Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework**

Consortium leader

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Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

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**Molekuláris Bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

***A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.

NEURAL INTERFACES AND IMPLANTS

(Neurális interfészek és implantátumok)

LECTURE 9

RETINAL IMPLANTS

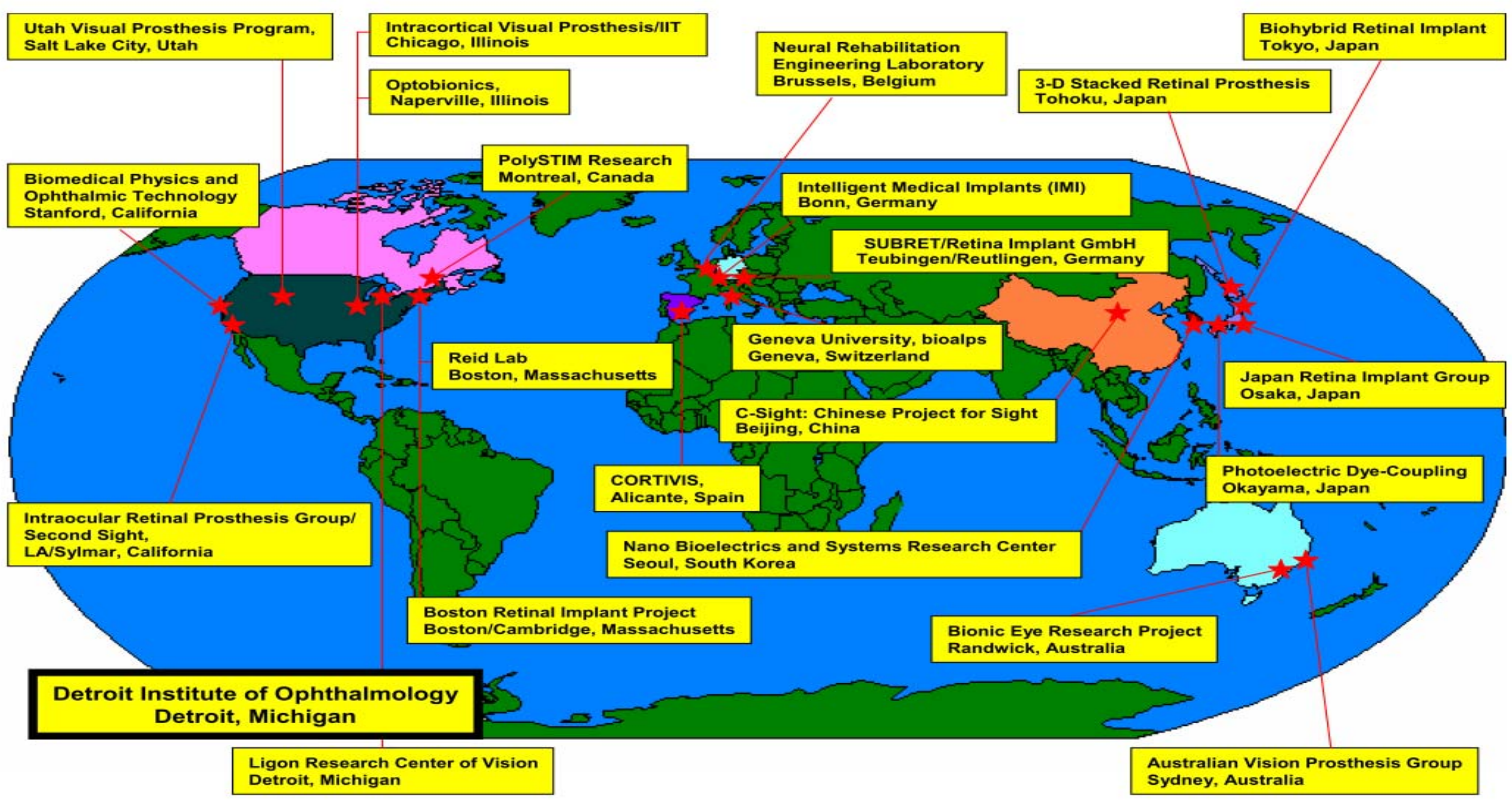
(Retina implantátumok)

Ákos Kusnyerik, Bálint Péter Kerekes and György Karmos

CONTENTS

- Aims
- Biological basics
  - The structure of the eye
  - The structure of the retina
  - The visual pathway
  - Retinal degenerations
- Basic research areas on visual prostheses
- Visual implants
  - Retinal implants
  - Cortical implants
  - Other solutions

WORLD'S ARTIFICIAL VISION CENTERS



Merabet LB, Rizzo JF, Pascual-Leone A, Fernandez E. Neural Eng. 4 (2007)

AIMS

The objective is to evaluate the safety and utility of the different artificial retina implants in providing visual function to blind subjects with severe to profound retinitis pigmentosa.

The outcome of clinical trial reveals the possibilities of the retinal implant to improve the situation of patients with hereditary retinal blindness caused by degenerations of the outer retina. Further aims are to study important information on safety and efficacy of sub-retinal implants.

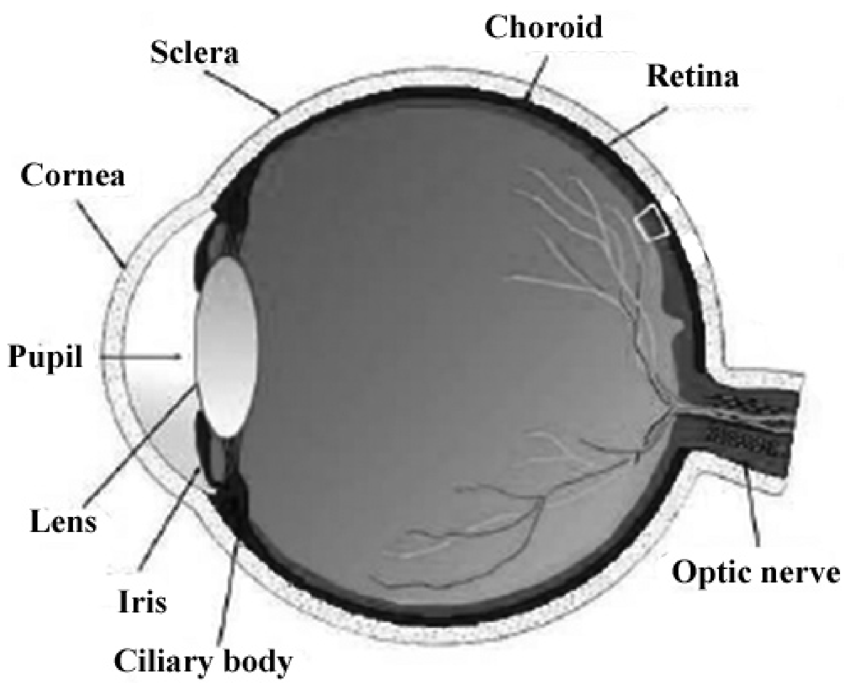
Patients suffering from hereditary retinal degeneration receive a retinal implant to restore sight.

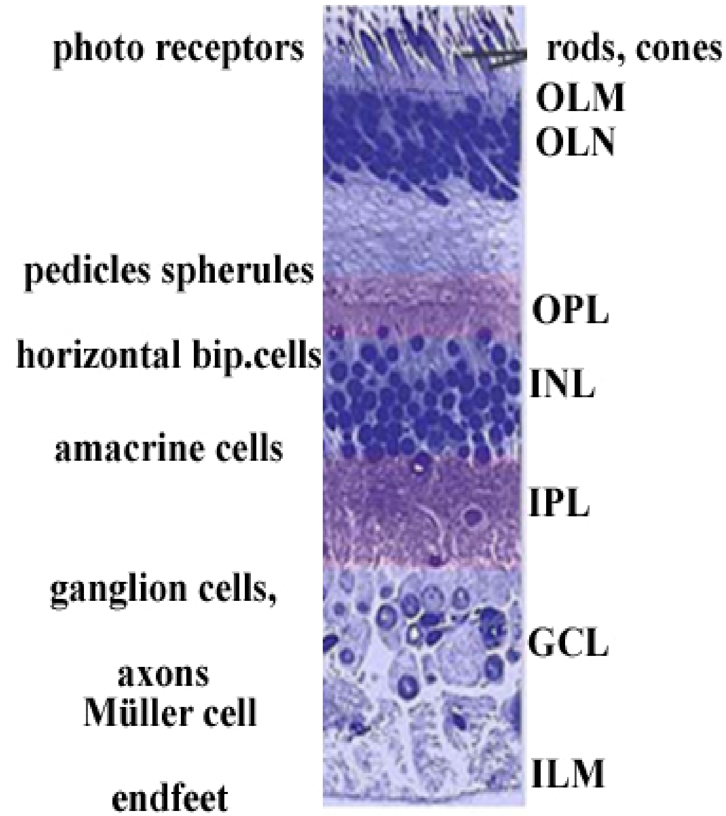
http://www.clinicaltrials.gov

BIOLOGICAL BASICS

- The structure of the eye
- The structure of the retina
- The visual pathway
- Retinal degenerations

THE STRUCTURE OF THE EYE





LAYERS OF THE VERTEBRATE RETINA (1.)

From innermost to outermost include:

- Inner limiting membrane – Müller cell footplates
- Nerve fiber layer – essentially the axons of the ganglion cell nuclei
- Ganglion cell layer – layer that contains nuclei of ganglion cells, the axons of which become the optic nerve fibers for messages
- Inner plexiform layer – contains the synapse between the bipolar cell axons and the dendrites of the ganglion and amacrine cells.
- Inner nuclear layer – contains the nuclei and surrounding cell bodies (perikarya) of the bipolar cells.

LAYERS OF THE VERTEBRATE RETINA (2.)

- Outer plexiform layer – projections of rods and cones ending in the rod spherule and cone pedicle, respectively. These make synapses with dendrites of bipolar cells. In the macular region, this is known as the Fiber layer of Henle
- Outer nuclear layer
- External limiting membrane – layer that separates the inner segment portions of the photoreceptors from their cell nucleus
- Photoreceptor layer – rods/cones
- Retinal pigment epithelium

THE STRUCTURE OF THE RETINA

R, rod;

C, cone,

FMB, flat midget bipolar cell; *IMB*, invaginating midget bipolar cell;

H, horizontal cell;

IDB, invaginating diffuse bipolar cell;

RB, rod bipolar cell;

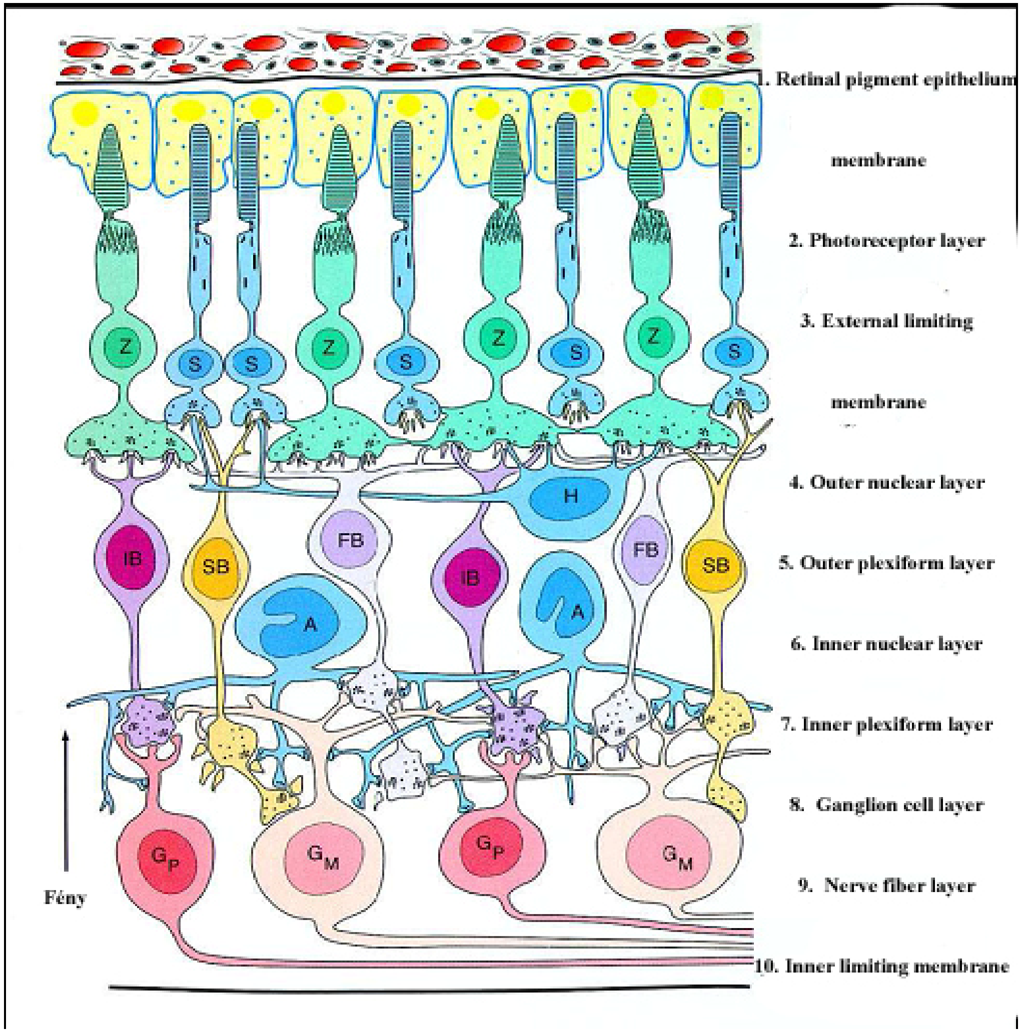
I, interplexiform cell;

A, amacrine cell;

G, ganglion cell;

MG, midget ganglion cell.

http://www.scholarpedia.org/article/Retina



Fovea:

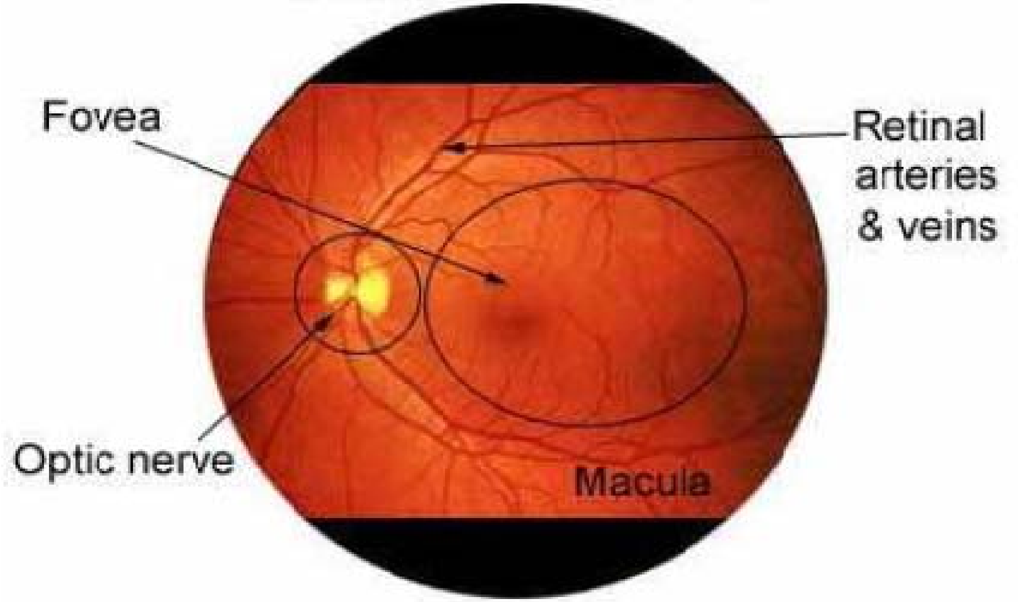
responsible for sharp central vision

Blind spot:

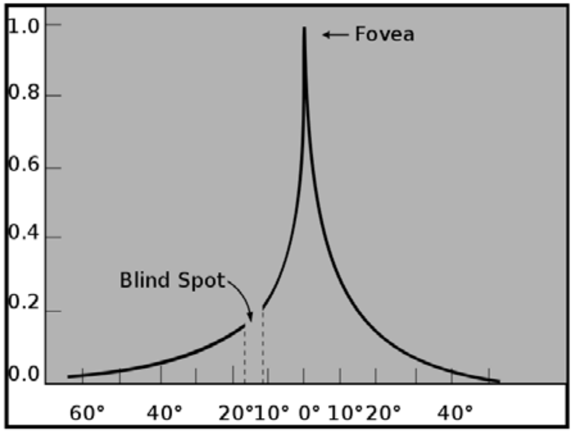
where the optic nerve escapes the eyeball (no cones, no rods)

Macula

dense with cones and rods



The diagram shows the relative acuity of the left human eye (horizontal section) in degrees from the fovea.



http://en.wikipedia.org/wiki/Retinal_prosthesis

THE „NUMBERS" RELATED WITH THE EYE

The eye: 10 cm3, axial length: 24 mm, Vitreous humour: 4-6,5 ml, 98% H2O

Retina: thickness 150-500 μm

~ 126 million photoreceptors

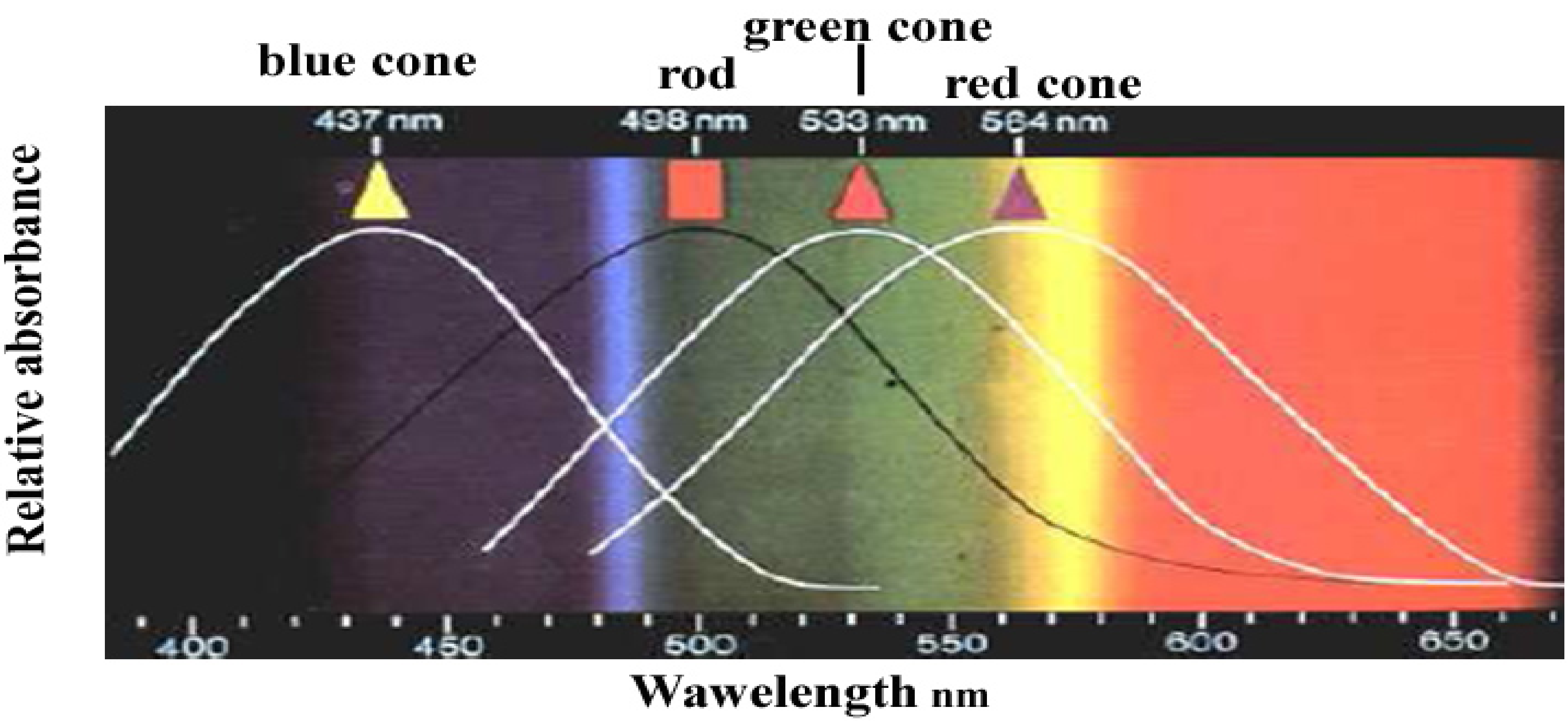
~ 1,2 million ganglion delegates the information to the cortex

120 M rod – 6.5 M cone – 1 M fiber(big convergence)

Photoreceptor : ganglion cell = 1:100

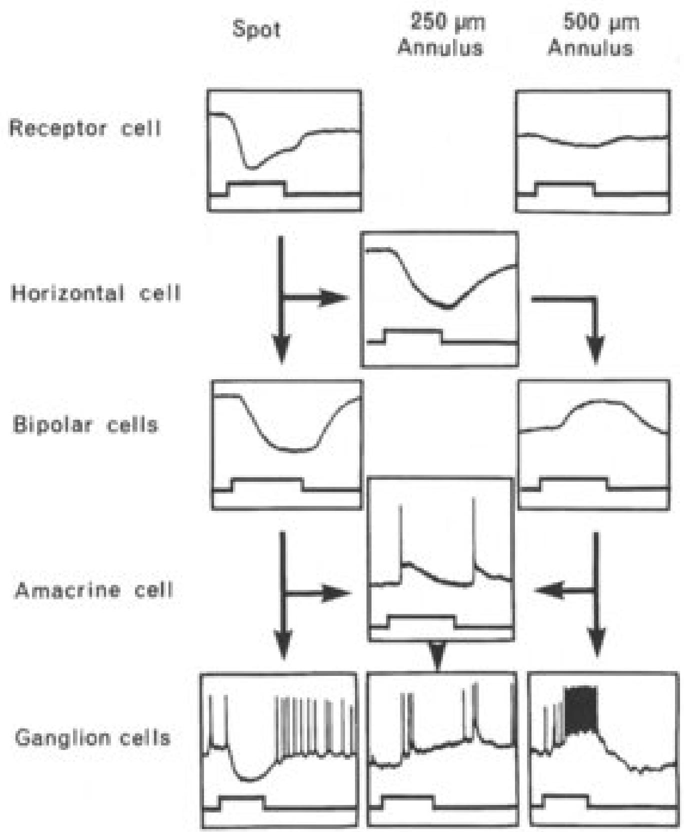
Fovea information processing capability: ~ 0.6 Mb/s

THE SPECTRAL SENSITIVENESS OF THE CONE TYPES



Dowling : "The Retina: an approachable part of the brain." HUP 1987

PHOTORECEPTORS REACTION AND ITS PROPAGATION



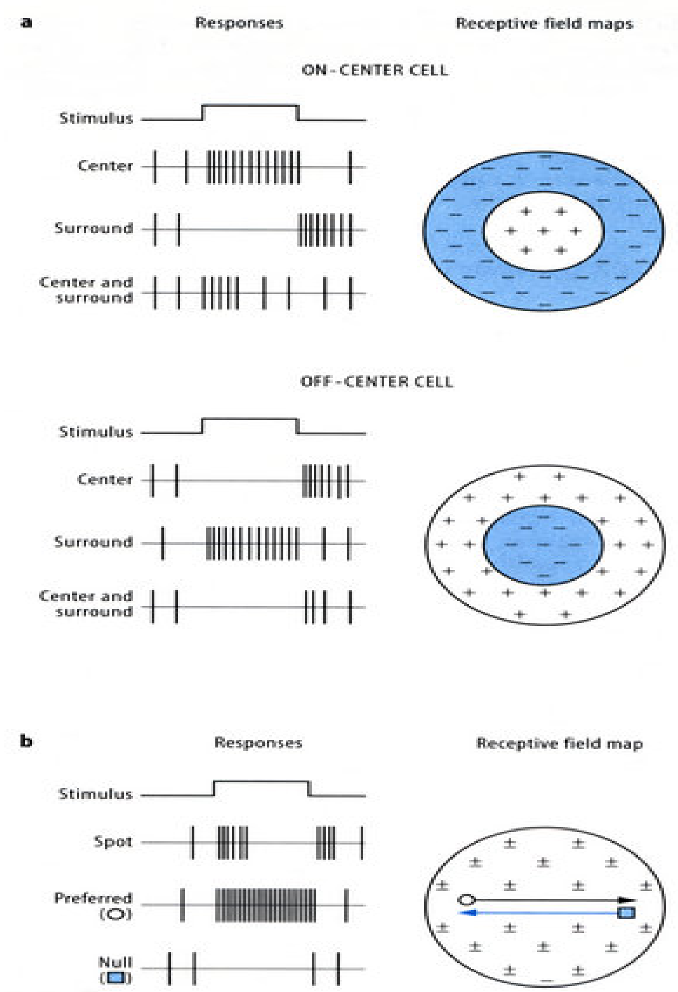
Intracellular responses from receptor, horizontal, bipolar, amacrine, and ganglion cells of mudpuppy retina. Distal retinal neurons (receptor, horizontal, and bipolar cells) respond to illumination with sustained graded potentials; proximal retinal neurons show both sustained and transient potentials and action potentials. Receptor, bipolar, and ganglion cells respond differently to center (spot) and surround (annular) illumination. Horizontal and amacrine cells usually respond similarly to spot and annular illumination; here, responses to a small annulus (250?m) are shown that stimulate both the center and surround of the receptive field. The bipolar cell illustrated is a center-hyperpolarizing cell, the amacrine cell shown is a transient amacrine cell, and the ganglion cell is an off-center cell. Arrows indicate in a general way how the responses are synaptically generated.

http://www.scholarpedia.org/article/Retina

ON- AND OFF-BIPOLAR CELLS

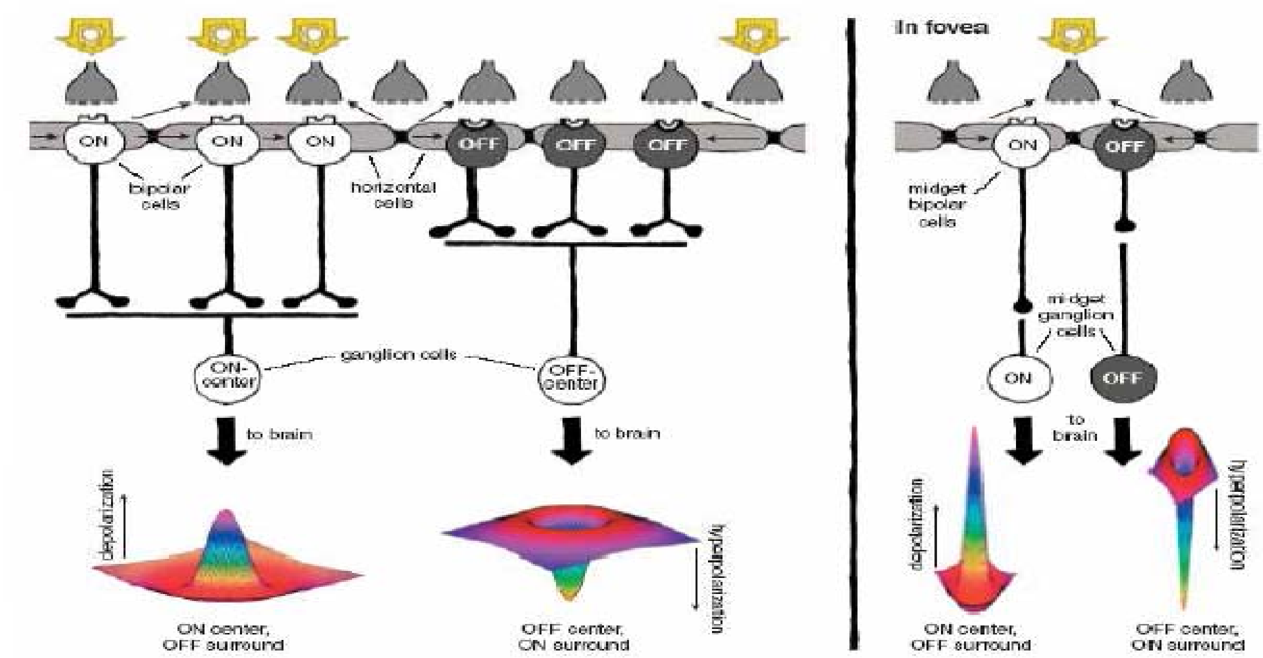
a) Idealized responses and receptive field maps for on-center (top) and off-center (bottom) contrast-sensitive ganglion cells. The drawings on the left represent hypothetical responses to a spot of light presented in the center of the receptive field, in the surround of the receptive field, or in both the center and surround regions of the receptive field. A + symbol on the receptive field map indicates an increase in the firing rate of the cell, that is, excitation; a – symbol indicates a decrease in the firing rate, that is, inhibition.

b) Idealized responses and a receptive field map for a direction-sensitive ganglion cell. Such cells respond with a burst of impulses at both the onset and the termination of a spot of light presented anywhere in the cell's receptive field. This response is indicated by + symbols all over the map. Movement of a spot of light through the receptive field in the preferred direction (open circle) elicits firing from the cell that lasts for as long as the spot is within the field. Movement of a spot of light in the opposite (null) direction (open square) causes inhibition of the cell's maintained activity for as long as the spot is within the receptive field.

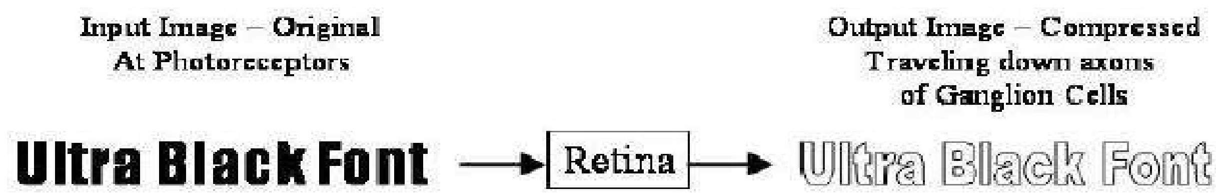


http://www.scholarpedia.org/article/Retina

GENERATION OF THE ON AND OFF REACTION



-1/8	-1/8	-1/8
-1/8	+1	-1/8
-1/8	-1/8	-1/8

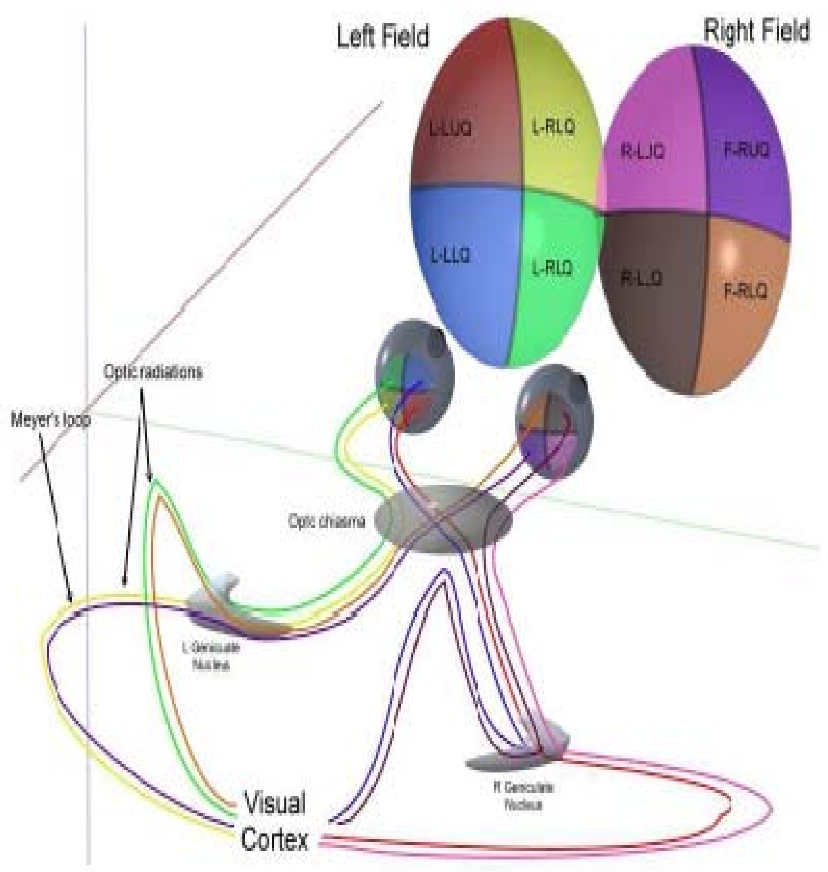


THE VISUAL PATHWAY:

eye -> retina -> optic nerve ->

LGN (6 layer) -> visual cortices ->

higher order cortices



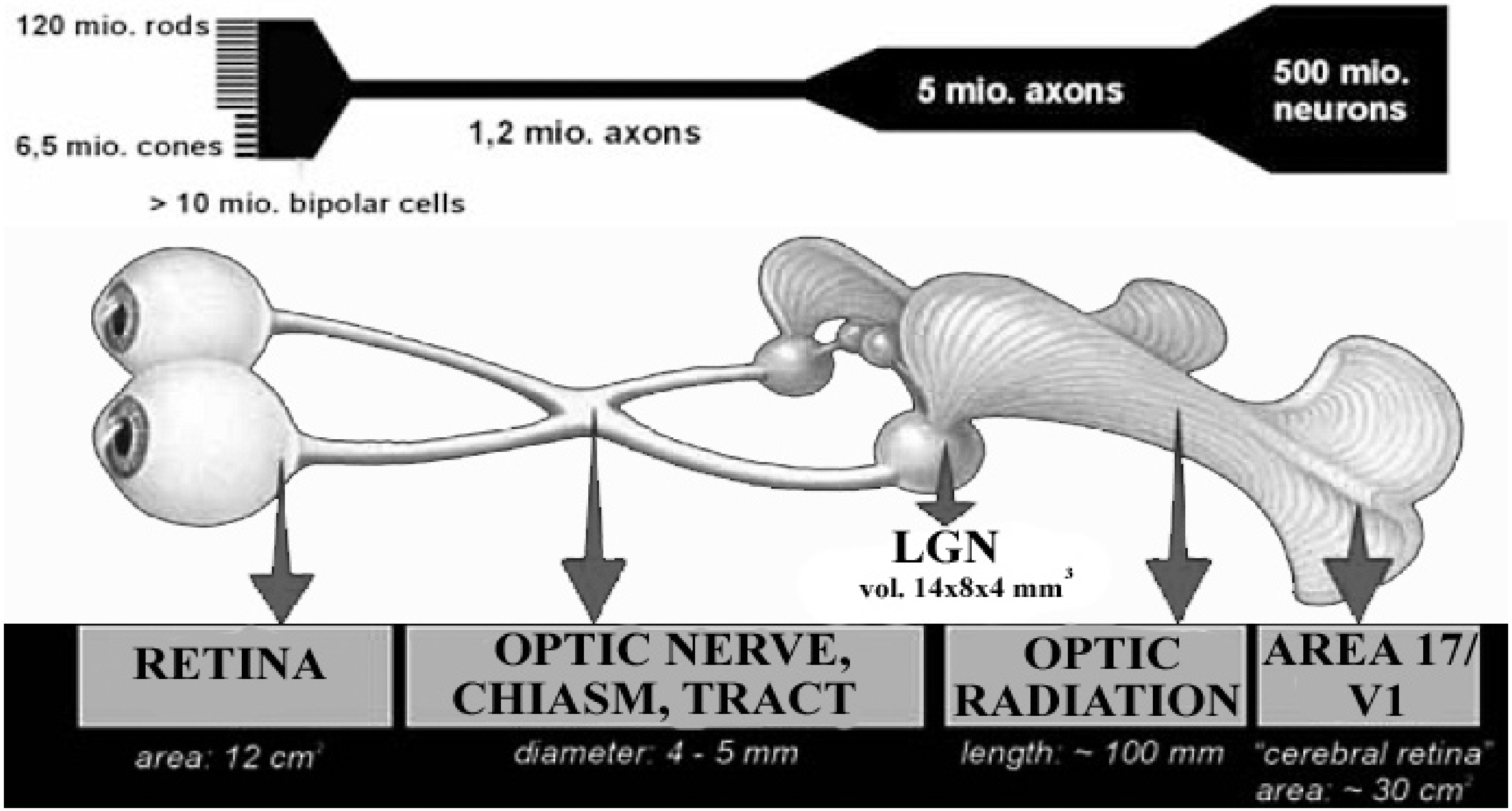
wikipedia.org

VISUAL PROCESSING:

visual convergence/ divergence, visual paths crossings,

objects placement on retina, LGN, and visual cortex

CONVERGENCE AND DIVERGENCE IN THE VISUAL PATHWAY



H.F. Krey and H. Brauer (1988)

RETINAL DEGENERATIONS

Age-related macula degeneration (AMD),

Retinitis pigmentosa (RP),

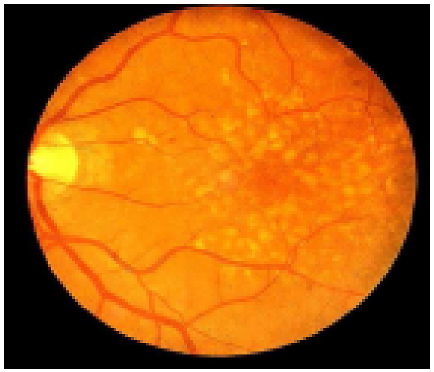
Choroidereamia

…

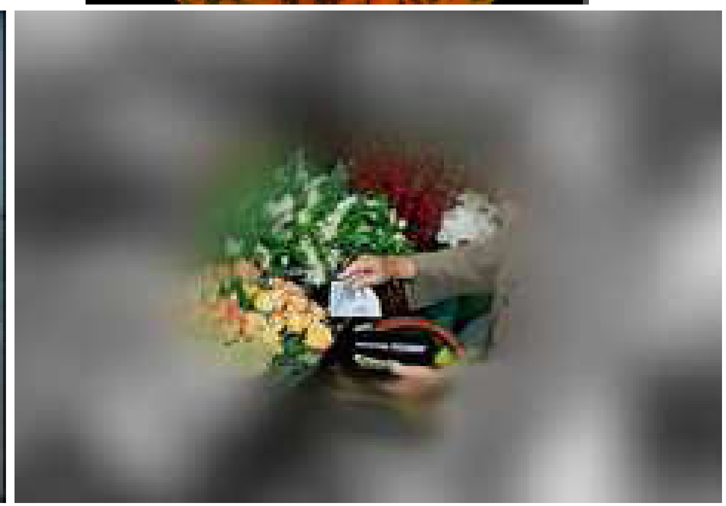
RESEARCH AREAS FOR TREATING RETINAL DISORDERS:

- genetically modified cells
- medicinal replacement of the dead cells cell transplantation,
- stem-cell research
- retinal implants

RETINAL DEGENERATIONS

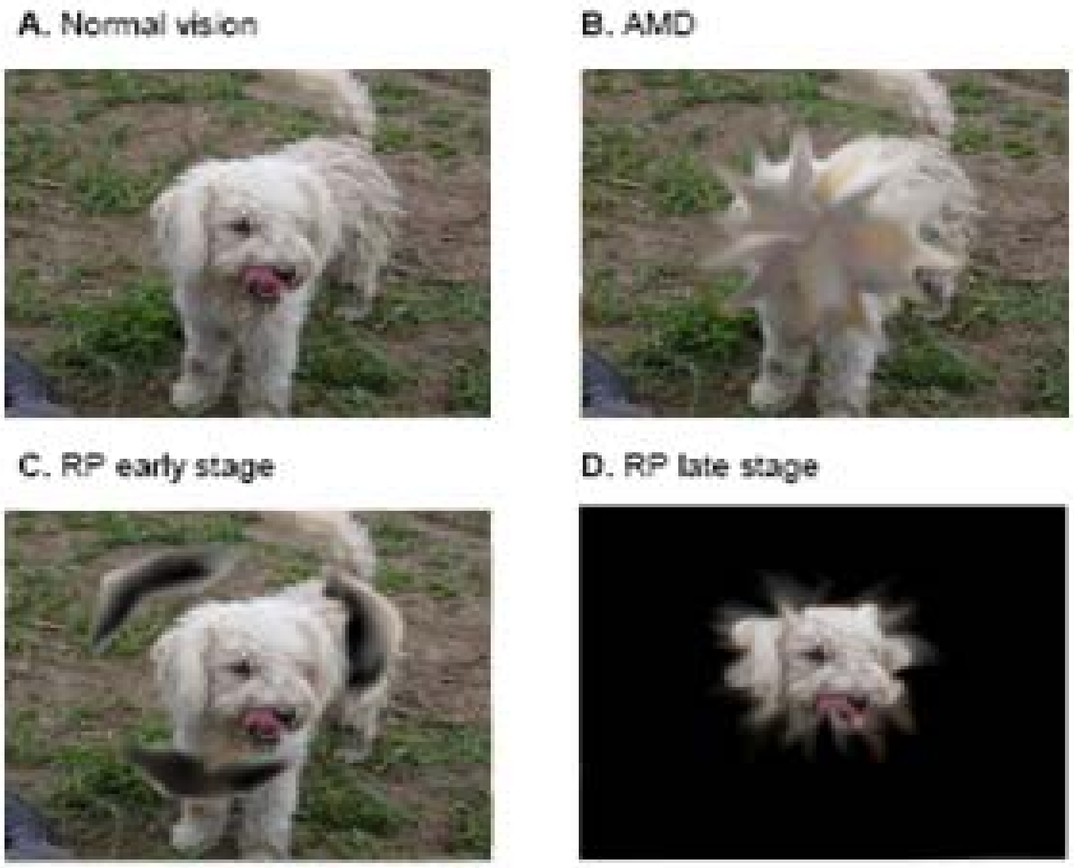


Age-related macula degeneration (AMD)



Retinitis pigmentosa (RP)

CHANGE OF VISION IN AMD- AND RP DISEASE



ARTIFICIAL SIGHT: IMPACT ON BLINDNESS

"Blindness is feared more than cancer"

Worldwide, many 100,000's totally blind from photoreceptor loss and loss of optic nerve function maybe helped by a low resolution device

Millions of patients profoundly impaired by these diseases may be helped by a higher resolution device

The Problem what needs to be solved:

1.5 million people related with the most inheritable blindness clinical picture-the retinitis pigmentosa- worldwide;

In developed world nearly 700.000 people diagnosed AMD yearly;

In Germany more than 100.000 blind people live ; and the number is growing with thousands a year.

The most frequent degenerate retinal disease:

- **Retinitis pigmentosa (RP)** (10%) and
- **Age-related Macular-Degeneration (15%) (ARMD)**

SPATIAL LIMITS: RETINAL REWIRING

by Robert Marc

- Ultra-structural evidence from donor RP/AMD retinas:
  - Extensive rewiring of inner retinal cells
  - Neurite processes spread over long distances (~300μm)
  - Glial cells migrate into choroid
- Injected electrical current may spread through

Progress in Retinal and Eye Research (2003) 22: 5, 607-655

SPATIAL LIMITS: IMPLICATIONS OF RETINAL REWIRING

- Stimulating degenerated retina may be like writing on tissue paper with a fountain pen:

– Charge diffusion over distances up to 1o

– Phosphenes likely to be blurry (Gaussian blobs), not sharp

– Minor effect if electrodes are widely spaced (>= 2o)

– Phosphenes from closely spaced electrodes may overlap/fuse

Retinal prosthetic vision may be pretty blurry…

G. Dagnelie, Lions Vision Research & Rehabilitation JHU, 2004

TEMPORAL LIMITS: PERSISTENCE

- Single electrode, acute testing:

– Flicker fusion occurs at 25-40 Hz

- Multi-electrode implant testing:

– Rapid changes are hard to detect

– Flicker fusion at lower frequency?

Maybe prosthetic vision will be not just blurry, but also streaky…

G. Dagnelie, Lions Vision Research & Rehabilitation JHU, 2004

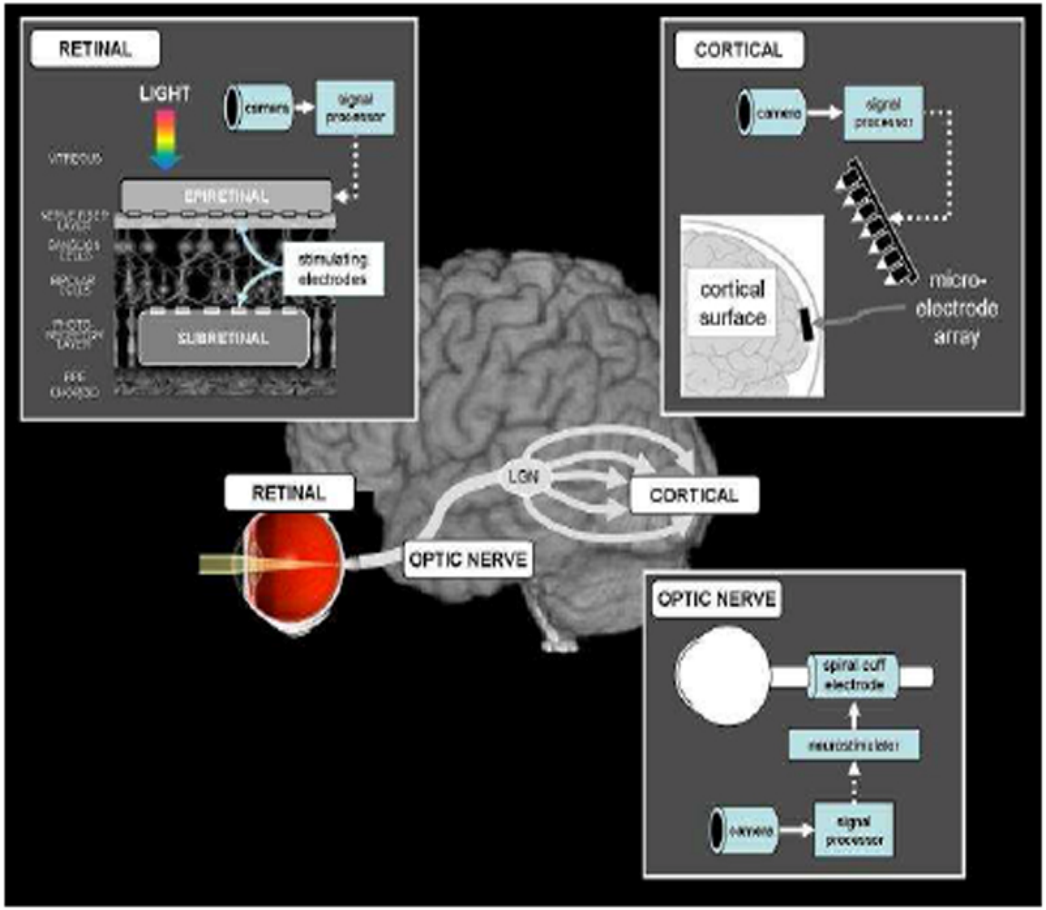
BASIC RESEARCH AREAS ON VISUAL IMPLANTS:

- Cortical stimulation (N. Cottaris, Detroit)
- Implants visual simulation (G. Dagnelie, Baltimore)
- Electronic impulses distribution (S. Fried, Boston)
- Dynamics of retina degeneration (R. Marc, Salt Lake City)
- Optimal impulse pattern making (R. Wilke,Tübingen)
- Picture coding (R. Eckmiller, Bonn)
- Chronic electrical stimulations effect in tissue (J. Weiland, Baltimore)

G. Dagnelie, Lions Vision Research & Rehabilitation JHU, 2004

VISUAL IMPLANTS

- Retinal prostheses
  - Epiretinal
  - Subretinal
- Cortical implants
- Optic nerve
- Other solutions



VISUAL IMPLANTS

epiretinal, subretinal solutions, comparison of retinal implants

Preclinical researches:

- MIT Visual Prosthesis (S. Kelly Cambridge, USA)
- The Australian Visual Prosthesis (G. Suaning, Sydney, Australia)
- Cortical Prosthesis Project (V.Towle, Chicago , USA)
- The C-Sight Project (Q. Ren, Beijing, China)
- The Seoul Visual Prosthesis (Hum Chung, S-Korea)
- The Suprachoriodal-approach (Y.Terasawa, Japan)
- Boston Retinal Implant Project (J.Rizzo, Wyatt,Boston,USA)
- High Res. Photovoltaic Prosthesis (D. Palanker, Stanford, USA)

Clinical surveys (clinicaltrials.gov)

VISUAL IMPLANTS

Epiretinal

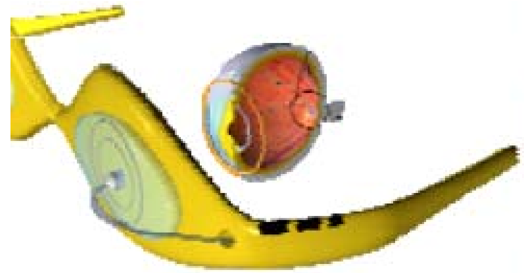
- Second Sight ARGUS Trials (M Humayun), USA
- The Epiret Trial (P Walter, Mokwa, Schanze), Aachen, Giessen, Germany.

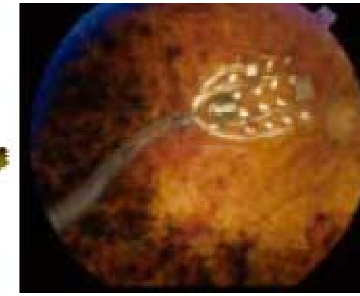
Subretinal

- Retina Implant Pilot Study (E Zrenner), Tübingen Germany.
- Under registration: Boston Retina Implant (J. Rizzo) Boston, USA

IMI-IRIS Trial – Gisbert Richard (Hamburg, Germany)

VISUAL IMPLANTS





<u>Epiretinal</u>

SECOND SIGHT ARGUS TRIALS

USA

Extra-ocular processing; only electrode array inside eye:

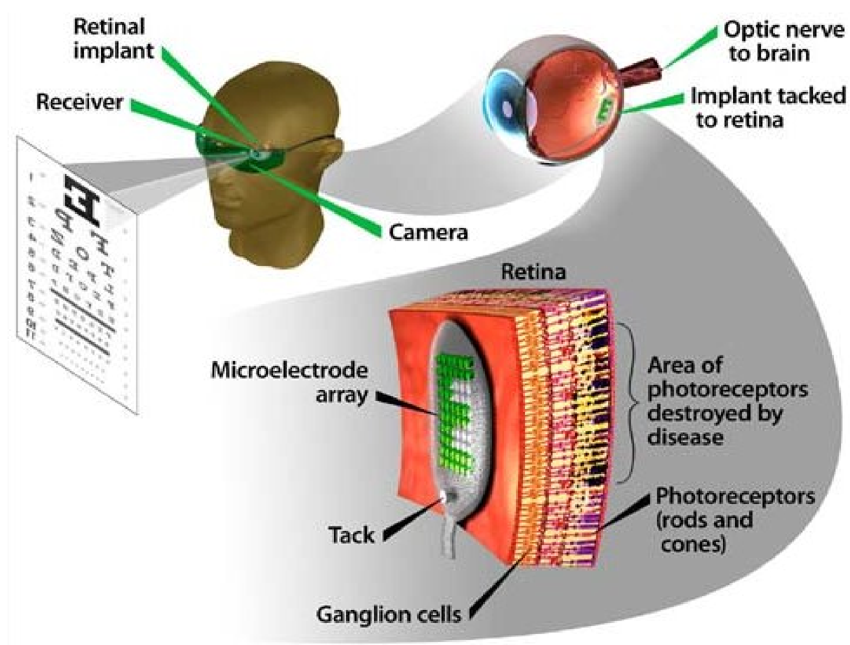
Based on proven cochlear implant technology

– Six patients implanted with 4x4 array

– External camera and image processor

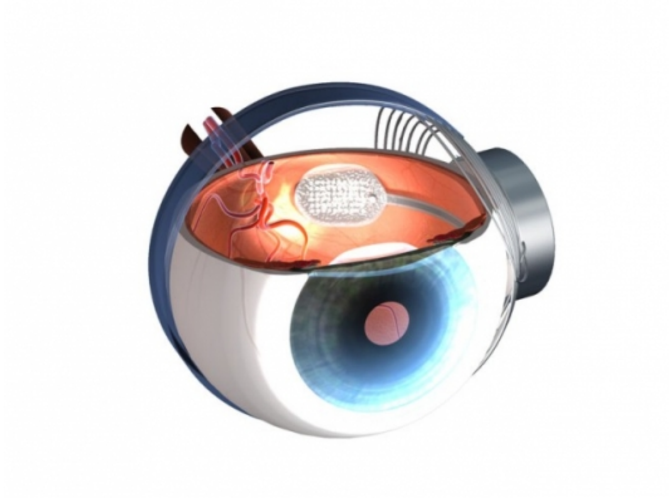
– Psychophysics in progress

– Today: 60 electrodes on a single chip



Website: http://www.2-sight.com

ARGUS

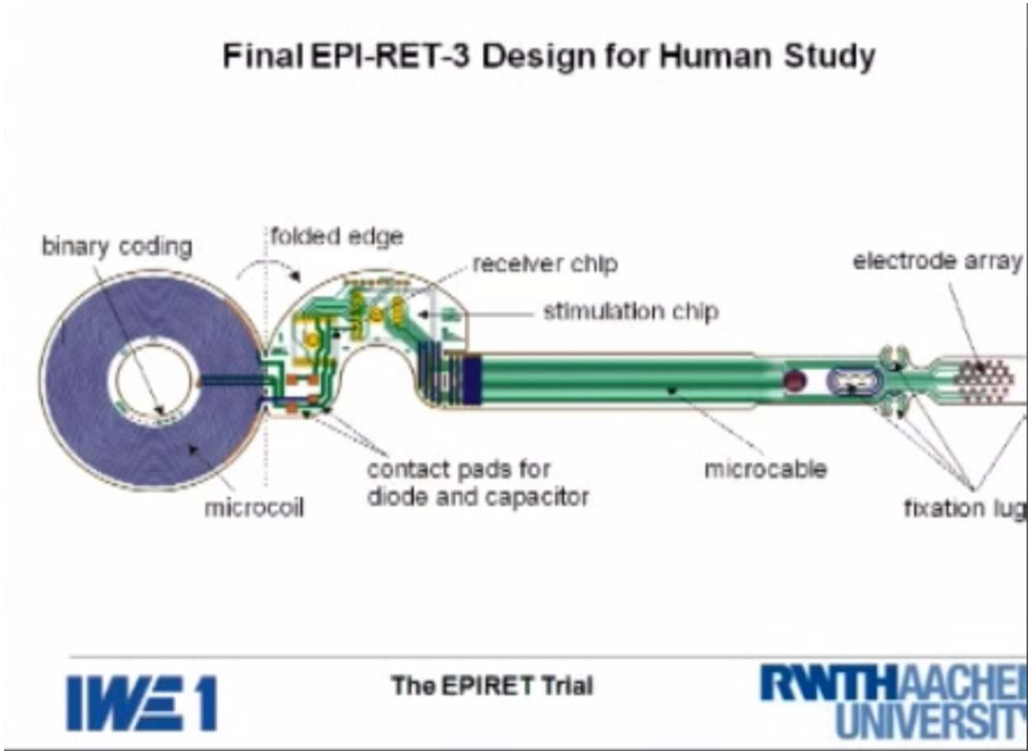


• Leader: M. Humayun, LA, CA,USA
• Argus I
– 2002-2004: 6 patient:
– 16 pixel
– Result: light seeing, moving recognized, eating devices were recognized
• Argus II
– from 2005l: 36 patient implanted
– 60 pixel
– Result: lines, lights, visual feeling

BBC's Inside Out London

Epiretinal

–**THE EPIRET TRIAL** (P Walter, Mokwa, Schanze), Aachen, Giessen, Germany.



Wiew the attachments on the links below
http://www.egms.de/static/de/meetings/ri2009/09ri20.shtml
http://www.egms.de/static/de/meetings/ri2009/09ri09.shtml

THE EPIRET TRIAL

2003-2006 EPIRET 3 prototype designed and fabricated.

EPIRET 3 is a completely intraocular retinal stimulator with integrated electronics and inductive links for data and energy transfer, data handling, and pulse generation.

25 iridium oxide electrodes are mounted on a polyimide base.

Minimally invasive implantation procedure.

Animal experiments demonstrated the long term functionality and biocompatibility of the system.

Cortical recordings and metabolic mapping of the visual cortex in implanted cats, local activations occurred within the visual cortex corresponding to the area of stimulation in the retina.

6 blind volunteers with Retinitis pigmentosa.

http://www.egms.de/static/de/meetings/ri2009/09ri20.shtml

THE EPIRET TRIAL

The implant was inserted after enlargement of the corneal incision. The receiver module was inserted in the posterior chamber and transsclerally sutured. The stimulator module was placed on the retinal surface in the macula and retinal tacks were used for stable fixation.

No intraoperative complications. Postoperatively, mild inflammatory responses were seen.

At three time points stimulus thresholds were determined for selected electrodes and perception patterns were recorded in comparison to the stimulation patterns.

In all patients the implant was fully functional after the implantation procedure.

The phosphene patterns corresponded to the stimulus patterns and stimulus thresholds on average were 15nC/cm².

Angiograms showed no vascular changes.

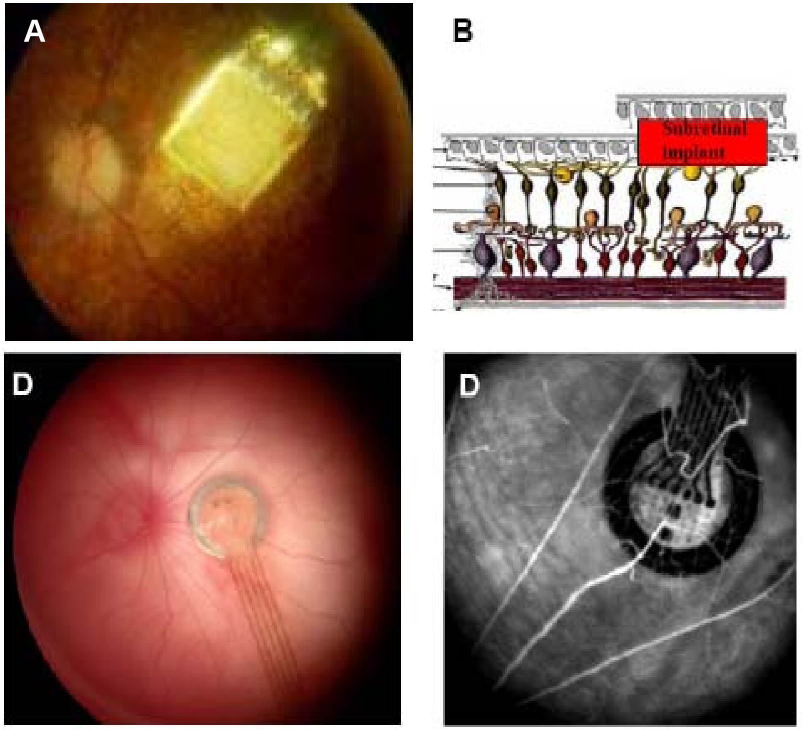
In summary, the EPIRET 3 system proved that a completely implantable retinal implant system without any transscleral connections for data and energy can be fabricated and implanted.

http://www.egms.de/static/de/meetings/ri2009/09ri20.shtml

VISUAL IMPLANTS

Subretinal

–**RETINA IMPLANT PILOT STUDY** (E Zrenner), Tübingen Germany.



Leader: E. Zrenner Tübingen Germany

– from 2005: 11 patient implanted.

– Resolution: 1520 pixel (40x38)

– Result: lines, lights, visual feeling, more greytone, moving-, and some daily stuffs were recognized.

Landolt C test

(VA=20/1240 (logMAR 1.79

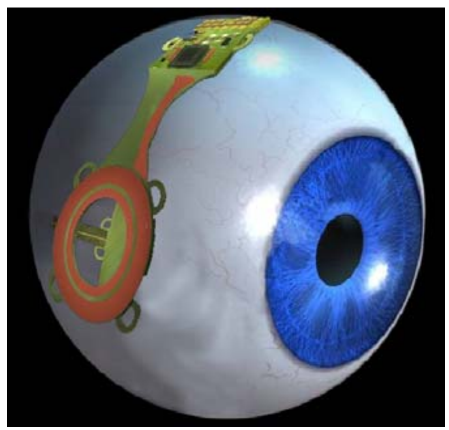
VISUAL IMPLANTS

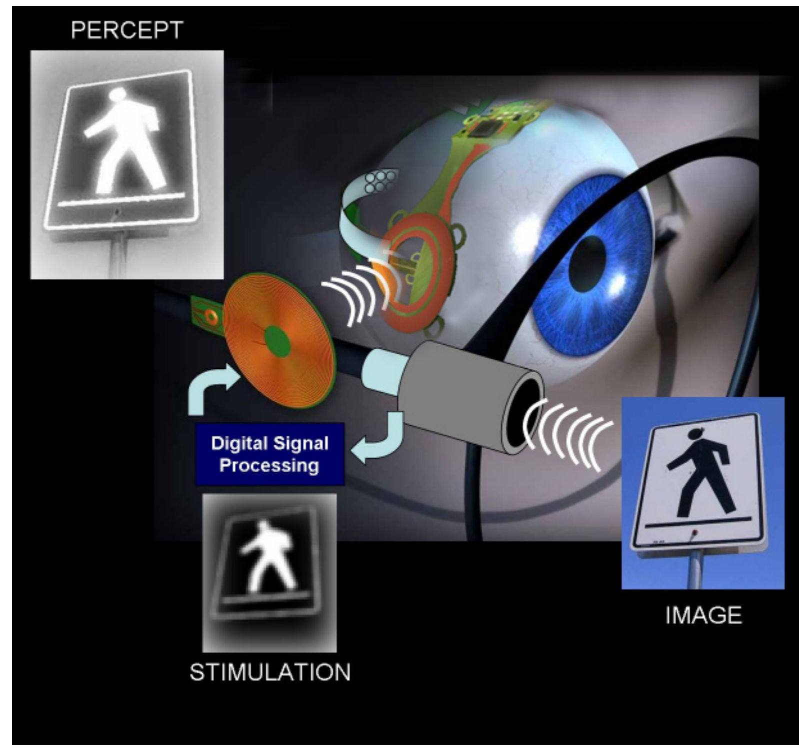
Subretinal

–**BOSTON RETINA IMPLANT** (J. Rizzo) Boston, USA

Emphasis on extraocular transmission and processing away from stimulation site:

- Receiver coil on temporal sclera
- Multi-chip implant
- Hermetic packaging

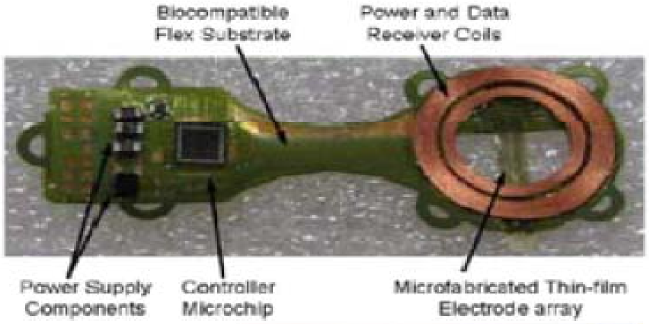


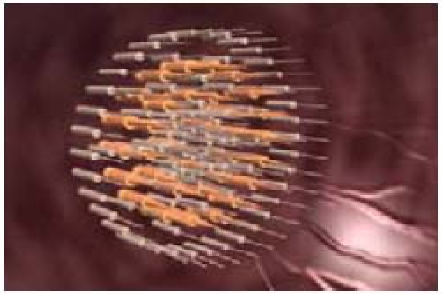


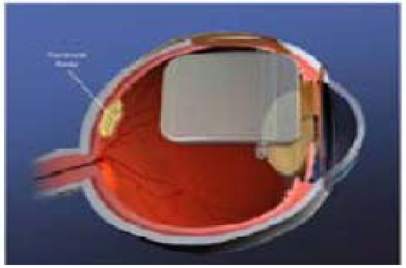
Interactive modell: http://www.bostonretinalimplant.org/chip.php
http://www.bostonretinalimplant.org/implant2.html

BOSTON RETINA IMPLANT

Artist's conception of the second generation implant system. The image obtained by an external camera is translated into an electromagnetic signal transmitted wirelessly from the external primary data coil mounted on a pair of glasses to the implanted secondary data coil attached to the outside wall (sclera) of the eye surrounding the iris. Power is transmitted similarly. Most of the volume of the implant lies outside the eye, with only the electrode array penetrating the sclera. Right: The electrode array is placed beneath the retina through a scleral flap in the sterile region of the eye behind the conjunctiva.







http://www.bostonretinalimplant.org http://www.rle.mit.edu/media/pr150/20.pdf

VISUAL IMPLANTS

IMI-IRIS Trial – Gisbert Richard (Hamburg, Germany)

Leader: Gisbert Richard, Hamburg, Germany

- First etap:

  in 2003: 45min 20 patient

- Second etap:

  in 2005: 4 patient

- Third etap:

  from 2007

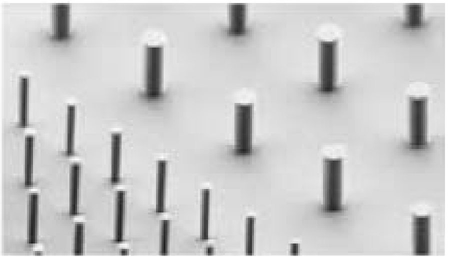
VISUAL IMPLANTS

THE RETINAL IMPLANT PROJECT (MIT)

Mockup of the second-generation implant. All electronic parts are hermetically sealed in a titanium case with 19 feedthrough pins connected to an external flex circuit. The power and data coils are sutured to the eye around the iris (under the conjunctiva) while the electrode array is inserted subretinally at the back of the eye. The case is sutured to the sclera through the two suture tabs shown .

Left: Penetrating electrode array.
Right: SEM image of the 70 μm tall SU8 pillars.

http://www.rle.mit.edu/media/pr150/20.pdf



COMPARISON OF RETINAL IMPLANTS

EPIRETINAL APPROACH:

- *Pros*
  - Stimulating close to the photoreceptors so one can take advantage of native processing power in thalamus and cortex.
  - Surgical complications not necessarily as significant as cortical approach.
- *Cons*
  - Requires functional optic nerve pathway.
  - May stimulate optic nerve fibers rather than cell bodies: this will greatly complicate visuotopic organization.
  - Hard to imagine how saccadic eye motions will not cause very high sheer loads on implanted arrays(and eventual dislodging of array).
  - Difficult surgical access.
  - Difficult to adhere electrode array to retina.

COMPARISON OF RETINAL IMPLANTS

SUBRETINAL APPROACH

- *Pros*
  - Stimulating closest to the photoreceptors so one can take advantage of retinal, thalamic and cortical signal processing.
  - If bipolar cells can be directly stimulated, retinotopic organization should be preserved.
  - Surgical complications not necessarily as significant as cortical approach.
- *Cons*
  - Requires functional optic nerve pathway to convey signals to cortex.
  - Blockage of nutrients from choroid to remnant retina by the implant.
  - Very complex surgical access.
  - Can't stimulate cells passively with microimplants (requires external power).

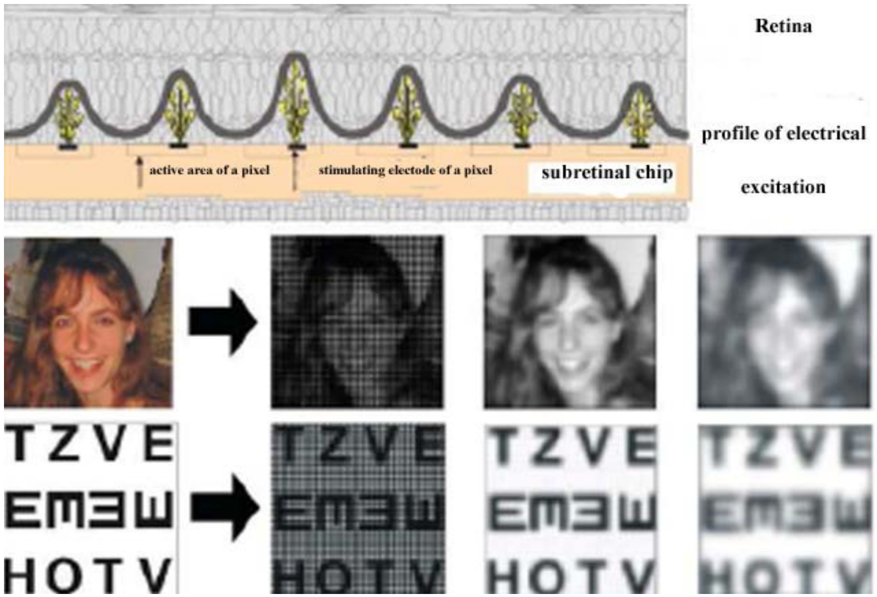
COMPARISON OF RETINAL IMPLANTS

		Advantages	Disadvantages
epiretinal	Intelligent Implants, Rizzo implant, Second Sight-implant	injection of electrical charge is adaptable; individual amplification of the transmitted current; applicable also under unfavourable optical conditions; feasibility of epiretinal electrostimulation has been shown in patients (Rizzo and Intelligent Implants in Acute trials, Second Sight chronic implantation)	long term stability of the attachment has not been demonstrated; danger of proliferative vitreous reaction (PVR); so far only a modest optic resolution; problem of fibre stimulation; external camera necessary; high costs
subretinal	Optobionics Implant (Chow)	already implanted in 6 patients	no “active” Chip, requires very high levels of brightness, no adaptation to surround light conditions;requires additional visual aids;cannot function under normal light conditions
	Retina Implant	amplification of the signals through additional external energy supply; no external camera necessary	more complex implant procedure

http://www.retina-implant.de/en/doctors/technology/

THE PICTURE OF A 40X40 ELECTRODE RETINAL IMPLANT

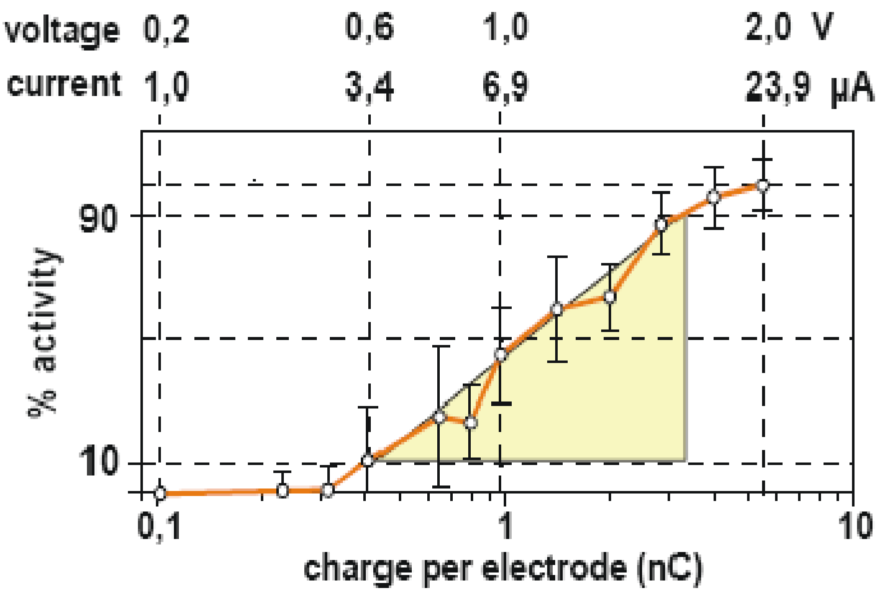
Example of a profile of electrical excitation produced by light-sensitive areas of a subretinal implant, activated by electrodes spaced 70 µm apart. (**Bottom**) If a regular three dimensional image (the face or optotype) is transformed into a two-dimensional excitation profile, the image would be represented by a two-dimensional array of 40 by 40 small excitation spots (pixels), sized according to the width of the local electrical wave (see second column). When the light intensity is increased, each of the excitation spots enlarges and a more homogeneous picture emerges (see third column). A further increase in luminosity causes a merging of excitation spots, resulting in a blurred picture (see fourth column).



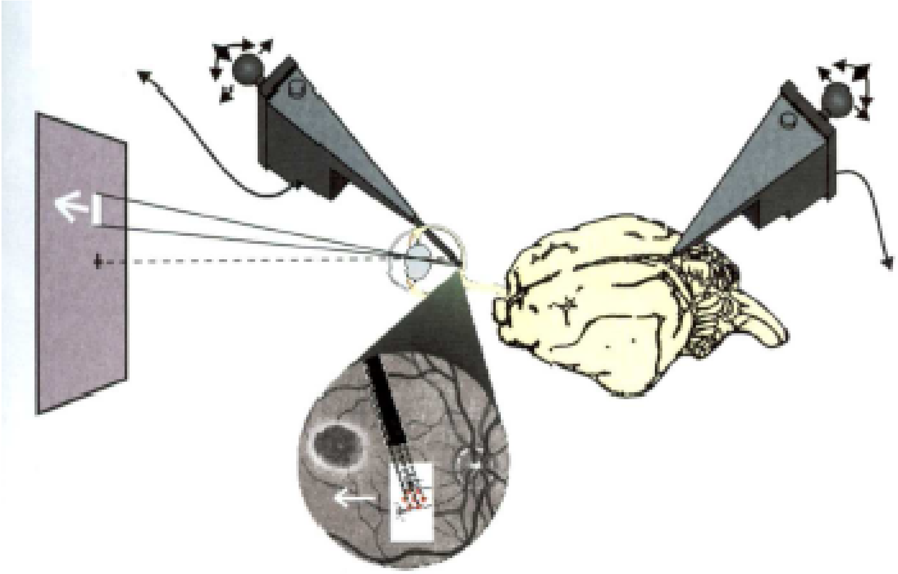
VISUAL IMPLANTS

Other Solutions:

in vitro and **in vivo** experiments



Stett A., et.al., Electrical multisite stimulation of the isolated chicken retina. Vision Research 40:1785-1795 (2000)



Eckhorn et.al., Ophthalmologe 2001

Other Solutions:

In vitro:

Successful subretinal stimulation of neural network of intact and degenerated retinas

Threshold: 0.5 …. 1 nC

Dynamic range: 0.5 to 10 nC

Spatial resolution: 0.5° viewing angle

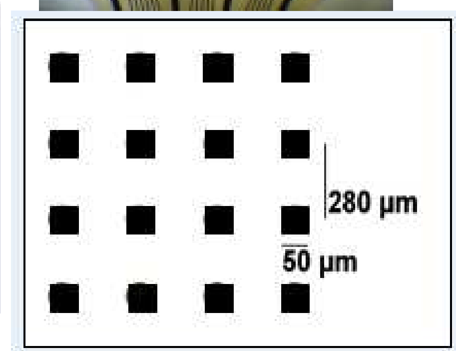
In vivo:

Epi/subretinal stimulation generates retinotopic correct cortical excitation

Spatial resolution: 1°viewing angle

DIRECT STIMULATION WITH ELECTRODES

	Active Multiphotodiode Array	Direct Stimulation Electrodes
Size	1500 pixels	16 electrodes (arranged in 4x4 grid)
Function	Work autonomously when light strikes photodiodes	Each electrode can be remotely stimulated individually or together
Adaptability	Frequency and gain can be adapted, pulse shape is fixed (anodic voltage controlled pulses)	Stimulation parameters can be chosen freely during experimentation



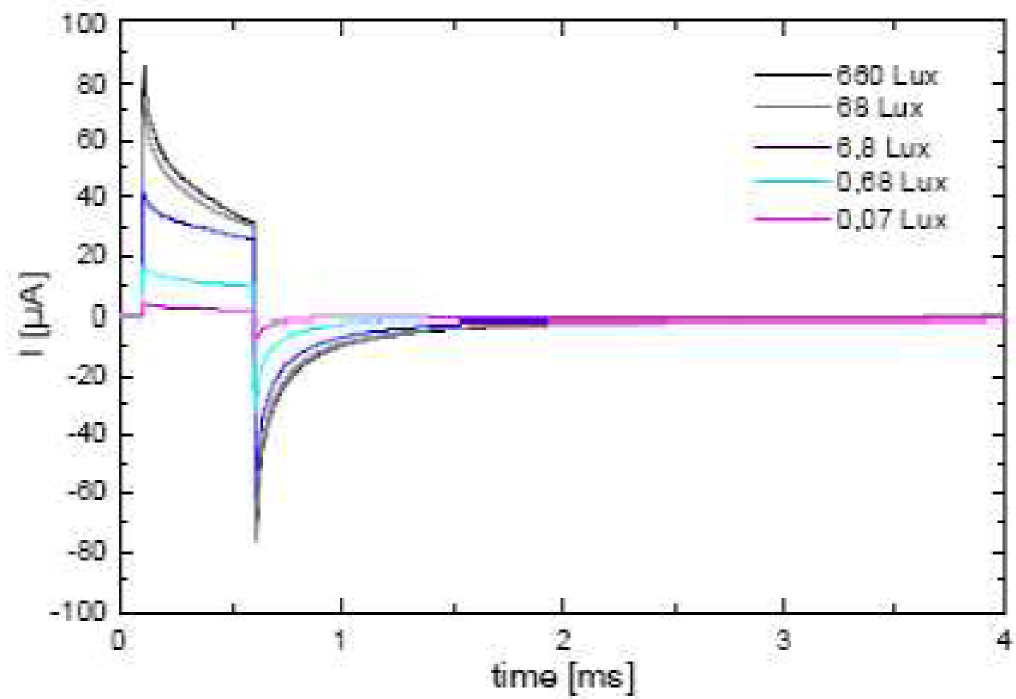
CHIP DESIGN

Anodic Pulses:

0,5 -2,0 V (0,5 ms – 5 ms @ 0…20 Hz)

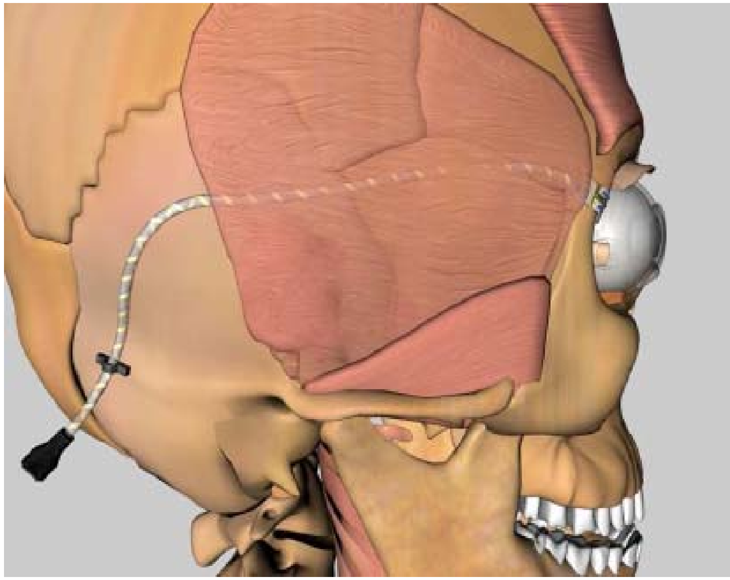
-> nearly charge-balanced

1500 pixel firing simultaneously

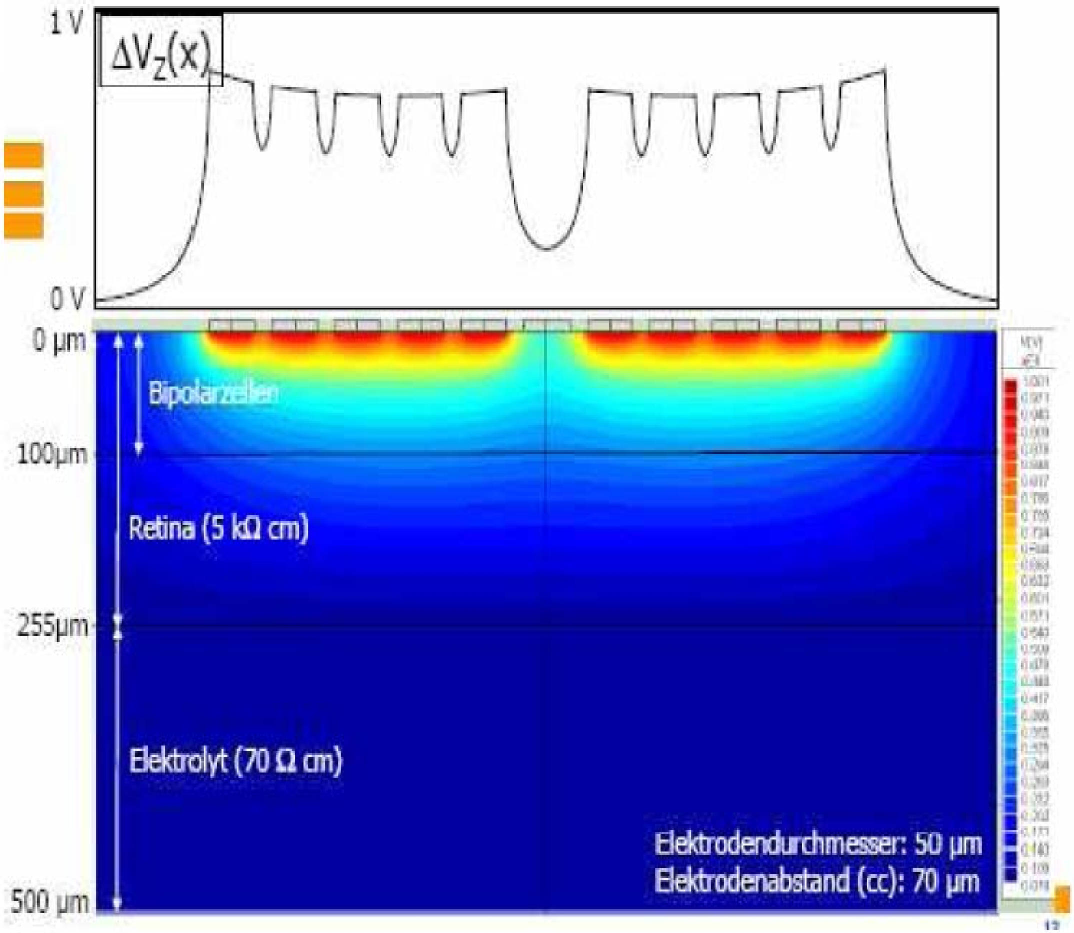


POWER-SUPPLY

After the second postop. week it enables free movement



EFFECT OF THE ELECTRIC FIELD



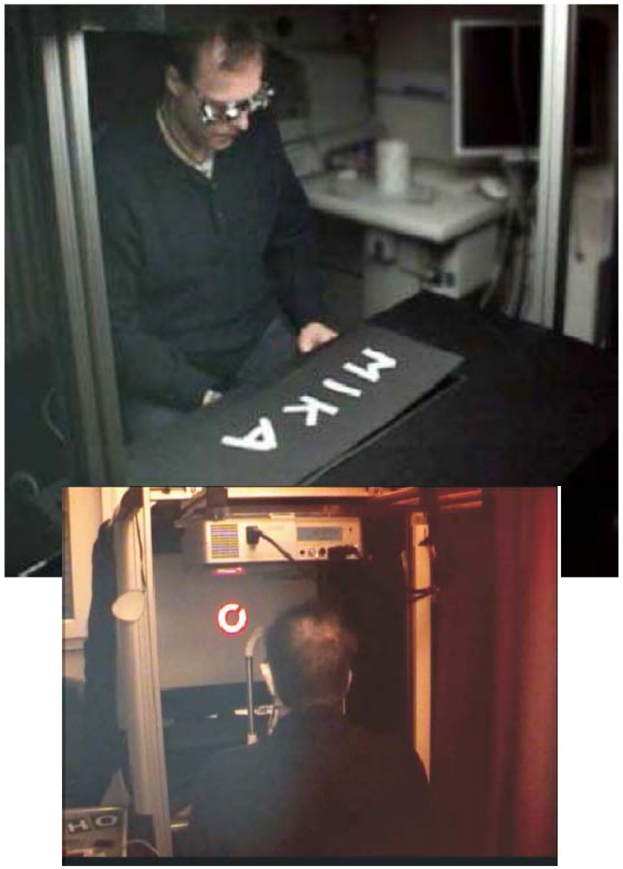
Laboratory testing: electrode interaction negligible

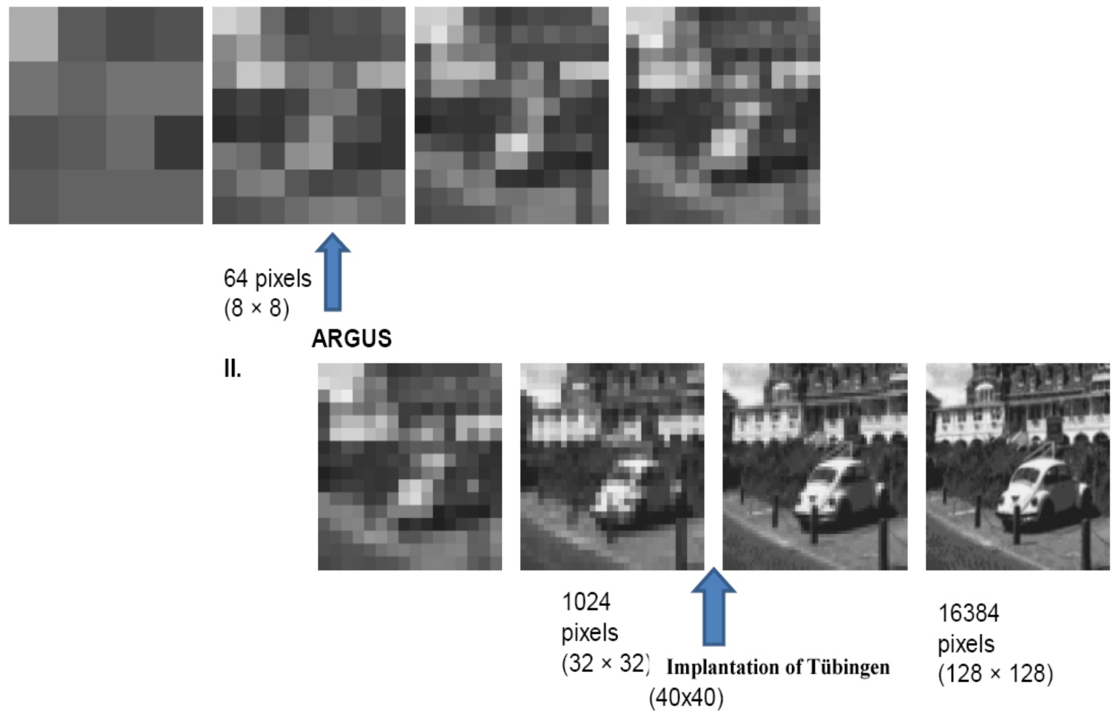
Electric field simulation: some edge effects with extended stimulation („picture frame“)

- delicate patterns to be preferred
- avoid black-on-white scenes

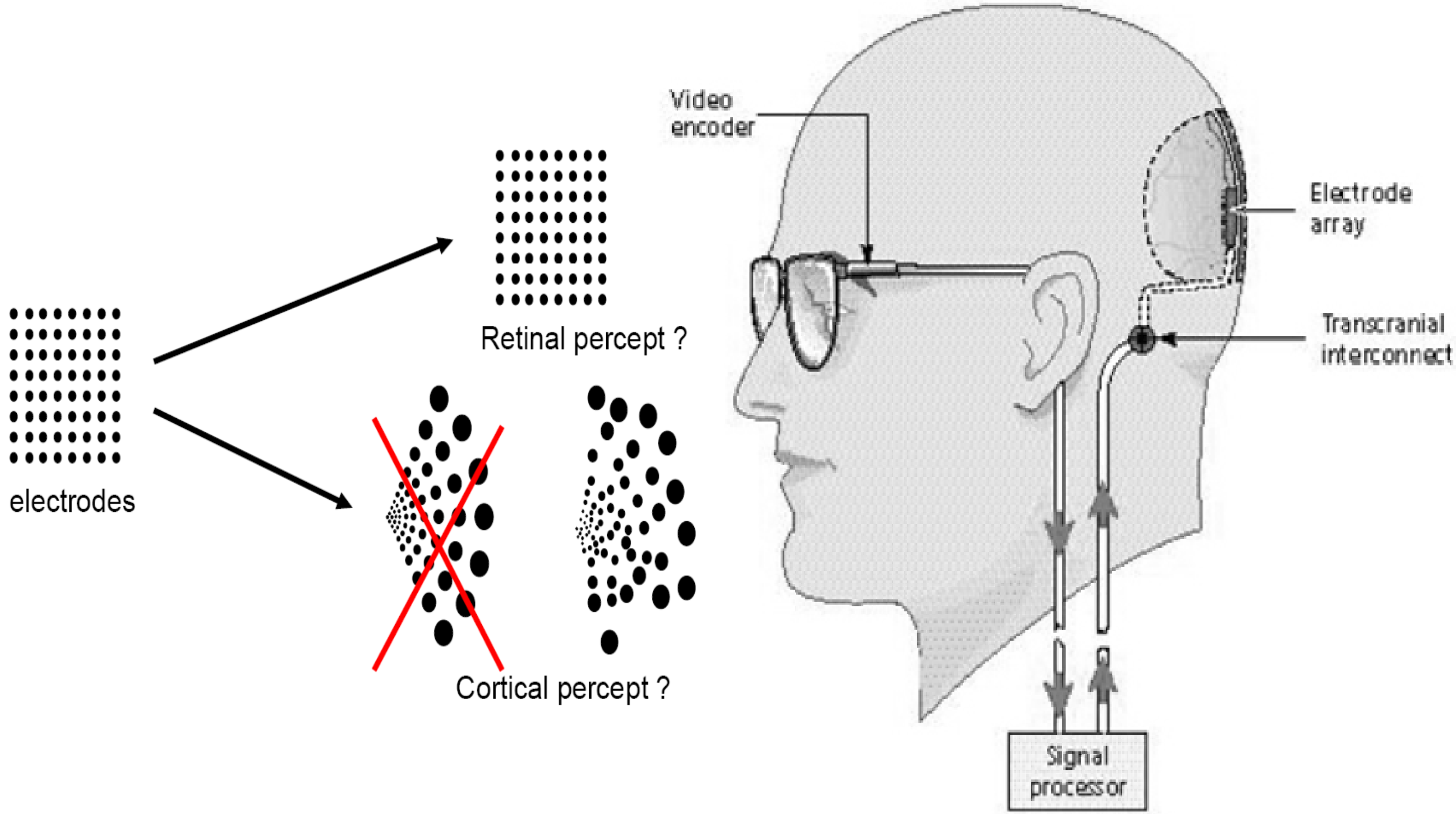
A.Stett, M.Gerhardt, 2007

DETERMINING THE VISUAL SHARPNESS OF IMPLANTED PATIENTS, EFFECT OF THE RESOLUTION





CORTICAL IMPLANTS: CONCEPT

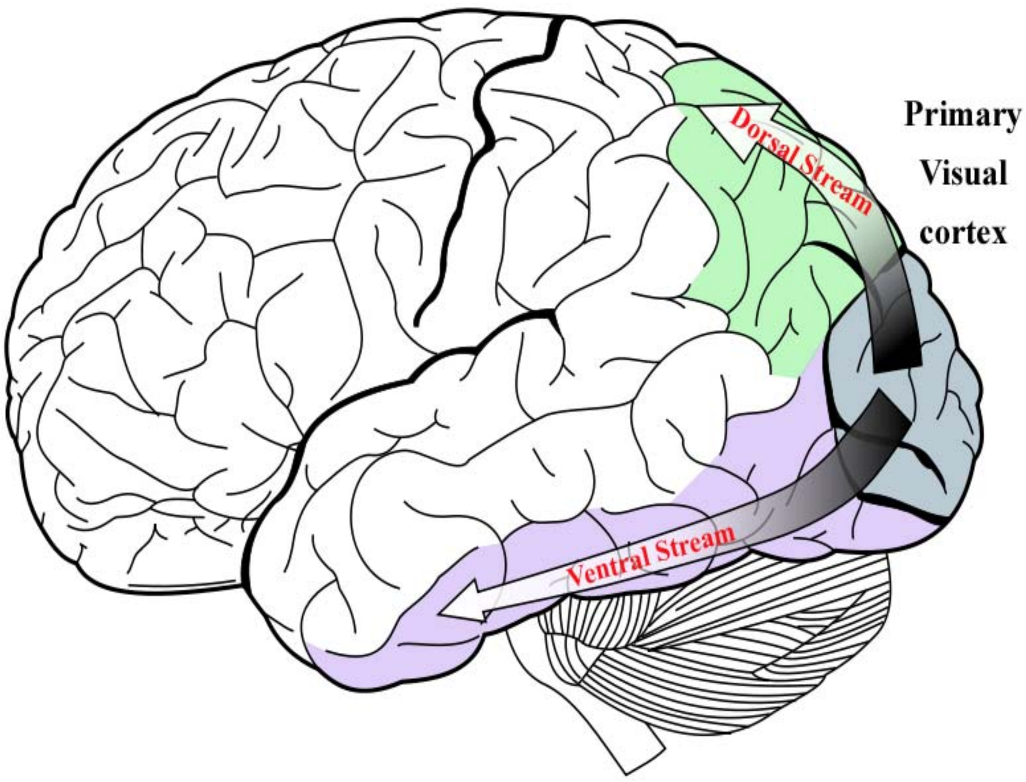


CORTICAL IMPLANTS: CONCEPT

Secondary visual cortex

<u>The Two Streams hypothesis</u> is a widely accepted, but still controversial, account of visual processing. As visual information exits the occipital lobe, it follows two main channels, or "streams".

The ventral travels to the temporal lobe and is involved with object identification. The dorsal stream (or, "where pathway") terminates in the parietal lobe and process spatial locations.



http://en.wikipedia.org/wiki/Two_Streams_hypothesis

CORTICAL IMPLANTS:

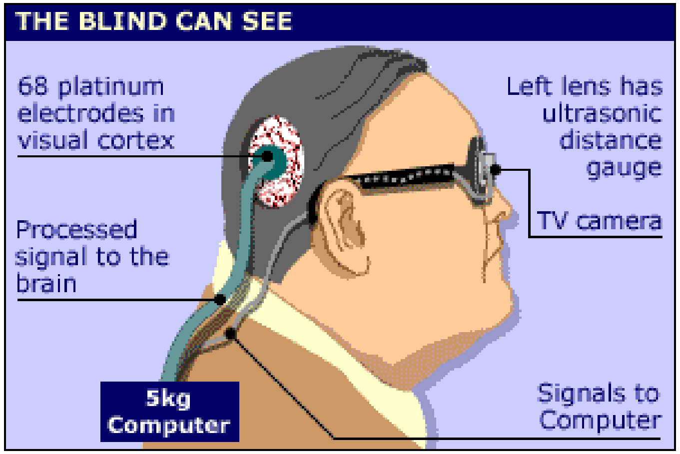
Dobelle

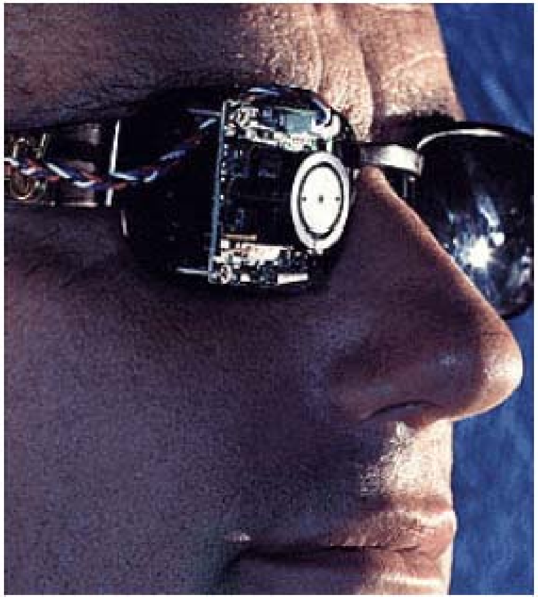
William Dobelle († 2004)

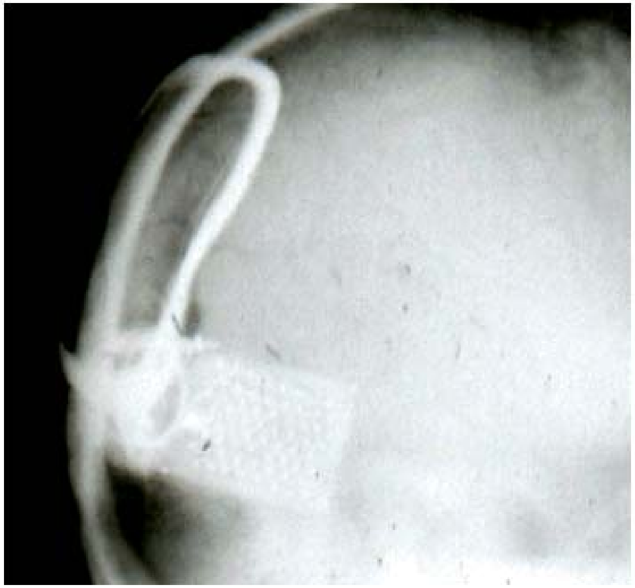
- Antiquated electrode technology, but it works, somewhat…
- Sobel vision filtered input may not convey real form vision, but does provide crude localization

Jerry reportedly had 68 electrodes, technically offering up to 68 pixels, but resulting in only some 20 effective pixels (phosphenes) at irregular positions and narrow field 16 pixels in a of view, like in tunnel vision.

Dobelle,W.H., et al., 1976







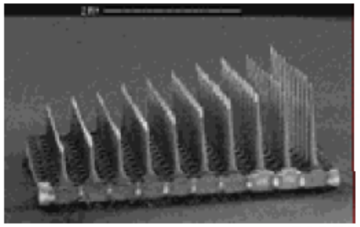
CORTICAL IMPLANTS

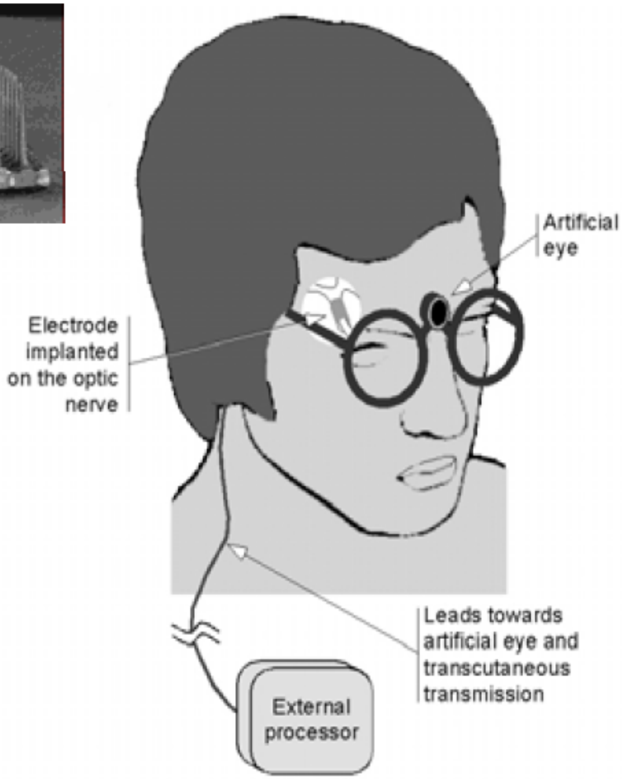
Dobelle Laboratories



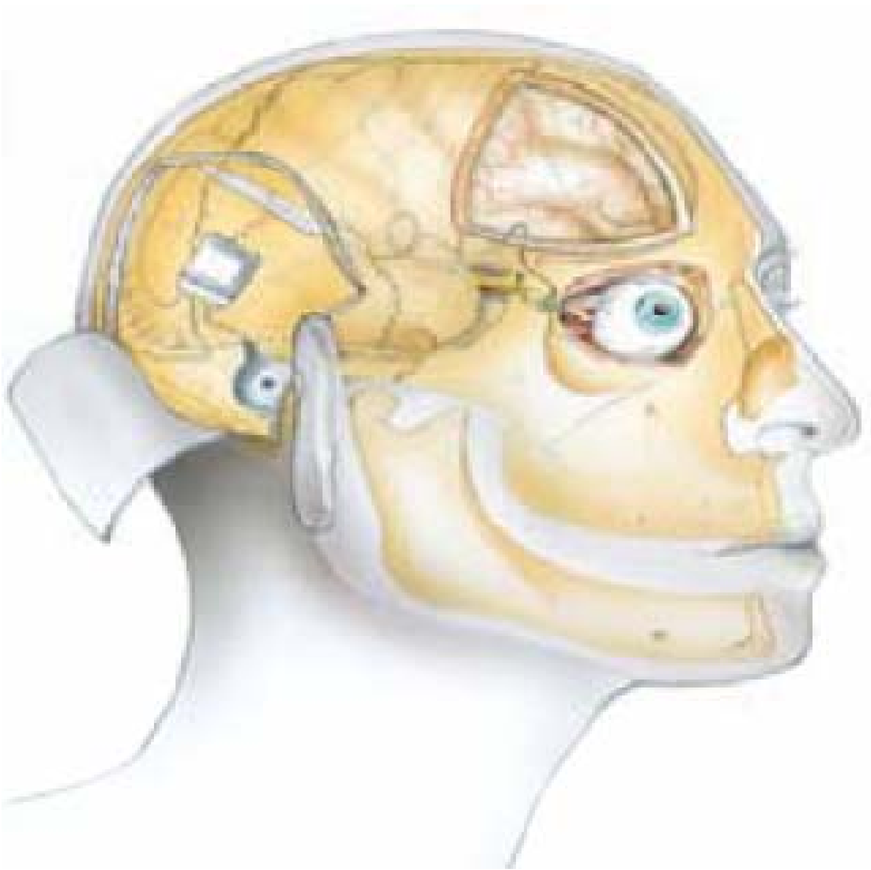

Other solutions:

Concept of the optic nerve stimulation





OPTIC NERVE STIMULATION



Claude Veraart

• Emphasis on processing crude information:

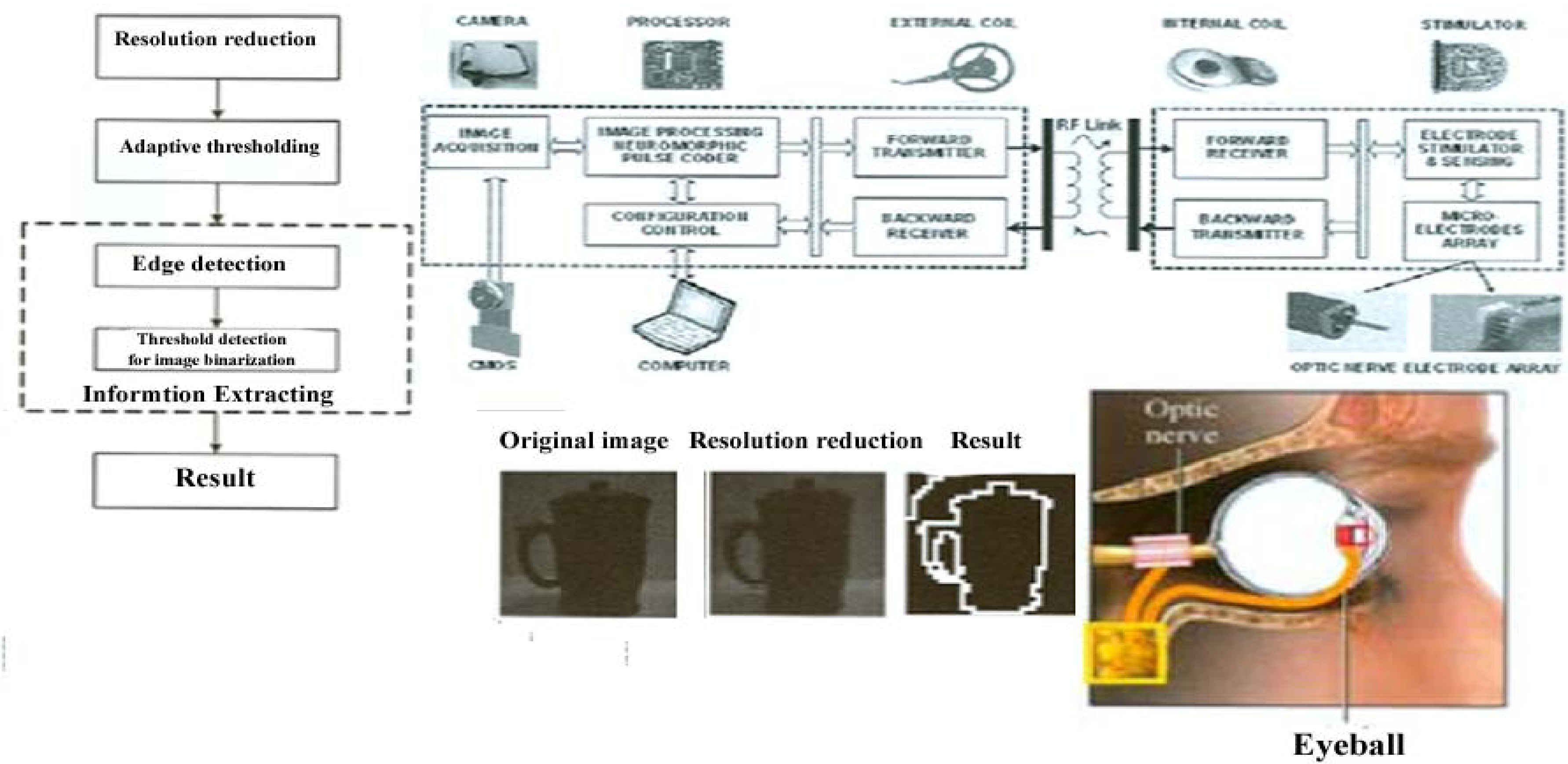
– 4-8 electrodes in cuff around optic nerve

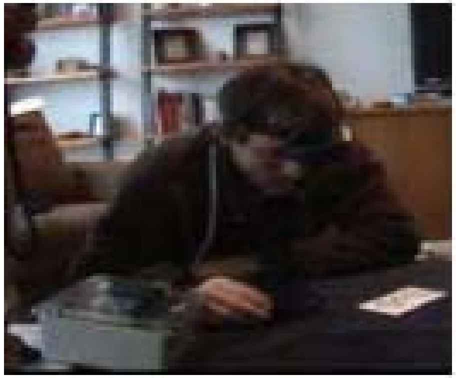
– Light-dark, direction, and stimulus strength can be learned

• Two RP patients implanted (1998/2004)

Website: http://www.md.ucl.ac.be/gren/Projets/optivip.html

SANGHAI OPTIC NERVE VISUAL PROSTHESIS



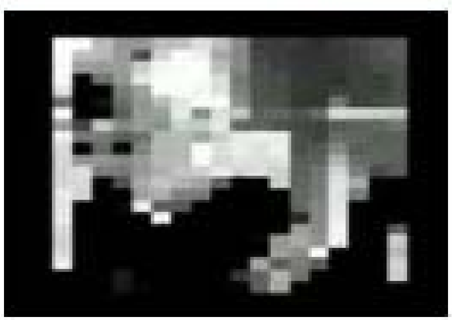


OTHER SOLUTIONS:

BRAINPORT

Neuroscientist Paul Bach-y-Rita hypothesized in the 1960s that "we see with our brains not our eyes.”

University of Pittsburgh Medical Center's UPMC Eye Center



http://www.nei.nih.gov/news/briefs/weihenmayer.asp

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Pázmány University, Information Technology Faculty

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University of Regensburg, Regensburg, Germany

Dept. of Ophthalmology

prof. H. Sachs

LINKS:

Name	Developer	Place of stimulation	Camera	Resolution	Web
Second sight	USC	Epiretinal	Yes	60 electrode	http://www.2-sight.com
Boston retina implant	Harvard/MIT	Epiretinal	Yes	24 electrode	http://www.bostonretinalimplant.org
Epi-Ret	Uni Bonn	Epiretinal	Yes	100 electrode	http://www.nero.uni-bonn.de/projekte/ri/ri-index-en.htm
Australian Vision Prosthesis	Ausztrália	Epiretinal	Yes	100 electrode	http://bionic.gsbme.unsw.edu.au
Japan Visual Preosthesis	Japán	retinal	Yes		http://www.io.mei.titech.ac.jp/research/retina
MPDA	Tübingen	Subretinal	No	1500 diode	http://www.retina-implant.de
Optoelectronic Retinal Prothesis	Stanford	Subretinal	Yes		http://www.stanford.edu/~palanker/lab/retinalpros.html
Artificial Silicon Retina	Optobionics	Subretinal	No	3500 diode	http://www.stanford.edu/~palanker/lab/retinalpros.html
Optivip	UC Leuven	Optic nerve	Yes	4-8 electrode	http://www.gren.ucl.ac.be/Projets/optivip.html
Intracortical Visual Prosthesis	IIT, Chicago	Visual cortex	Yes		http://www.iit.edu/engineering/bme/faculty/highlights
Utah Visual Neuroprosthesis	Utah	Visual cortex	Yes	625 electrode	http://www.bioen.utah.edu/cni/projects/blindness.htm
CORTIVIS	Alicante	Visual cortex	Yes	128 electrode	http://cortivis.umh.es

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REVIEW QUESTIONS

- Describe the structure of the vertebrate retina.
- Describe the photoreceptors and their functions.
- What kind of information processing is done in the retina?
- What are the characteristic degenerative diseases of the retina?
- Which are the main types of the visual implants?
- What are the characteristics of the epiretinal implants?
- What are the characteristics of the subretinal implants?
- What kinds of non-retinal implant were suggested as visual prostheses?