Neural Prosthesis:

Engineering helping the deaf hear and the blind see

신경보철:

감각및 운동장애장애를 위한 전자이식체기술

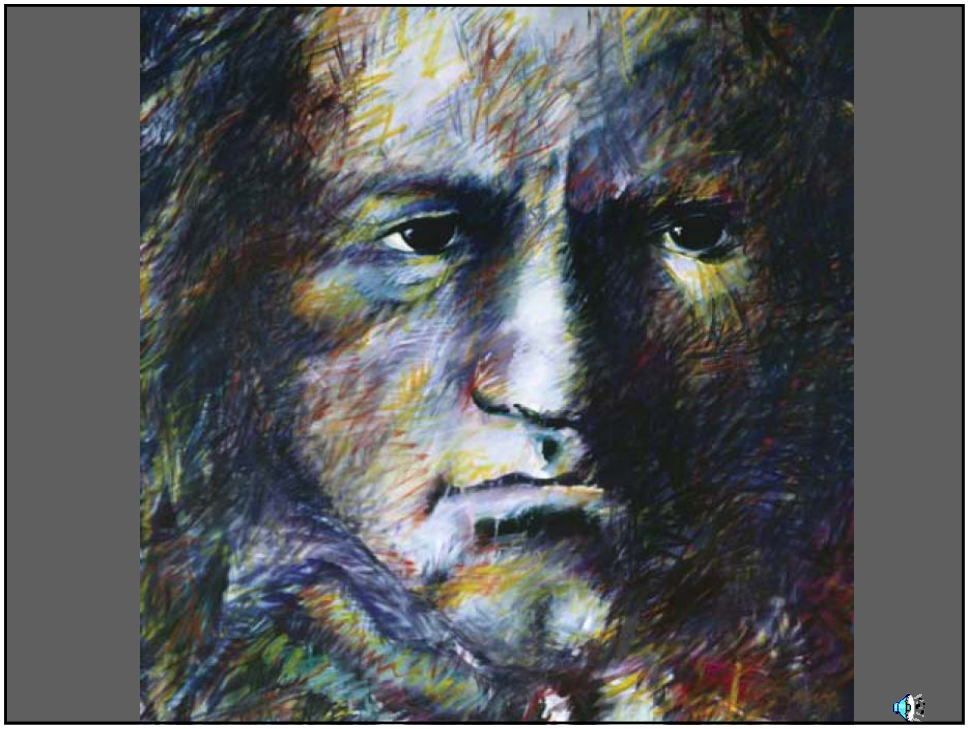
김성준
Sung June Kim

Nano Bioelectronics & Systems Research Center
School of Electrical Engineering
Seoul National University

Seoul National University

서울대학교 초미세생체전자시스템연구센터

Some of the slides were borrowed from Dr. Veraart of Belgium (Vision Prosthesis) and from Prof. Blake Wilson of RTI (Cochlear Implant).

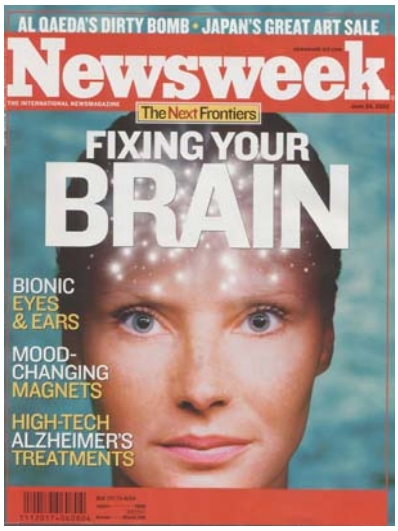


Neural Prosthesis

- A device that connects directly with the nervous system to replace or supplement sensory or motor function.
- A device that improves the quality of life of a neurologically impaired individual so much that he/she is willing to put up with the surgery, gadgetry, etc.

Now it is a science.

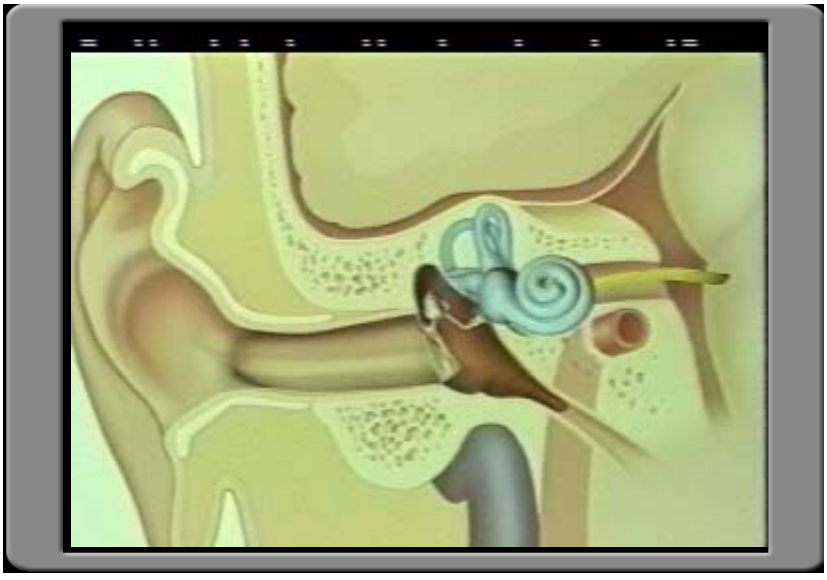
And it is newsworthy.



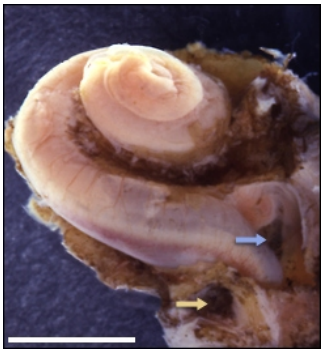
2002.6.24. NEWSWEEK

Successful Areas of Neural Prosthesis

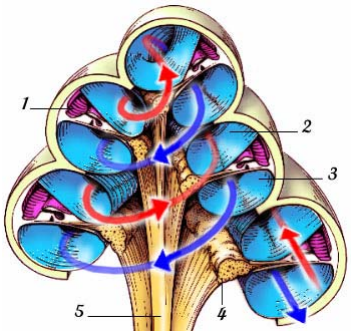
- Hearing: Cochlear Implant
- Parkinson's Disease: DBS (Deep Brain Stimulation)
- Vision (in research)



Functional anatomy of the Cochlear

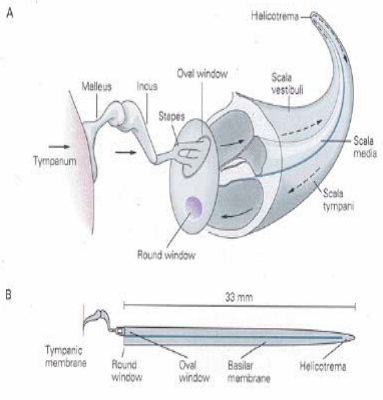


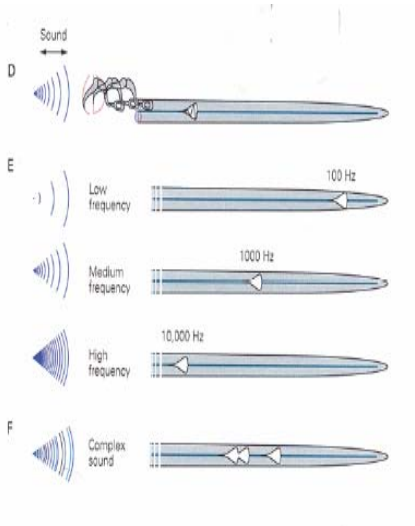
Cochlea from a human fetus
(5 months of gestation)
http://www.iurc.montp.inserm.fr/cric/audition/english/cochlea/fcochlea.htm



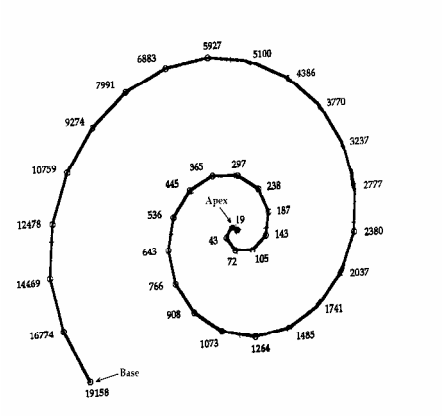
(1) the scala media which contains endolymph
(2) the scala vestibuli (3) scala tympani.
(4)the spiral ganglion
(5)the auditory nerve fibres

The Basilar Membrane is a Mechanical Analyzer of Sound Frequency.





Tonotopicity:Encoding Frequency



- Place Theory
- 1950s Georg von Bekesy: different frequencies cause maximum vibration amplitude at different points along the basilar membrane. → tonotopic (high freq. At the base & low freq. At the apex)

인공와우를 필요로 하는 사람들
FDA-Approved Candidacy Guidelines, 1998

- Children
  - >18 months
  - Bilateral profound deafness
    - Lack of progression of simple auditory skills
      - With appropriate amplification and aural rehabilitation for over 3-6 months
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- Adults
  - Profound deafness >90dB
  - Do not benefit from appropriate hearing aids
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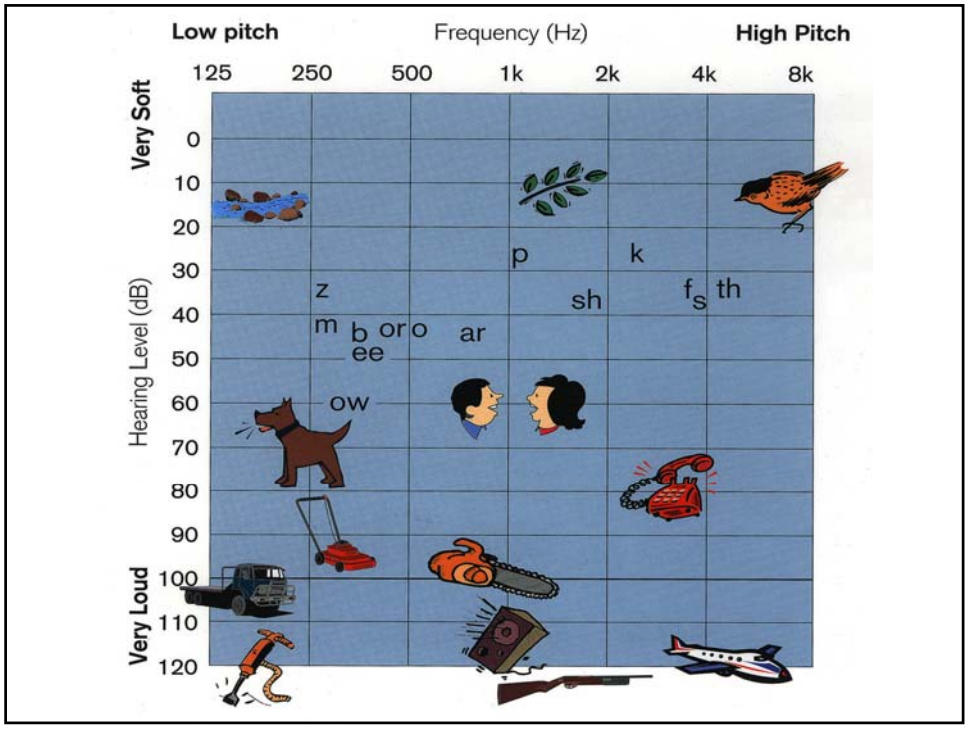
Low pitch
Frequency (Hz)
High Pitch
125
250
500
1k
2k
4k
8k
Very Soft
Hearing Level (dB)
Very Loud
0
10
20
30
40
50
60
70
80
90
100
110
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z
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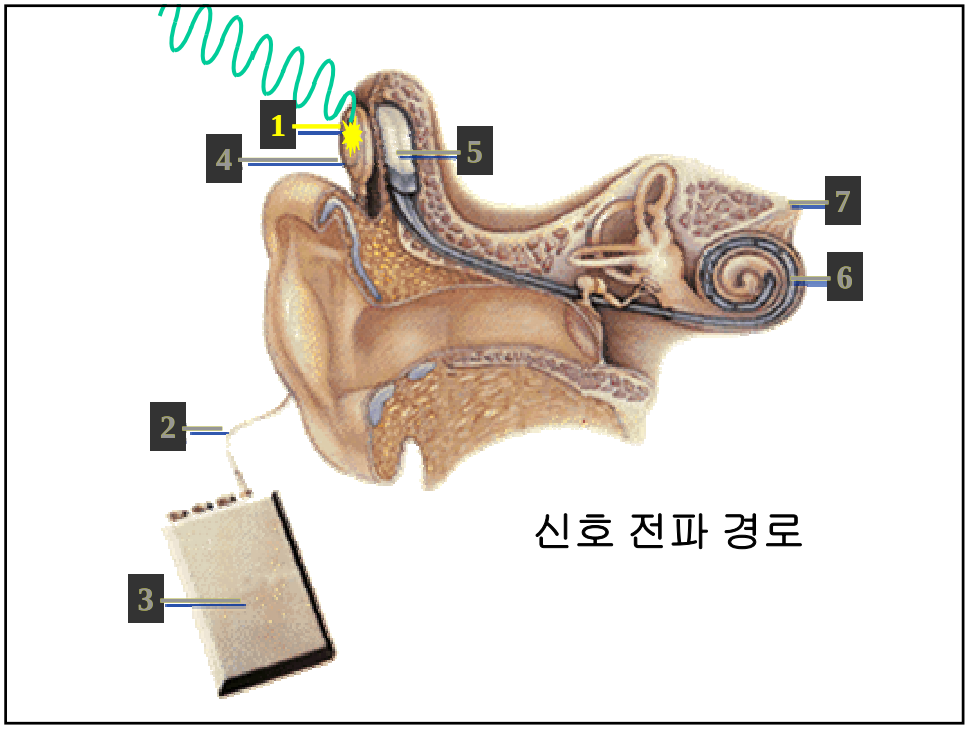
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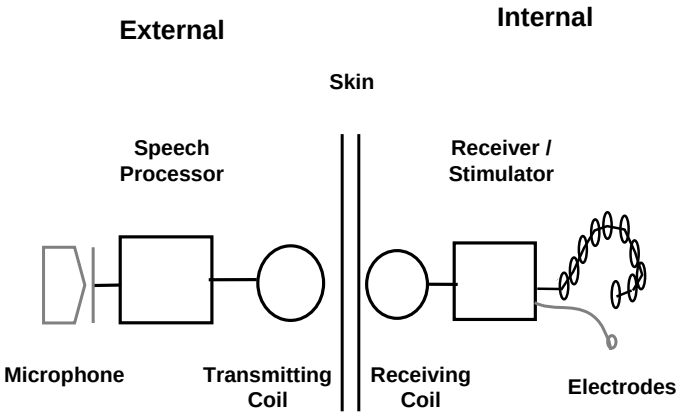
2
3
4
5
6
7
신호 전파 경로

In Blocks



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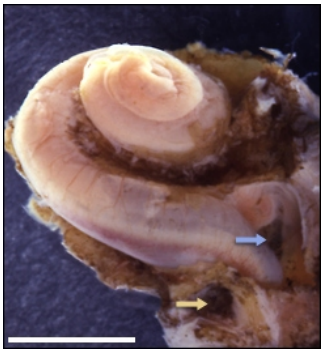

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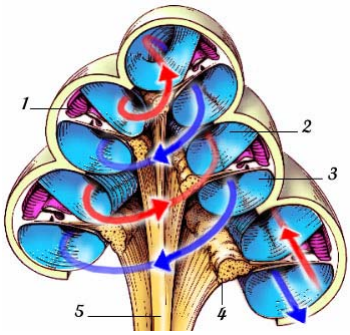

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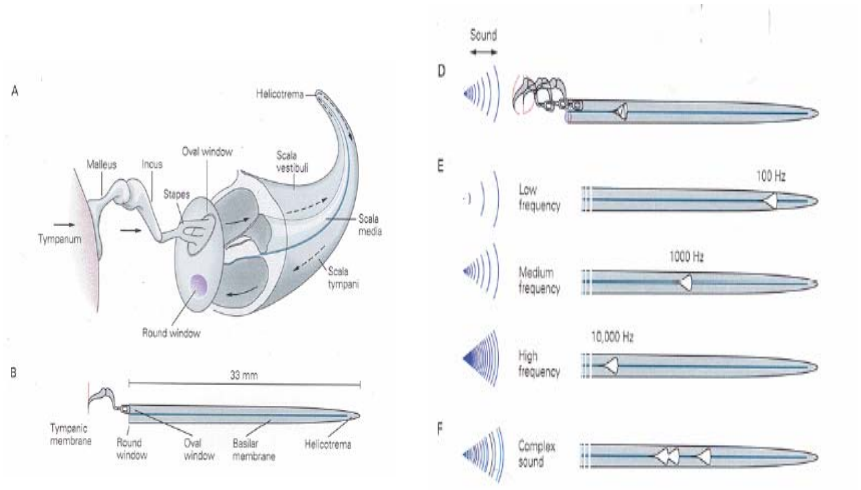

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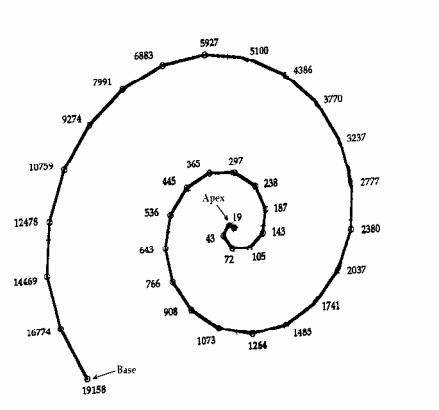

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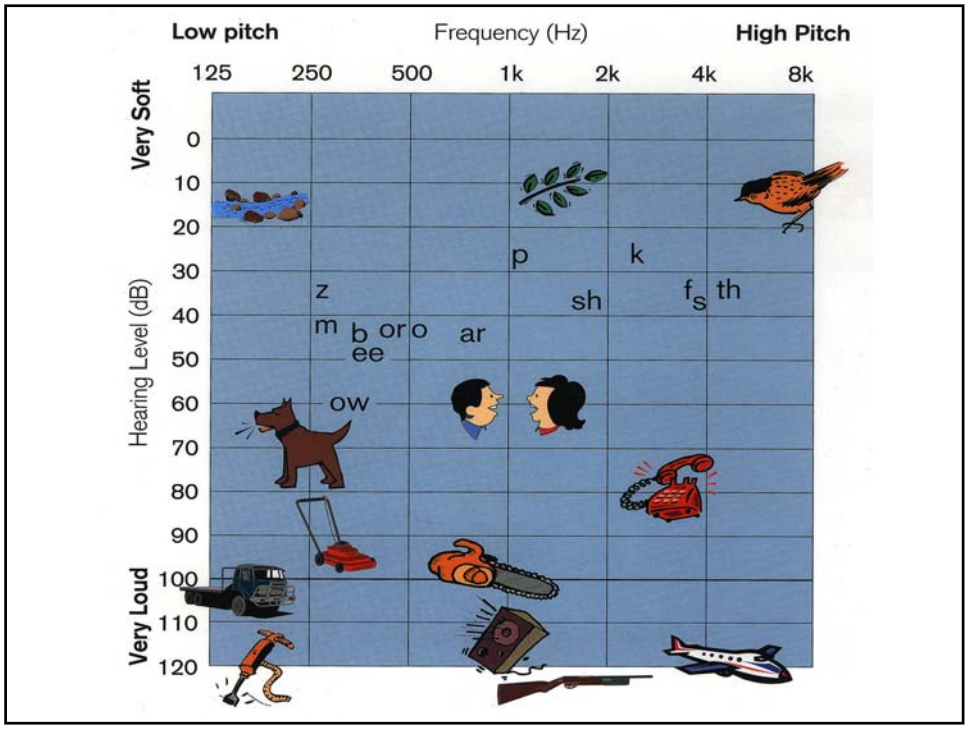

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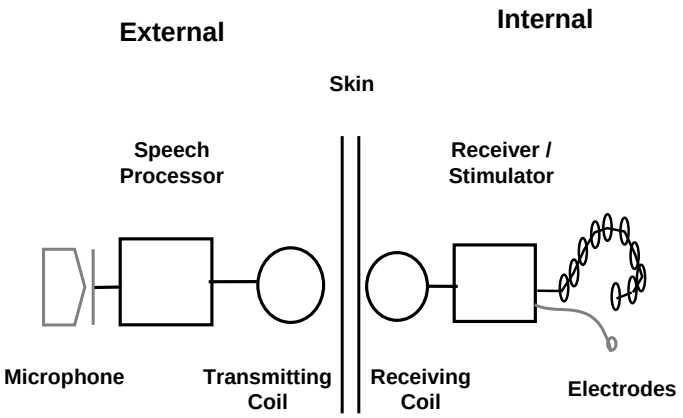
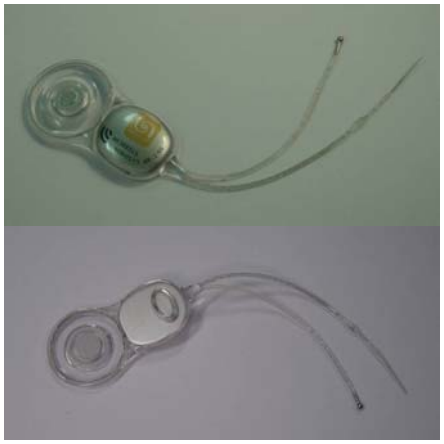


Internal Implant



System Specifications

(1) Data transmission
- **A. Forward telemetry**
  - Bit rate : 128kbps
  - Demodulation : Pulse Counting
- **B. Backward telemetry**
  - Modulation : Time Coded Load Modulation

(2) Stimulation
- CIS strategy.
- 16ch mono/ 8ch bipolar biphasic stimulation
- Stimulation rate : 1,000pps/channel
- Duration : 0usec ~ 56usec (8usec step)
- Amplitude : 0uA ~ 1810uA (7.1uA step)

(3) Electrode
- Straight, Pri-curved shape with ball type site

(4) Housing
- Ti alloy

Wearable Speech Processor

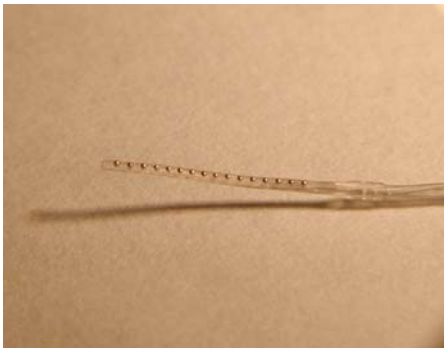
General Description

(1) DSP based WSP
(2) 8ch CIS Strategy
(3) PC interface for mapping
(4) Forward telemetry for stimulation
(5) Backward telemetry for
Impedance check and system check

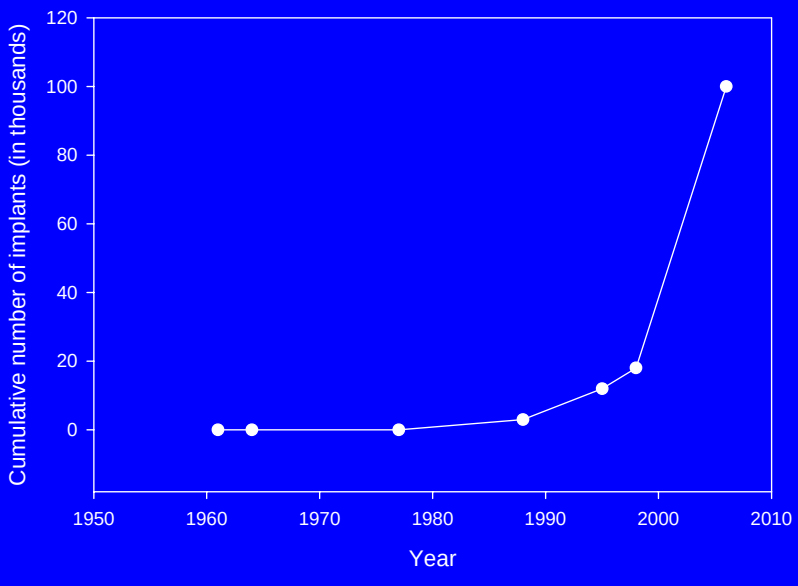
Hardware Spec.

(1) Size (L-W-H, mm) : 80 X 55 X 23 (including batteries)
(2) PCB size (L-W-H, mm) : 70 X 45 X 8
(3) Batteries : 1400mAh 3.3.V Ni-MH battery 2ea.
(estimated total power : about 3267mWh)
(4) Power consumption : 200mW
(5) Estimated operation time : min. 16 hours.

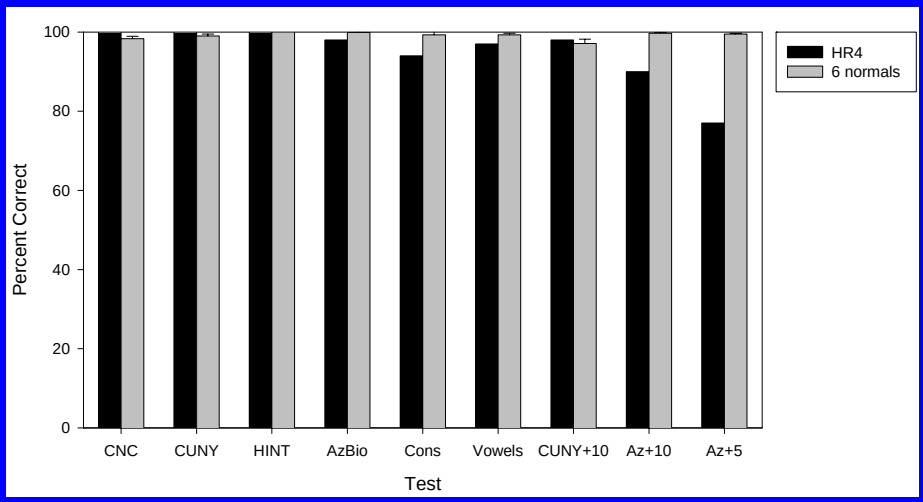
전극: Intra-cochlear Electrode



The basic premise was: There is no way to replace even crudely the exquisite structure and function of the cochlea



Speech test scores for a CIS user and for 6 subjects with normal hearing*

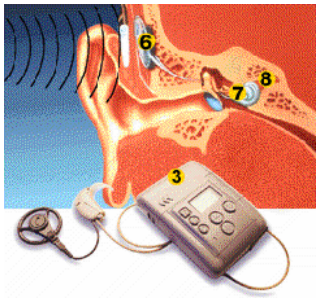


CIS parameters: 16 channels of processing and stimulation; 1449 pulses/s/channel; 11 µs/phase pulses

*Data from studies by Wilson and Dorman

Processed sounds

Processed Speech	Original Speech
1-channel simulation	Original sentence
2-channel simulation	Original sentence
4-channel simulation	Original sentence
8-channel simulation	Original sentence

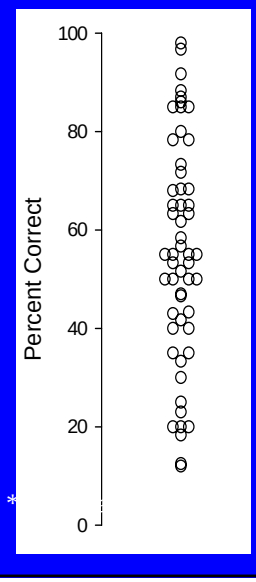


인공와우를 통한 음성인식 과정 시뮬레이션

1 2 4 6 8 16 24 32 64 N

What are the (remaining) problems associated with unilateral implants?

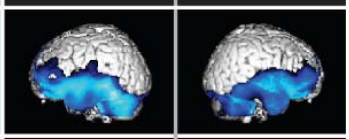
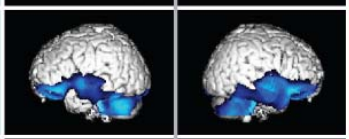
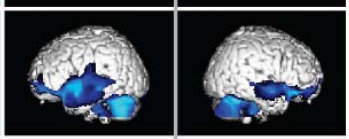
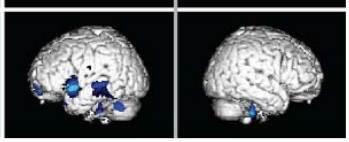
- Wide range of outcomes
- Speech reception in noise
- Sound localization
- Reception of signals more complex than speech, e.g., symphonic music
- High effort in listening for the great majority of patients



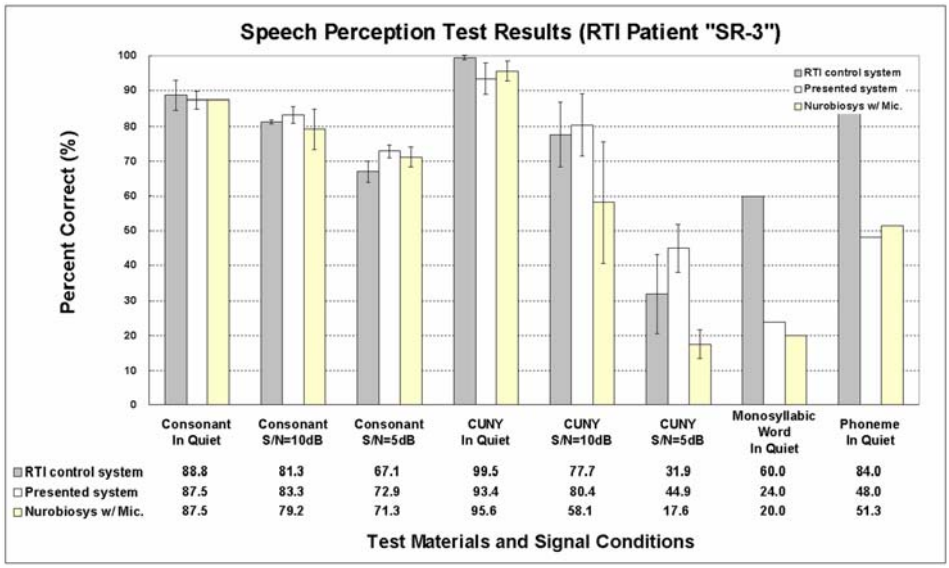
Possibilities for the future

- Further development and refinement of bilateral electrical stimulation and of combined EAS
- Closer mimicking of processing in the normal cochlea
- Representation of "fine structure" or "fine frequency" information with implants
- A "cognitive neuroscience" or "top down" approach to implant design
- Availability of low cost – but still highly effective – implant systems for widespread application in India, China and other developing countries
- Controlled delivery of neuro-protective or neurotrophic drugs to the implanted cochlea

Lee et al., "Cross modal plasticity and cochlear implants," *Nature* 409: 149, 2001.

duration of deafness (years)	left	right	sentence score (% correct)	duration of training (years)
6.5			90	3.8
6.5			67	1.1
11.2			7	1.4
20.3			0	1.9

Patient Test Results (RTI patient "SR-3")
Jan. 8th – 12th, 2007



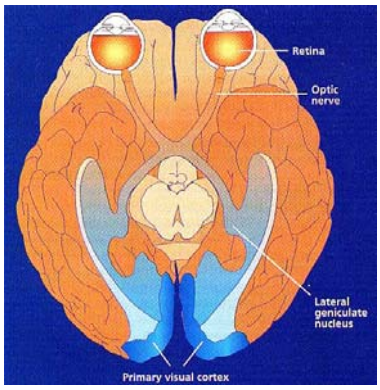
	Consonant In Quiet	Consonant S/N=10dB	Consonant S/N=5dB	CUNY In Quiet	CUNY S/N=10dB	CUNY S/N=5dB	Monosyllabic Word In Quiet	Phoneme In Quiet
RTI control system	88.8	81.3	67.1	99.5	77.7	31.9	60.0	84.0
Presented system	87.5	83.3	72.9	93.4	80.4	44.9	24.0	48.0
Nurobiosys w/ Mic.	87.5	79.2	71.3	95.6	58.1	17.6	20.0	51.3

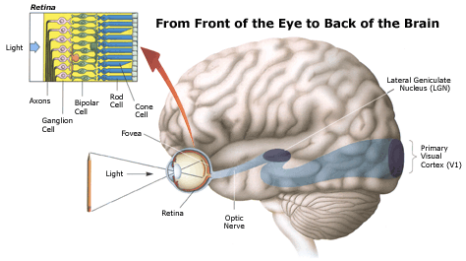
Cochlear implants have a bright future

- Combined EAS
- Bilateral implants
- Representation of fine frequency information
- Better mimicking of normal processing
- Fruits of a "top down" approach to implant design
- Advent of low cost but still highly effective devices
- Delivery of drugs to the implanted cochlea

Visual Pathway

- Photoreceptor → bipolar cell (BC) → ganglion cell (GC) → optic nerve (ON) → lateral geniculate nucleus (LGN) → primary visual cortex (VC)
- in brief, BC → GC → ON → LGN → VC

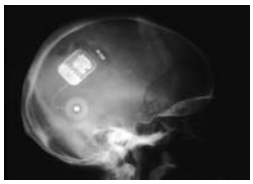




Diseases causing vision disorder

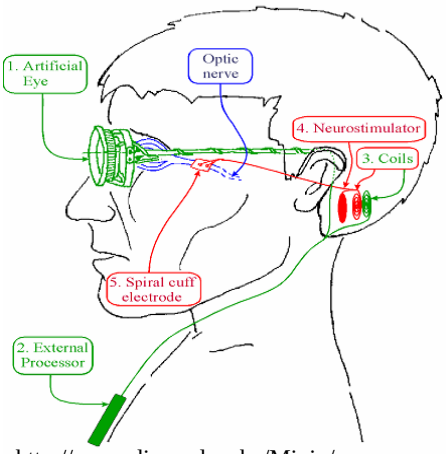
- Corneal Diseases
- Cataracts/Glaucoma
- Retina Diseases
  - **retinitis pigmentosa (RP) 망막색소상피변형증; 1/4000 in normal population**
  - **age-related macular degeneration (AMD) 연령 관련 황반변성; 1/20 in over 65**
  - **30% of etiology of blindness in adult**
- Optic Nerve
- Brain

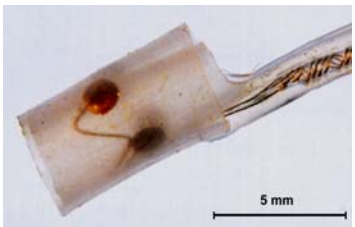
visual prosthesis
video

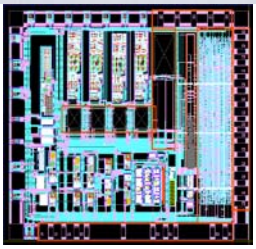


Courtesy of Dr. Claude Veraart, Université catholique de Louvain, 2004

Functional prototype of visual prosthesis
interfaced
with the optic nerve.



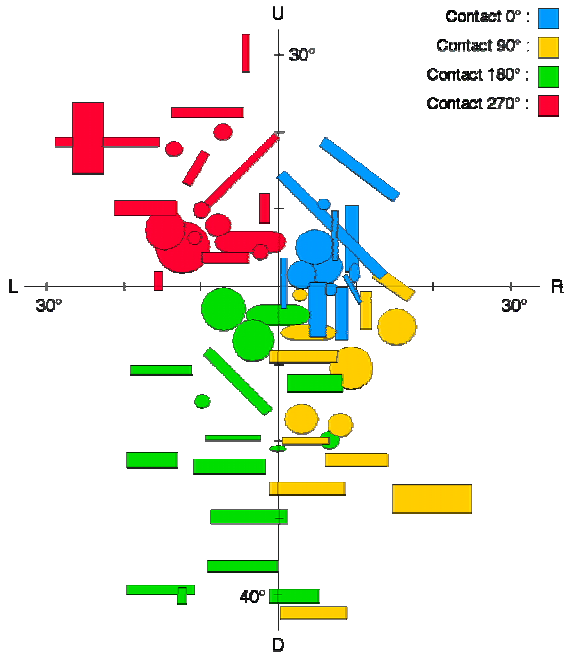




http://www.dice.ucl.ac.be/Mivip/

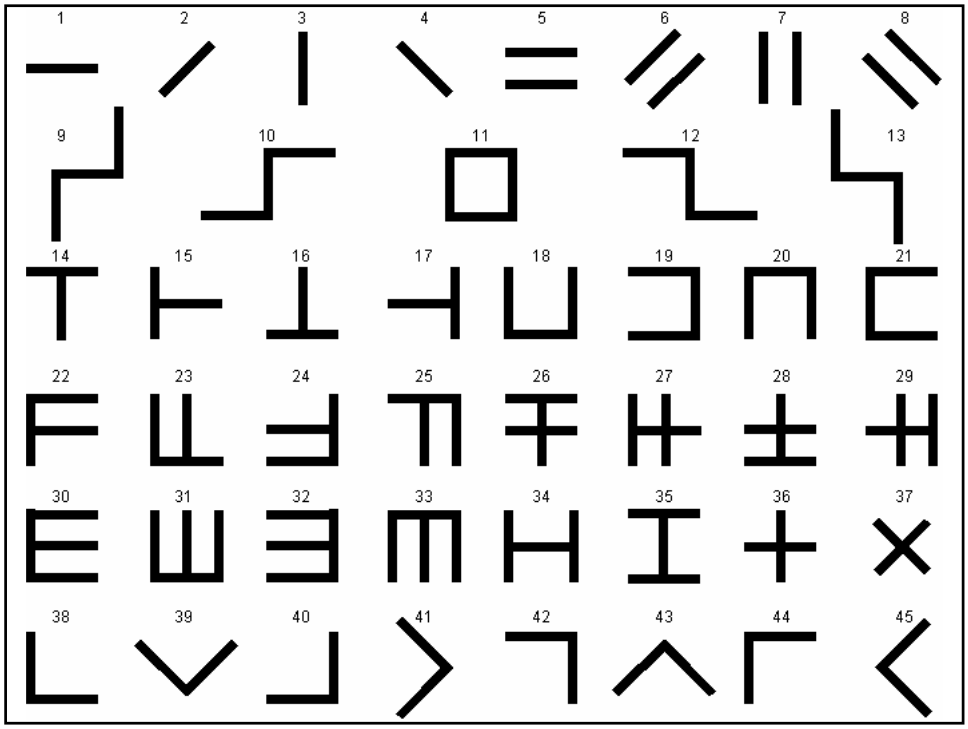
Claude Veaart, Universite Catholique de Louvain, Belgium

Optic nerve selective stimulation

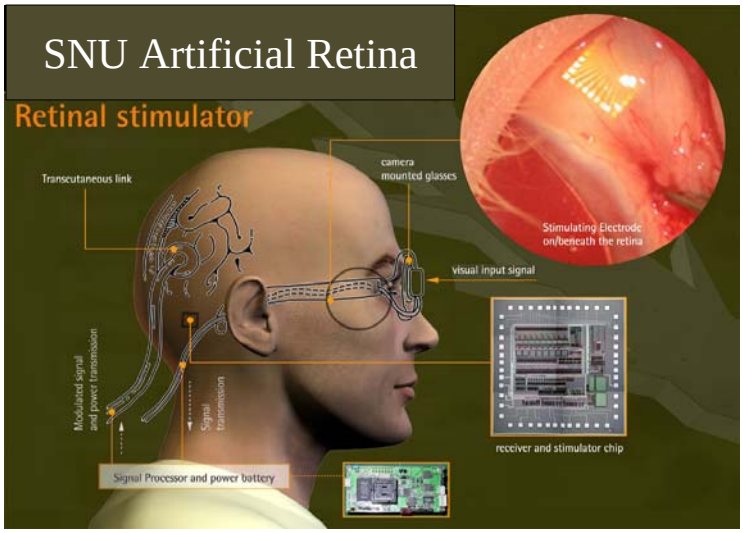


Phosphene position depends on the cathodic contact selected to deliver the stimulation

Veraart et al, Brain Research, 1998,813:181-186)



Retinal Implant :
Cochlear Implant like power and data transmission



뇌심부 자극기(Deep Brain Stimulator)

Neurological Movement Disorder

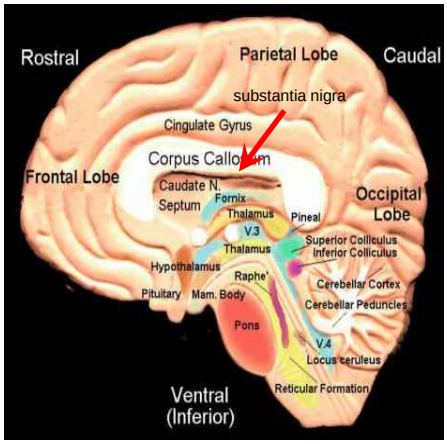
발병 원인

운동기능을 담당하는 뇌심부 구조물(substantia nigra) 에 존재하는 억제성 신경세포(inhibitory neuron)의 소실로 인하여 연접한 신경망의 over-activities 발생

➔ Movement Disorders 야기

종류 및 증상

- Parkinson's Disease
  - Tremore at rest state
  - lower shaking frequency
  - Ceases during purposeful movement
- Essential Tremor (본태성 진전)
  - Tremore during movement
  - Higher shaking frequency
- Dyskinesia (이상운동증)
  - Power Impairment of voluntary movement
- Dystonia (근긴장이상증)
  - Disordered tonicity of muscles



Treatments for Movement Disorders

Ablative Surgery

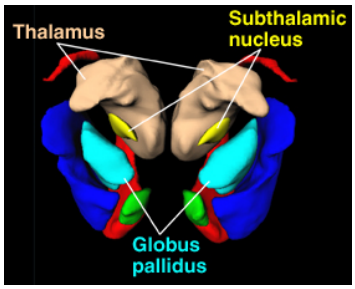
- Over activities를 보이는 심뇌부위를 제거함으로서 운동장애를 호전시키는 방법으로 20세기 초반부터 연구되어 온 가장 고전적인 방법
- 현재까지도 사용되고 있는 치료법이나, 절제 시 부작용에 의해 주변 뇌의 기능의 손상을 야기할 수 있음.

Drug Medication

- 신경전달물질을 이용한 약물을 투여하여 운동장애를 호전시키는 방법
- 증세가 호전되는 비율이 낮고, 시간의 경과에 따라 효과가 떨어짐.

Deep Brain Stimulation

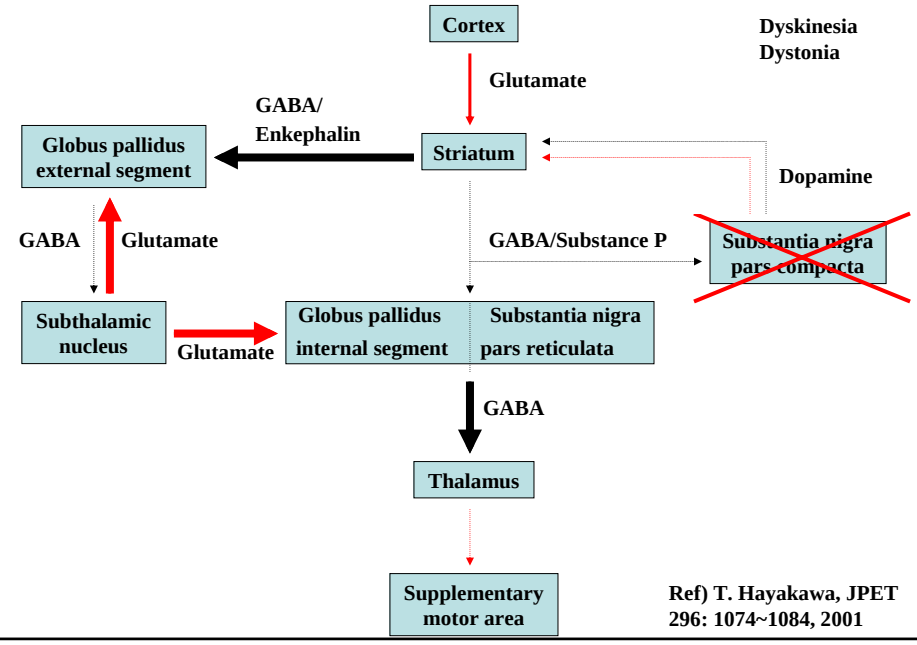
- 병변 부위에 전극을 삽입하여 전류자극을 줌으로서 운동장애를 극적으로 호전시키는 방법
- Tremor를 포함한 각종 운동장애에 효과가 있는 것으로 밝혀져 활발히 연구가 진행 중에 있음.



Three Stimulating Targets of DBS

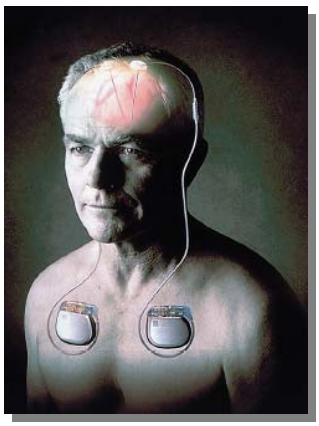
- Thalamic nucleus (시상핵)
- Subthalamic nucleus (시상하핵)
- Globus pallidus (창백핵)

PD pathway



Ref) T. Hayakawa, JPET
296: 1074~1084, 2001

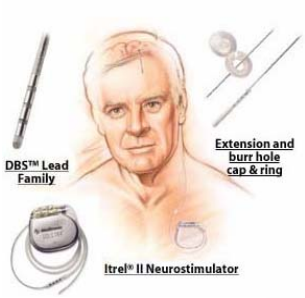
깊은 뇌 전기자극 (DBS; Deep Brain Stimulation)



DBS system 구성

Implantable Components

- Self-powered neurostimulator
- Electrode
- Connection leads



Patient Component

Use magnet link to turn neurostimulator off or on

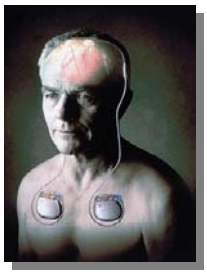
Neurological Test Stimulator

Device tests the effectiveness of stimulation intraoperatively or during a test stimulation period.

Physician Programmer

Programmer, printer, and programming head. Communicate via telemetry to adjust neurostimulator parameters.

DBS Video



Medtronic Inc. Activa® Tremor Control Therapy