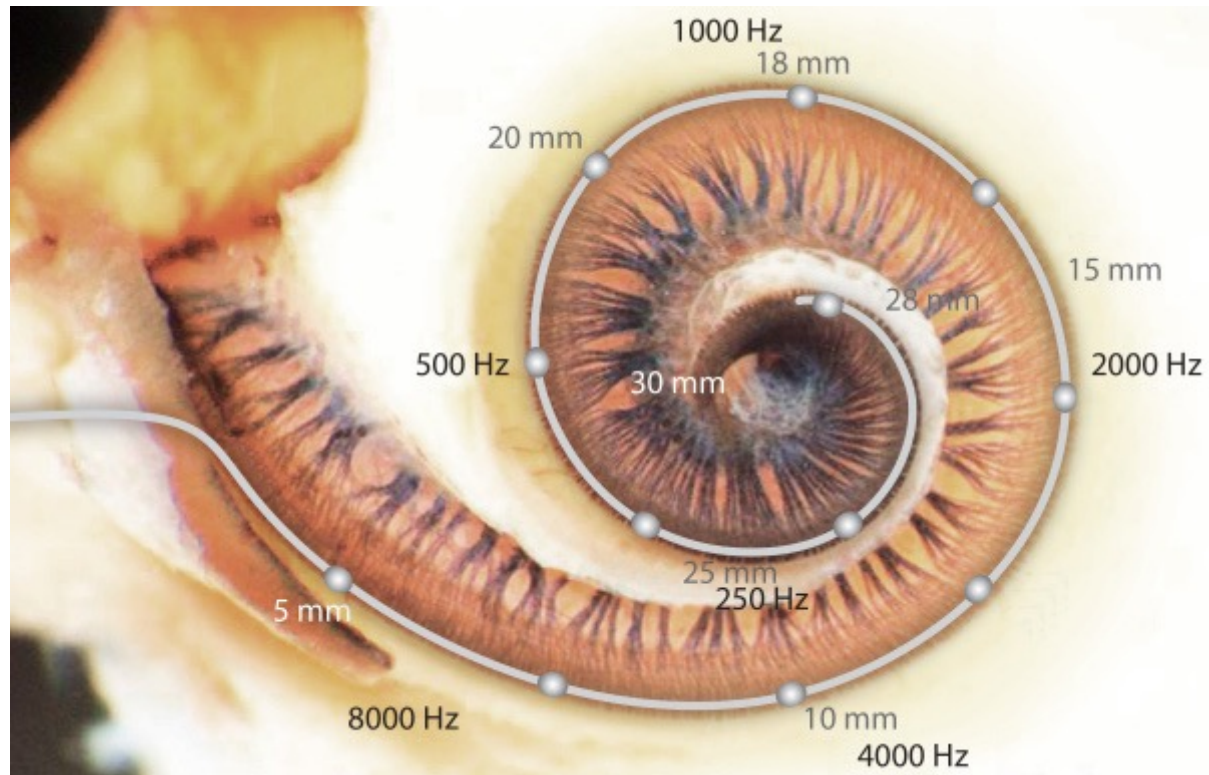


The cochlear implant



<https://www.youtube.com/watch?v=bDx12M5u4uY#t=45>

Accessing the cochlear tonotopy



The diameter of the cochlea canal is about **1mm** at the widest
Radius of curvature: **~ 4mm**

Cochlear implant



■ NX-422 ©LSBI



Nucleus® 8 Sound Processor
behind-the-ear



Nucleus® Kanso® 2
Sound Processor
off-the-ear



Nucleus implant

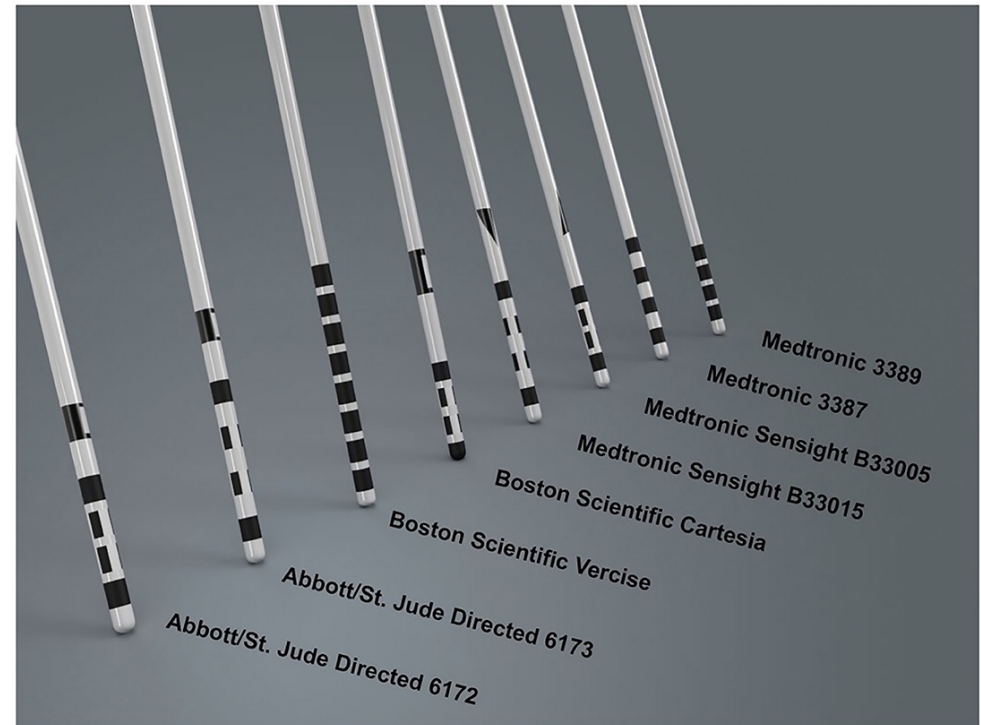
Enables speech understanding
in quiet and some noisy environment

Deep brain stimulation DBS

- Electrodes
- Cable (lead)
- Implanted electronics
- Control
- Recharge



- DBS lead (Electrodes)
- Extension
- Neurostimulator
- Adjustment



DBS Implantable Pulse Generator (IPG)

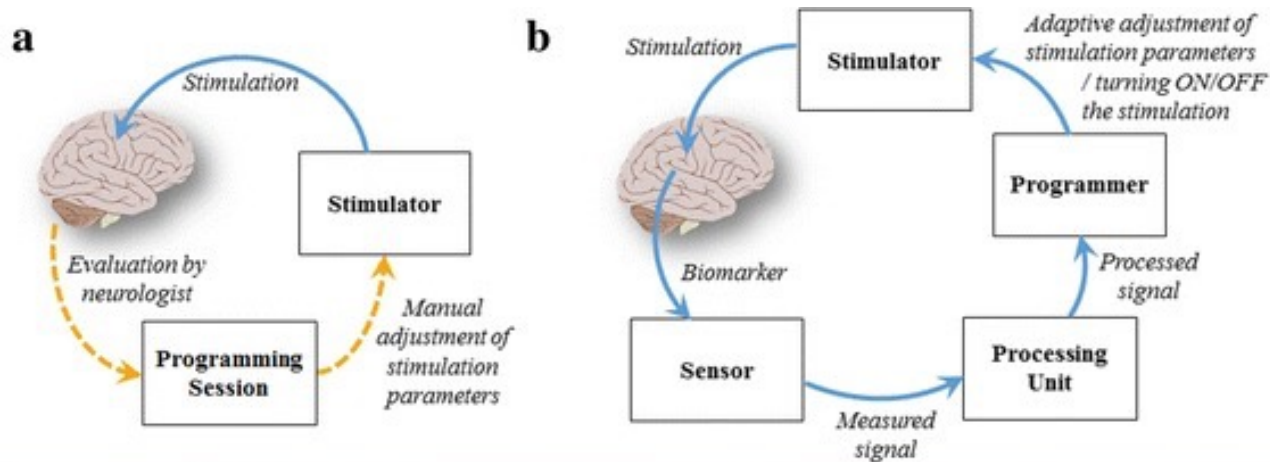
- DBS lead (Electrodes)
- Extension
- Neurostimulator
- Adjustment



Select and adjust

- DBS lead (Electrodes)
- Extension
- Neurostimulator
- **Adjustment**



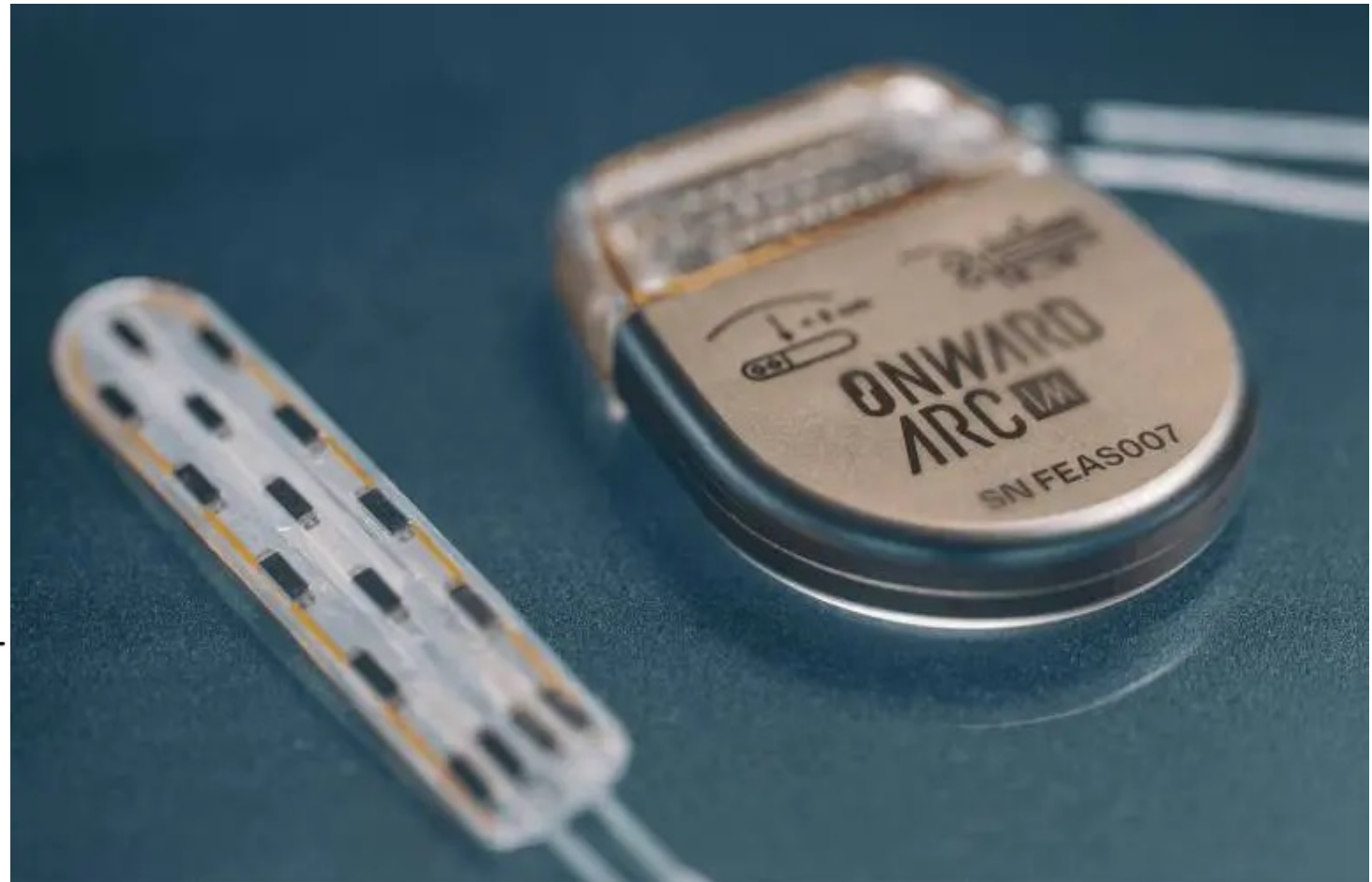
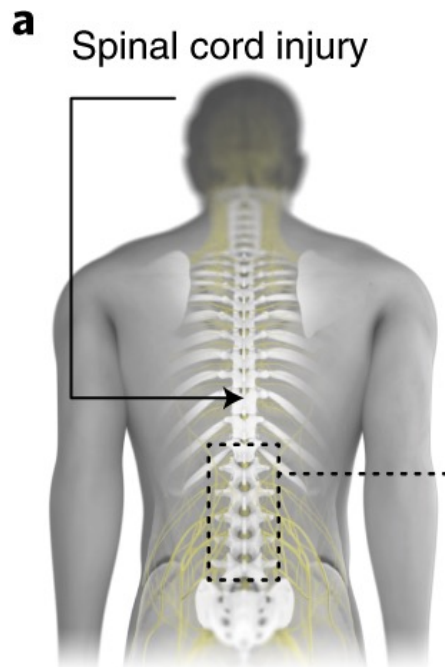


introduced in 2000s

Realtime adjustment of stimulation parameters as a function of biological metrics

J Neuroeng Rehabil. 2017; 14: 79.

Stimulation of the spinal cord



NX-422 ©LSBI

■ G. Courtine, J. Bloch EPFL/CHUV/UNIL

Rowald et al. **Nature Medicine** 2022

STIMULATION OFF



■ G. Courtine, J. Bloch EPFL/CHUV/UNIL

Wagner et al. **Nature** 2018

upper limb movement following paralysis



Nature 2012

Tactile sensation with a robotic hand



EPFL S. Micera

Science Trans. Med. 2014

Speech restoration through a BCI and an avatar



UCSF

Nature 2023

Biological metrics (1/2)

- **The aqueous internal environment**
 - Water: 55 – 75% in weight
 - Intercellular fluid (1/3) and extracellular fluid (2/3)
 - Body temperature: 37°C

- **Biological fluidics**
 - **Bulk flow:** transport with the carrying medium (blood, air)
 - **Passive diffusion:** concentration gradient

■ Biological electricity

- Movement of ions across the membrane of the cells → **ionic currents**
 - Membrane potential E_m , between -60mV and -90mV
- Excitable tissues can generate **action potentials**
 - Transient depolarization of the cell as a result of ion channel activity
 - Action potentials **transmit information** to nerve cells
 - Action potentials **trigger contractions** in muscle cells

■ Actuators: Muscles

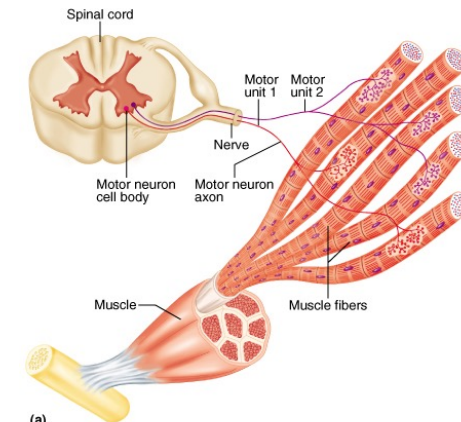
- Soft tissues, which change size and shape
- Produce force and motion
- Skeletal / cardiac / smooth (involuntary)

■ Sensors

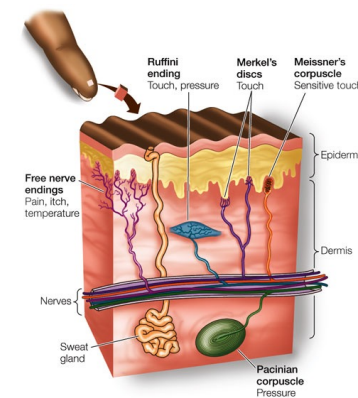
- Mechanoreceptors (touch)
- Chemoreceptors (taste)
- ...

■ Processor

- Neural circuits
- Peripheral nerves / spinal cord / brain



(a)
Copyright © 2001 Benjamin Cummings, an imprint of Addison Wesley Longman, Inc.



LIFE 8e, Figure 45.6

	Whole brain	CPU
weight	1.4 kg	< 100g
power	~22W	> 25W
units	10^{11} neurons	10^8 transistors
Glial cells	~3 x neurons	
connections	10^{15}	$> 10^{10}$
wiring	8 million of km of axons	~ 100 km

Based on
Intel Core i7-1260U

Supercomputers vs the brain

- the human brain: ~85 billion neurons with 1/10'000 connectivity
- the brain computing: very hard to estimate
 - 1 – 10 petaFLOP/sec, maybe 1 exaFLOP/sec and under **50W power**
- Supercomputers
 - 1960:
 - IBM7030 Stretch: > 1 million instruction per second
 - 2012:
 - IBM Blue Gene Q ® 16 petaFLOP/sec using 7.9MW (!)
 - 2024:
 - Train ChatGPT4 108 ExaFLOP/s, **50GWh**

Important considerations when designing a neural interface

- Assess the **topology** of the medium to interface
- Assess the **dynamics** of the host medium
- Assess the **function(s)** of the biological tissue
- Define the **form-factor** and **eventual range of compliance** of the neural interface (application-driven)
- Select the appropriate device **technology** (including biocompatibility)
- Manufacture the required **function** and assess its **reliability**