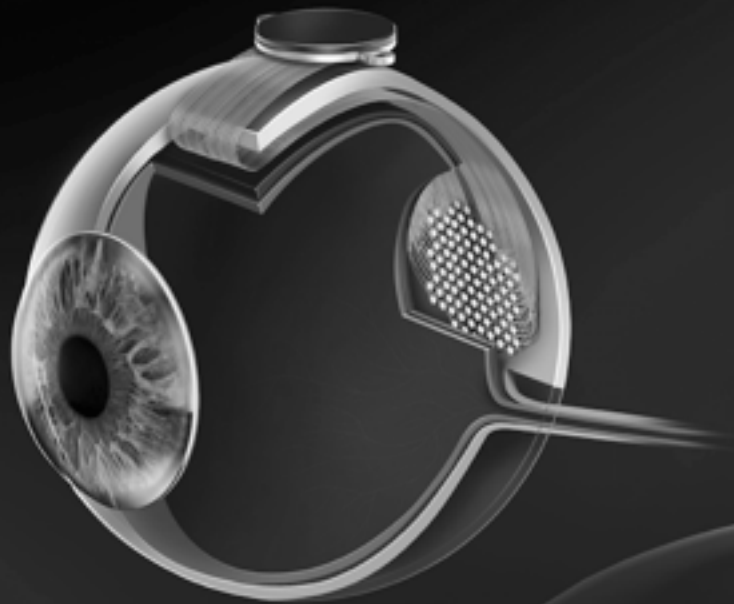


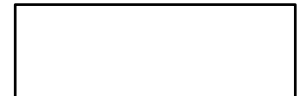
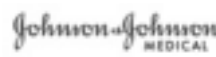
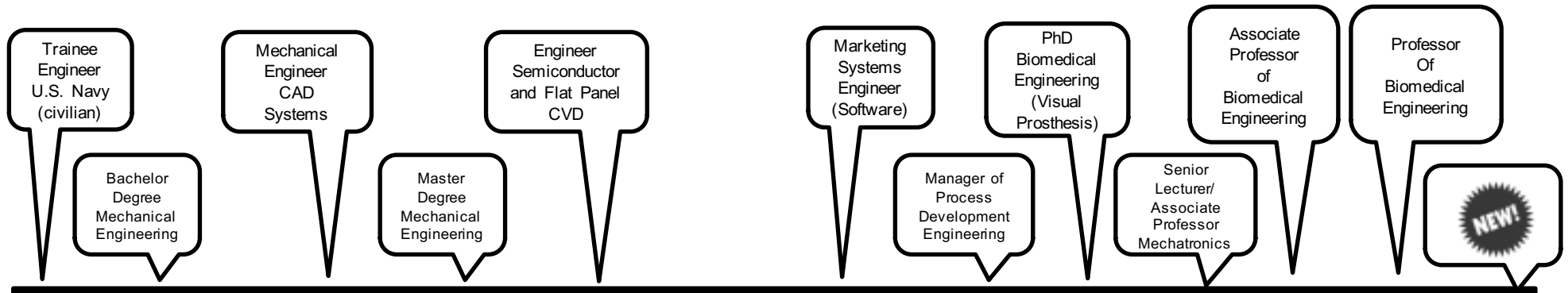
Lessons learned:  
Conducting pre-clinical  
testing of an advanced  
bionic eye in Australia



Gregg Jørgen Suaning

Professor of Biomedical Engineering

# Curriculum Vitae



# The start of a beautiful friendship

Cochlear ca 1992 (now over 2000 people world-wide)



# The start of a beautiful friendship

Cochlear ca 1992 (now over 2000 people world-wide)





# Striking a balance...

User expectations

Surgical ease

Small size

Life-long implantable

Fast Track to Regulatory Compliance

Versatility (e.g. channels)

Strong

Flexible

Fast implementation



Human limitations

Multiple iterations

Difficult fabrication

Hermetic challenge

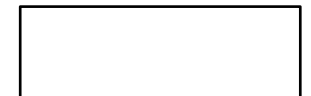
Existing biomaterials with associated limitations

More features = larger

Stiff materials

Compromises to strength

\$ + collaboration

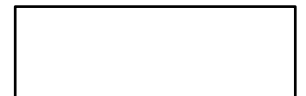


**Balancing the perfect device with the achievable outcomes**



**Arne Larsson 1915-2001**

- **Received the 1<sup>st</sup> implantable pacemaker on 8 October, 1958**



## Balancing the perfect device with the achievable outcomes



**Arne Larsson 1915-2001**

- **Received the 1<sup>st</sup> implantable pacemaker on 8 October, 1958**
- **Received the 2<sup>nd</sup> implantable pacemaker on 9 October, 1958**



## Balancing the perfect device with the achievable outcomes



### Arne Larsson 1915-2001

- Received the 1<sup>st</sup> implantable pacemaker on 8 October, 1958
- Received the 2<sup>nd</sup> implantable pacemaker on 9 October, 1958 (the first one failed in 3 hours, the second did not work at all).



## Balancing the perfect device with the achievable outcomes

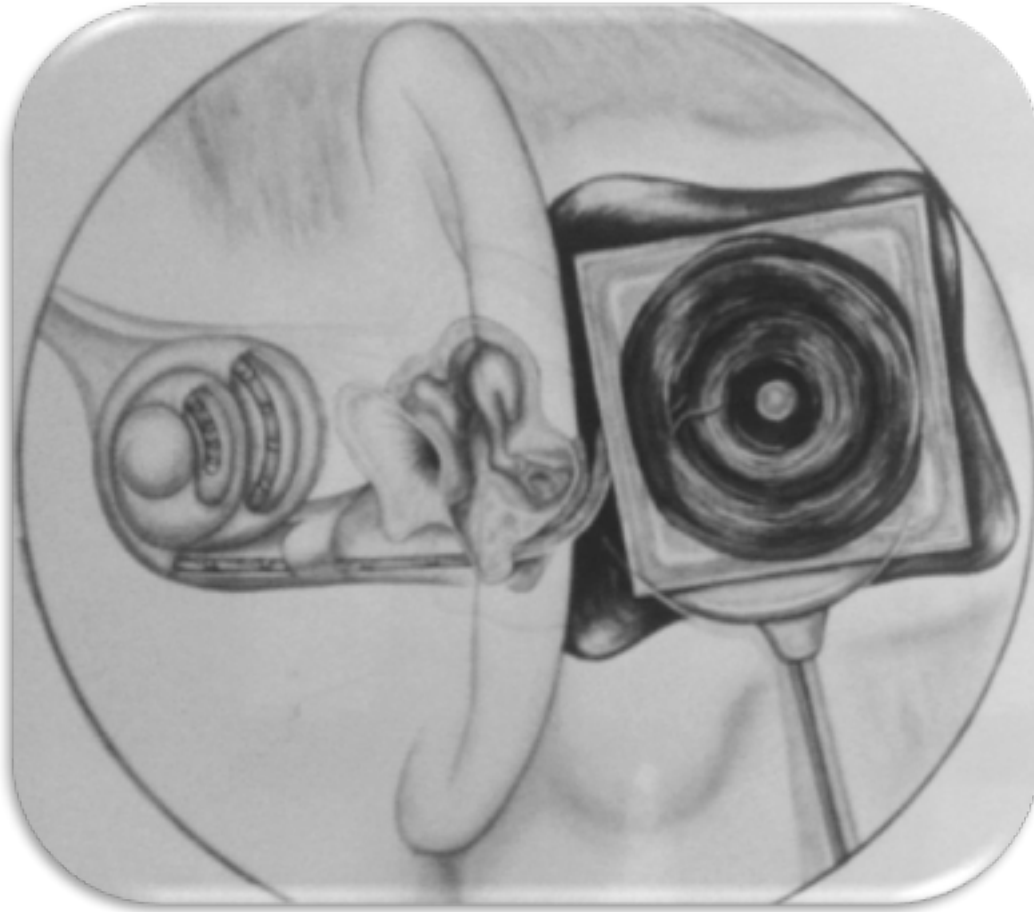


### Arne Larsson 1915-2001

- Received the 1<sup>st</sup> implantable pacemaker on 8 October, 1958
- Received the 2<sup>nd</sup> implantable pacemaker on 9 October, 1958 (the first one failed in 3 hours, the second did not work at all).
- By the time of his death at the age of 86, he had received 27 pacemakers

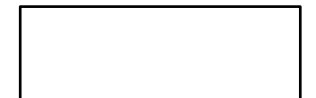


## Understanding risk...



### **The University of Melbourne Cochlear Implant - 1978**

- **Two out of three prototypes failed**
- **The company (Cochlear Limited) that came about as a result of this work now has ~70% of the world market, and has implanted in excess of 250,000 people.**



# Managing expectations...



ALL THE **EXCITEMENT**  
ALL THE **REALISM**  
ALL THE **'BIONIC' ACTION!**

YOU WORK HIS **POWERFUL "BIONIC" ARM!**  
It actually fits the engine block that comes with Colonel Austin!

Col. Steve Austin

**THE SIX MILLION DOLLAR MAN**  
**ACTION FIGURE**

**A BACK PACK RADIO THAT REALLY WORKS!**  
A working crystal set that picks up the AM radio broadcasts, works without batteries.

**BIONIC TRANSPORT and REPAIR STATION**  
Closed it's a space ship 17 1/2" tall, opened it's a repair station with "X-Ray", Diagnostic Computer, Magnifying Glass, and a "Bionic" Medical Center!  
Also serves as carrying case for Six Million Dollar Man.

**SEE THROUGH HIS BIONIC EYE!**  
See everything, through a wide-angle lens just as Colonel Steve Austin sees through his own Bionic Eye!

**13" TALL**

AA trademark of Universal City Studios, Inc.  
Character: © Universal City Studios, Inc. 1973  
All rights reserved.

**THE SIX MILLION DOLLAR MAN BIONIC ACTION CLUB**  
P.O. Box 1408, Cincinnati, Ohio 45201  
Enclosed is \$10 for postage and handling.  
Please email me in the Six Million Dollar Man "Bionic" Action Club and send me my official membership certificate, autographed color picture of Colonel Steve Austin, membership card, and decal of Six Million Dollar Man Seal.

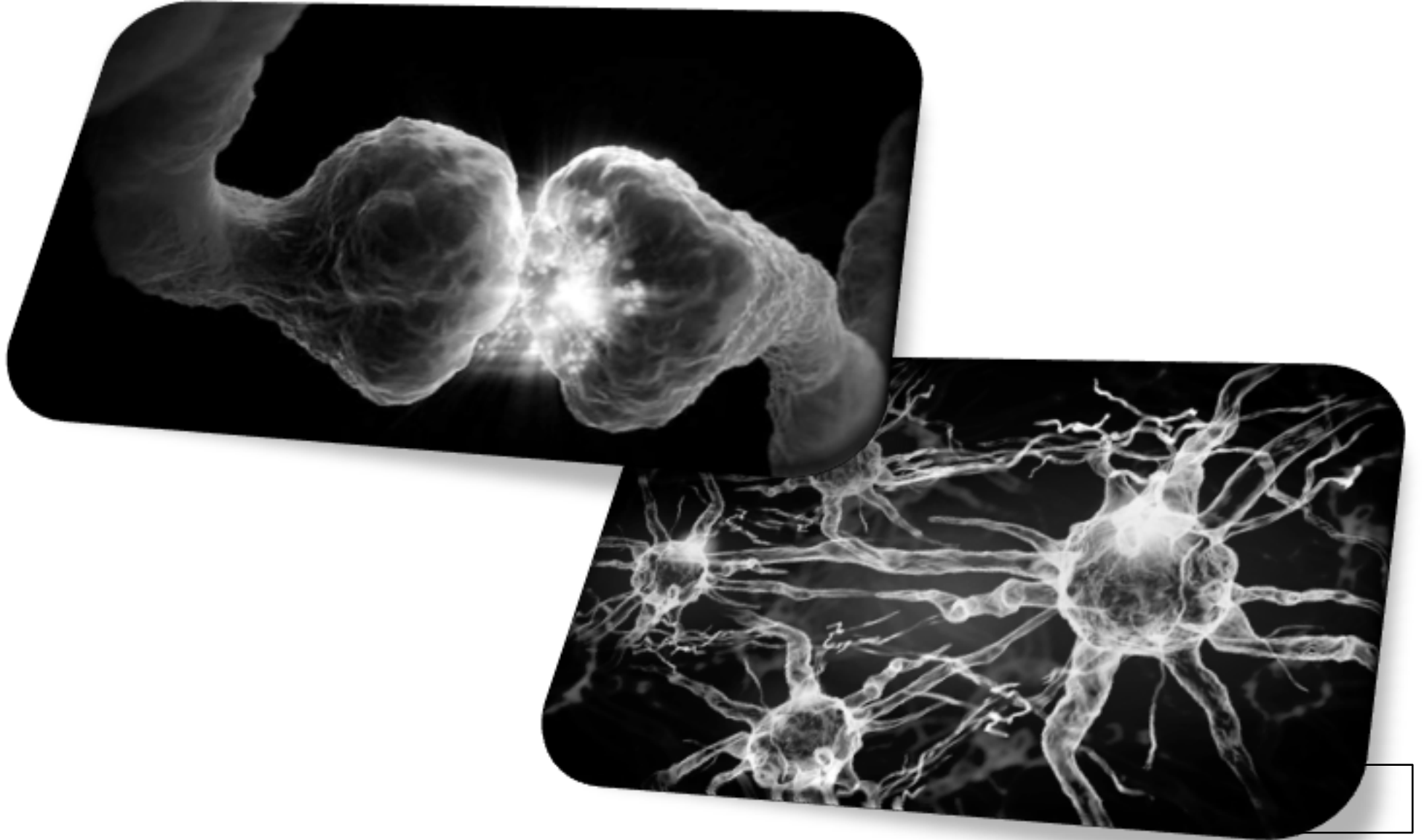
NAME \_\_\_\_\_  
ADDRESS \_\_\_\_\_  
CITY \_\_\_\_\_ STATE \_\_\_\_\_ ZIP \_\_\_\_\_

**Kenner**

© Kenner, Inc. 1973. All rights reserved. Please allow 4-6 weeks for delivery. Offer expires April 1, 1974.

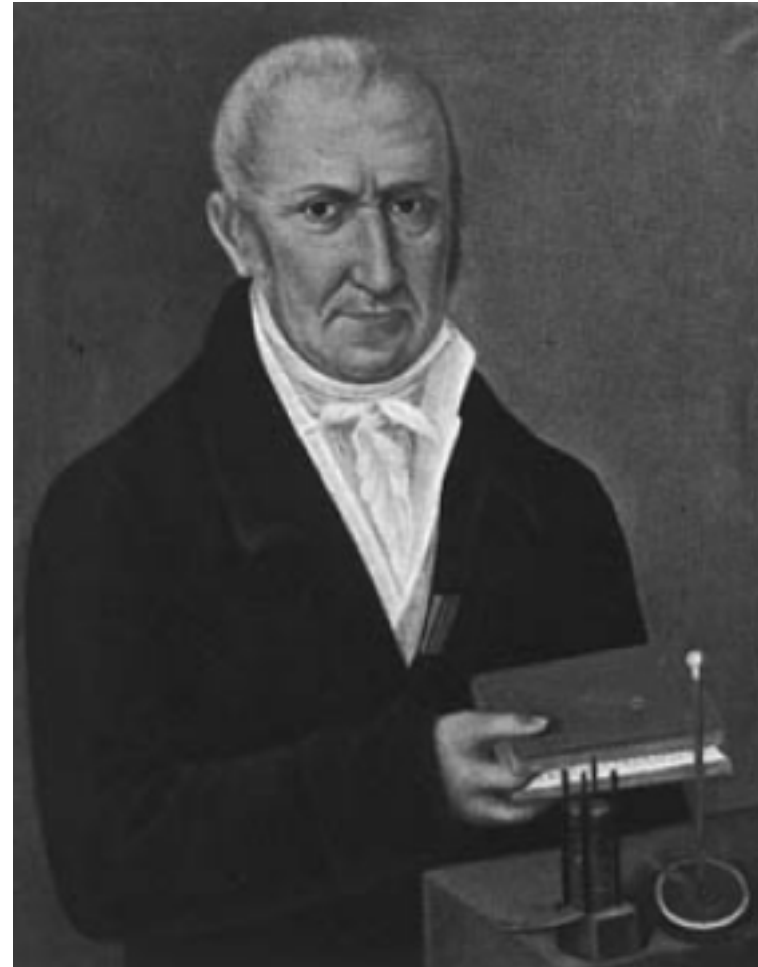
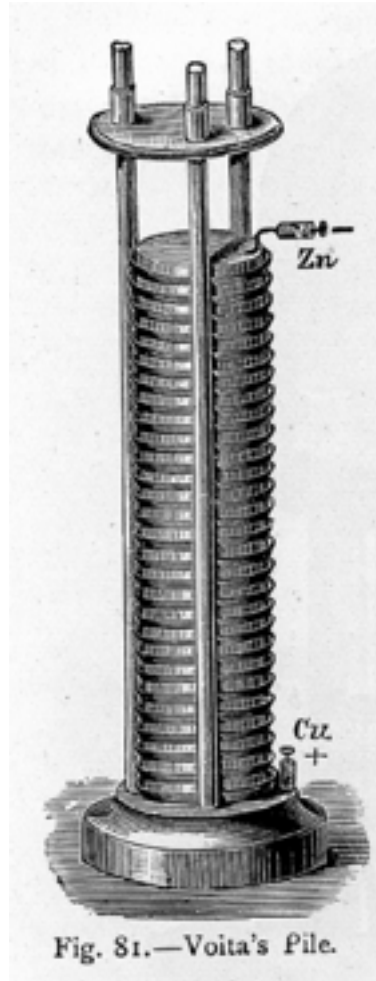


# neuromodulation





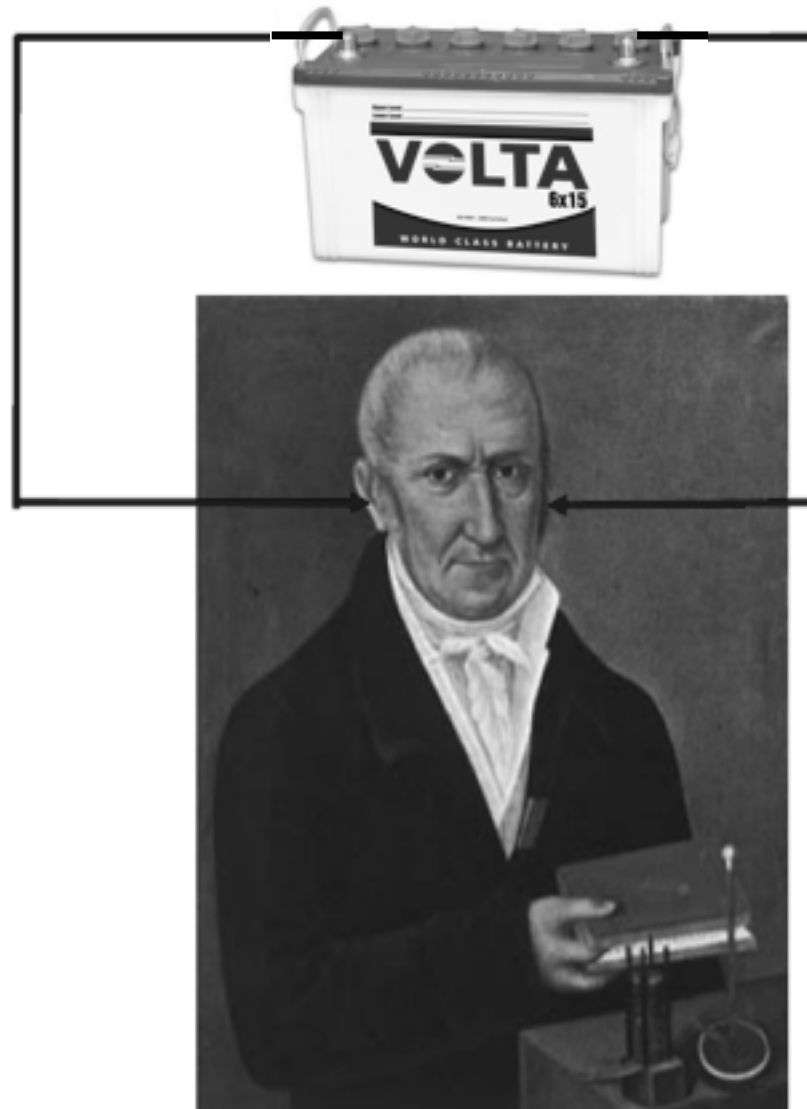
# The origins of neuromodulation



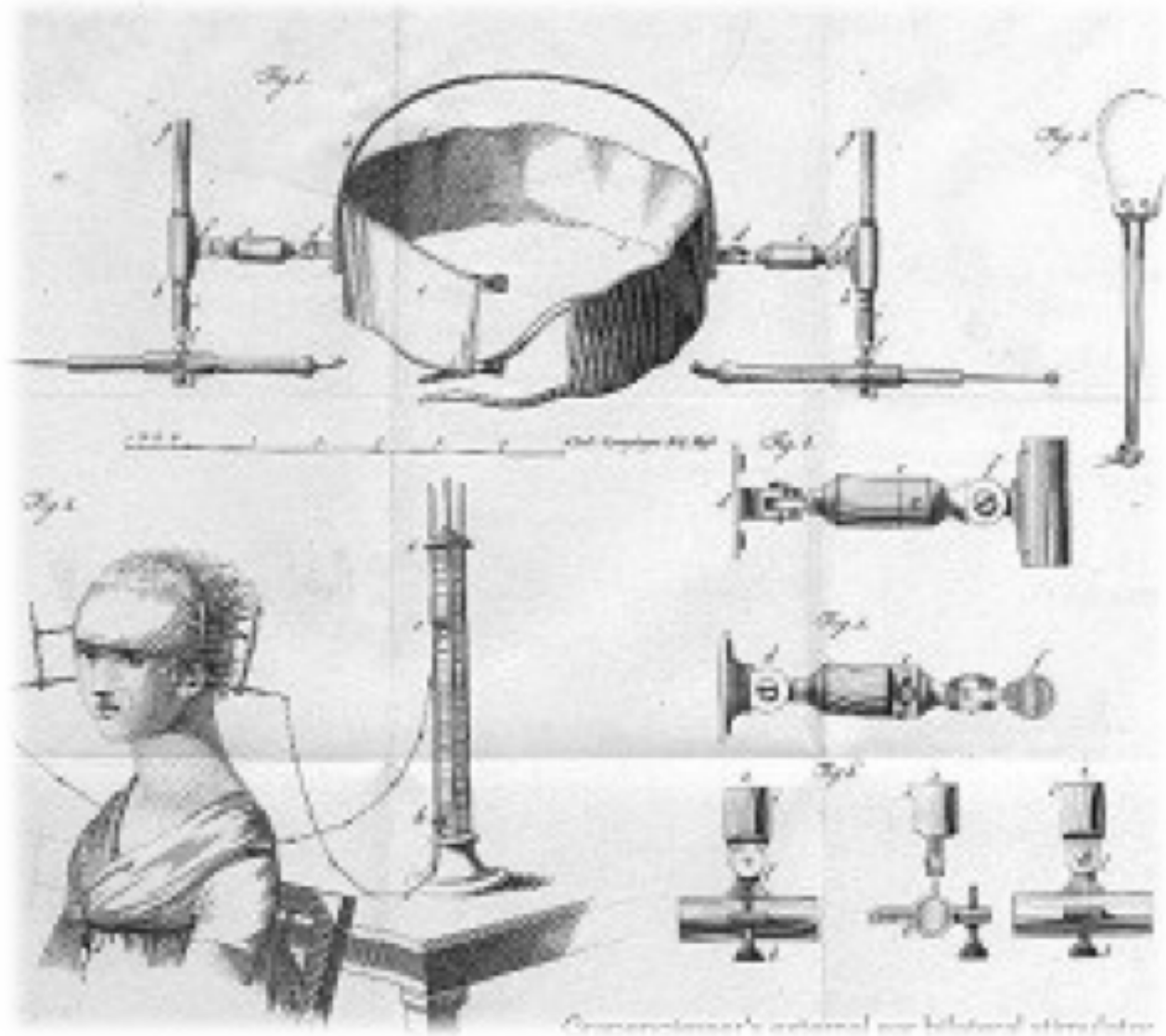
# The origins of neuromodulation

'une secousse'

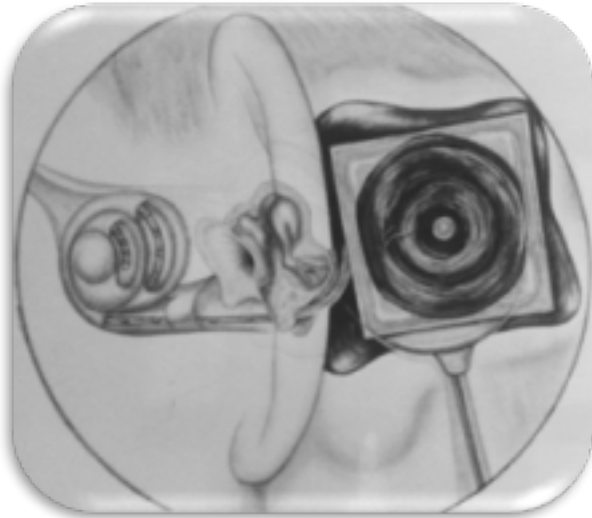
Described the experience as:  
'a jolt in the head'  
followed by the  
sound of 'thick soup  
boiling'



# The origins of neuromodulation

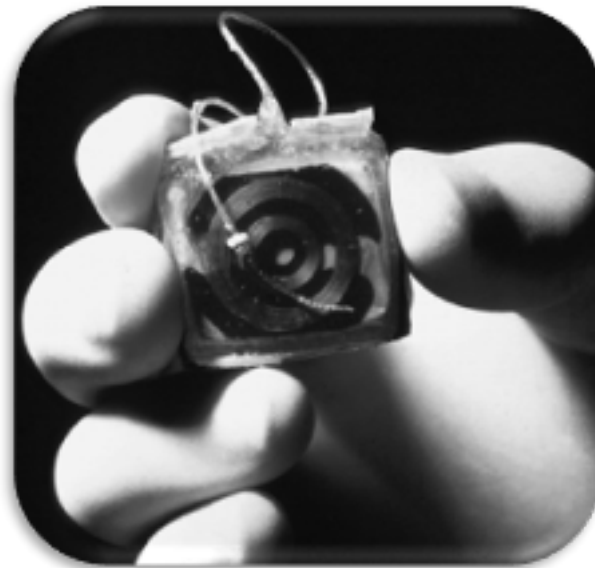


# Cochlear Implant Technology

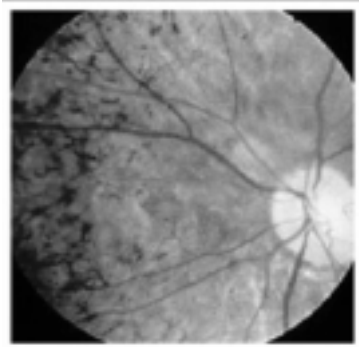


## The University of Melbourne Cochlear Implant - 1978

- Two out of three prototypes failed
- The company (Cochlear Limited) that came about as a result of this work now has ~70% of the world market, and has implanted in excess of 350,000 people.

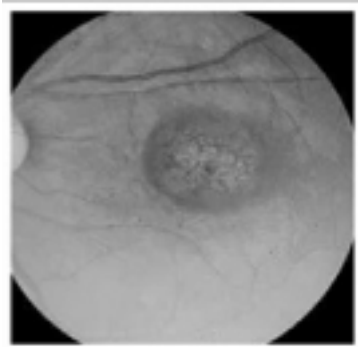


# Retinal degeneration - diseases



Retinitis pigmentosa (RP)

RP is one of the leading causes of blindness in young people



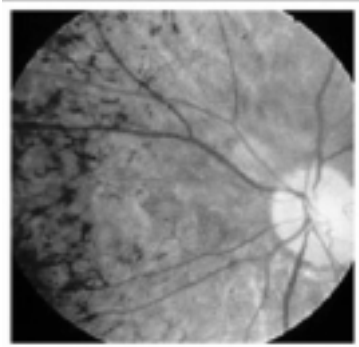
Age-related macular degeneration (AMD)

AMD is a leading cause of blindness in the elderly population

**\*\* Both leave behind a viable optic nerve \*\***

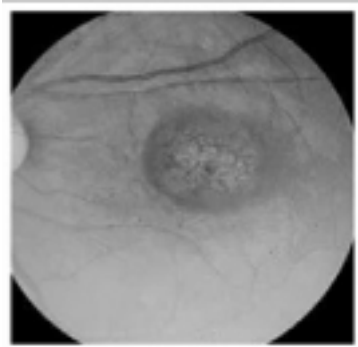


# Retinal degeneration - diseases



## Retinitis pigmentosa (RP)

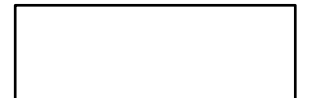
The leading cause of inherited blindness  
Affects 1 in 3500 in USA  
Approx. 1.5M affected world-wide



## Age-related macular degeneration (AMD)

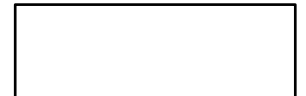
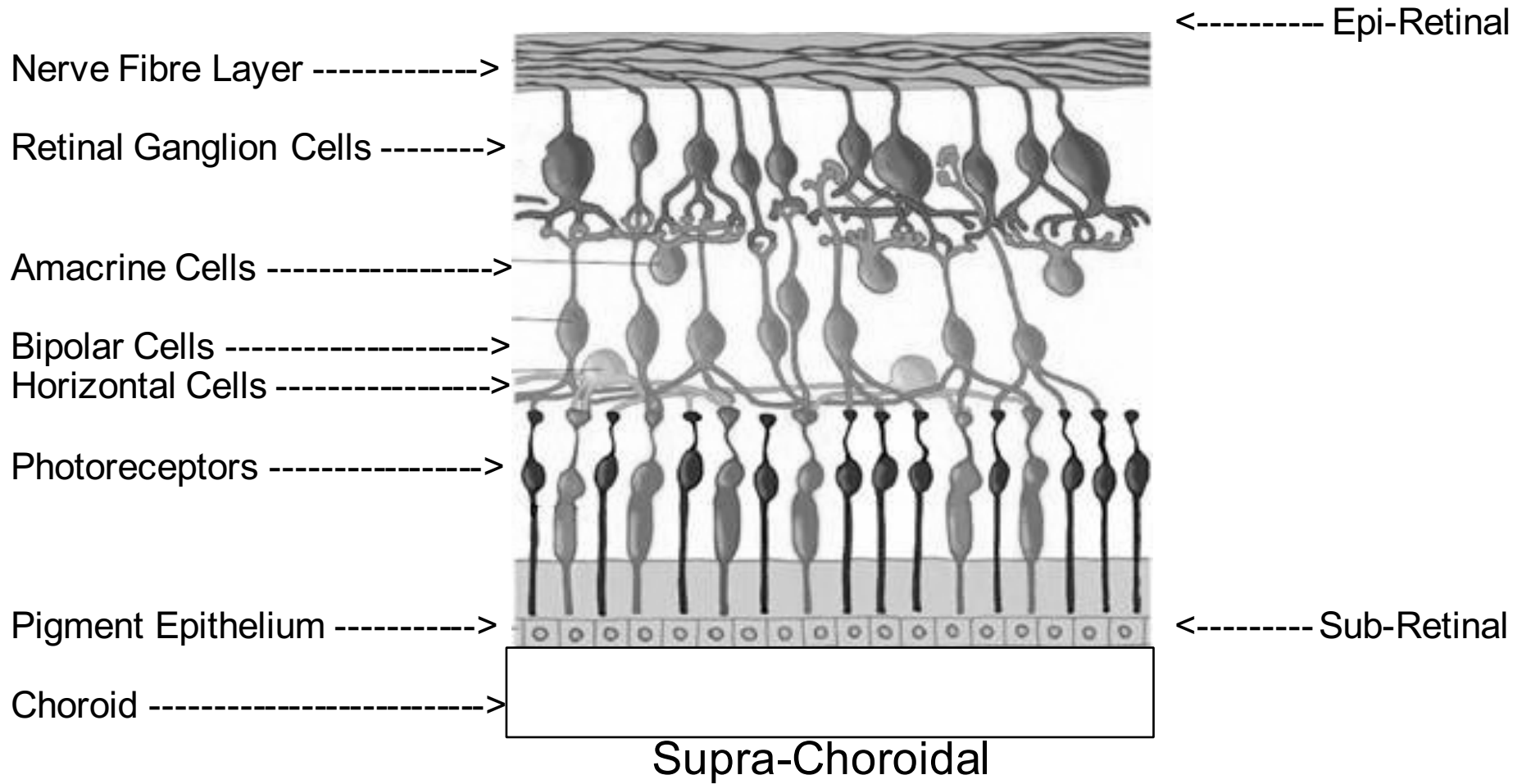
The leading cause of blindness in over 55's  
By 2020 it will affect 3M people in USA

**\*\* Both leave behind a viable optic nerve \*\***



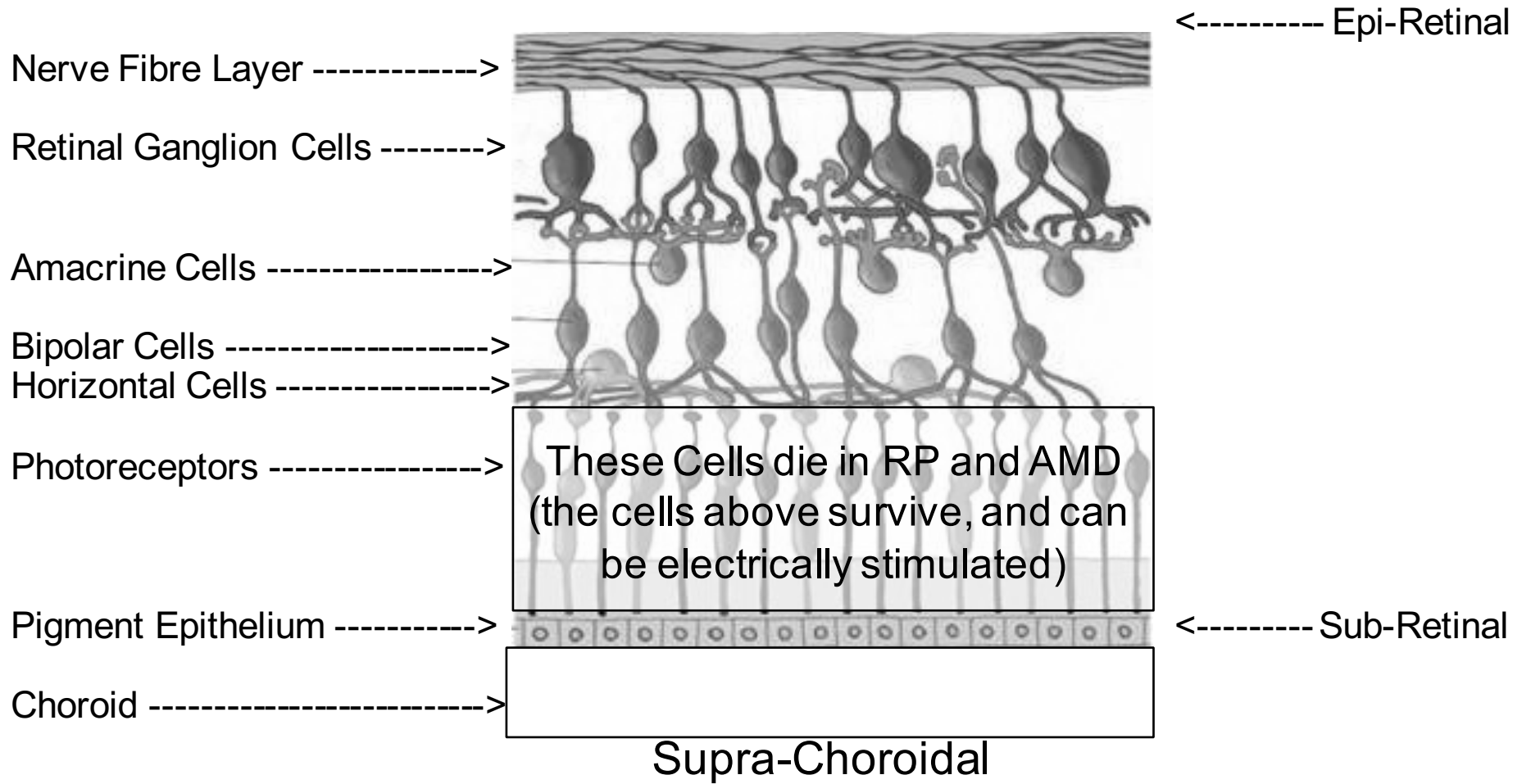
# Retinal prosthesis location

Image Adapted from: Eye Brain and Vision, D.H. Hubel



# Retinal prosthesis location

Image Adapted from: Eye Brain and Vision, D.H. Hubel





# The original bionic eyes

## United States Patent Office

2,760,483  
Patented Aug. 28, 1956

1

2,760,483

### RETINAL STIMULATOR

Graham Edward Tassicker, Surrey Hills, Victoria,  
Australia.

Application October 20, 1954, Serial No. 463,507

Claims priority, application Australia October 29, 1953

8 Claims. (Cl. 128—1)



Fig. 2.

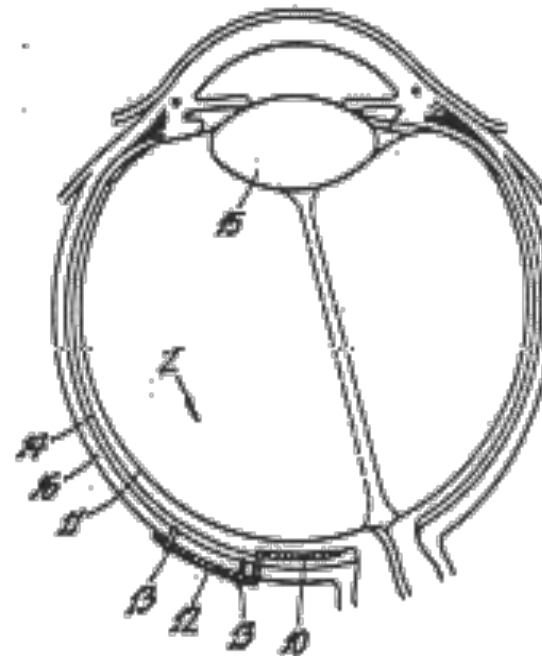
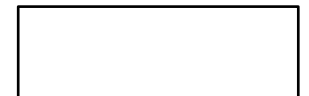


Fig. 1.



# The First Bionic Eye – 1956

## “supra-choroidal” implant

United States Patent Office

2,760,483  
Patented Aug. 28, 1956

1

2,760,483

### RETINAL STIMULATOR

Graham Edward Tassicker, Surrey Hills, Victoria,  
Australia

Application October 20, 1954, Serial No. 463,507

Claims priority, application Australia October 29, 1953

8 Claims. (Cl. 128—3)



FIG. 2.

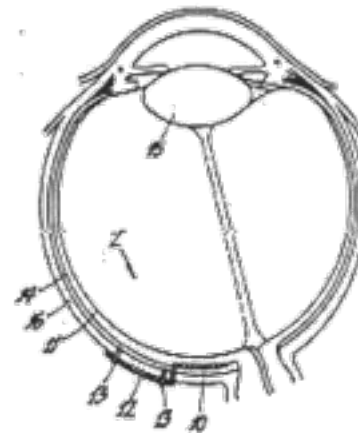
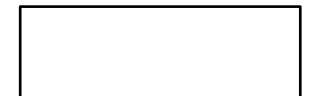


FIG. 1.

*The patient reported seeing uniform white light in the region of the implant where a "great dark patch" existed prior to the operation. The patient also reported increased confidence in mobility.*

Tassicker, GE "Preliminary Report on a Retinal Stimulator", British Journal of Physiological Optics V13 1956 pp 102-105



# Where do we intervene?

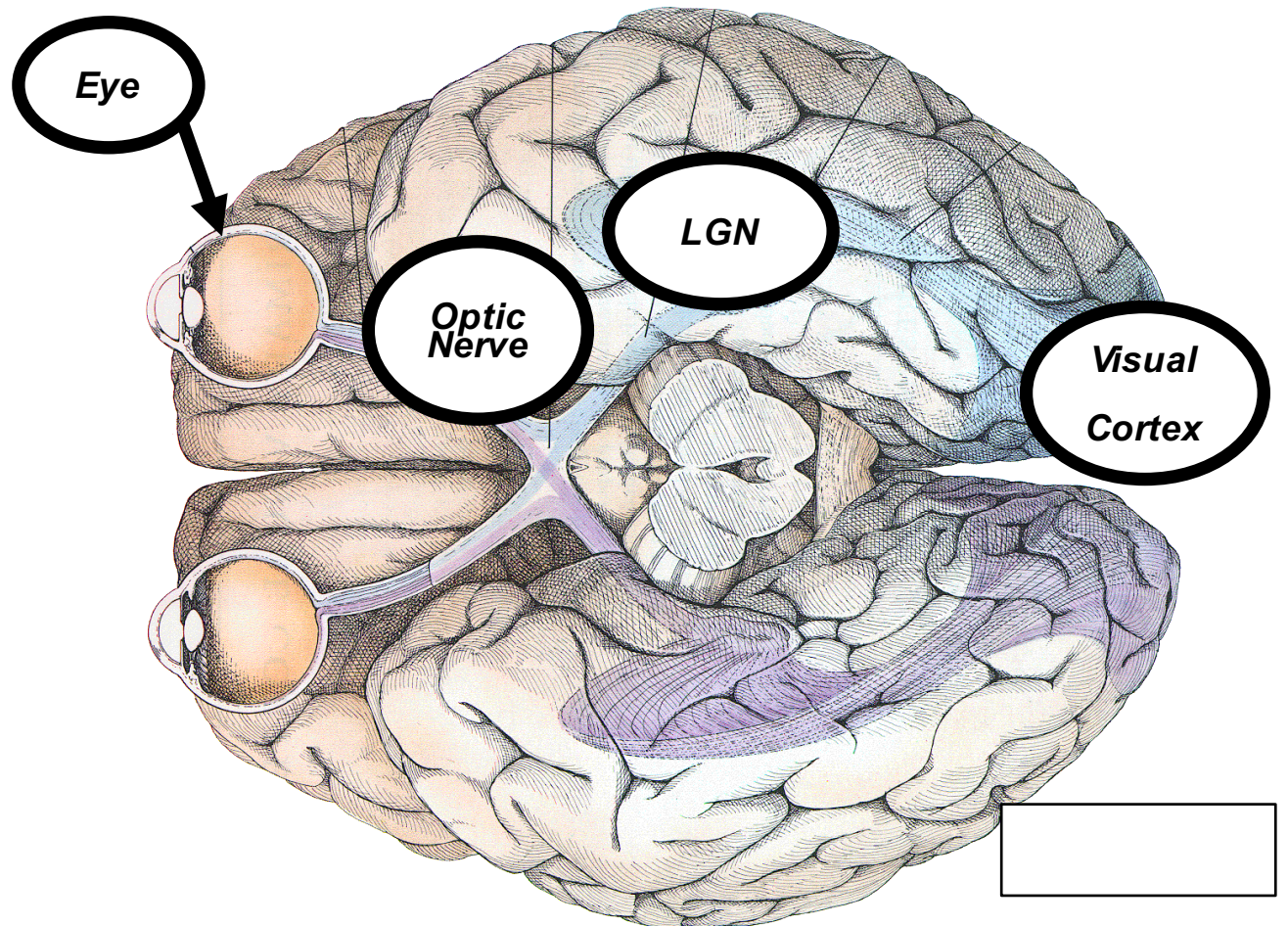
Alternatives:

Retina

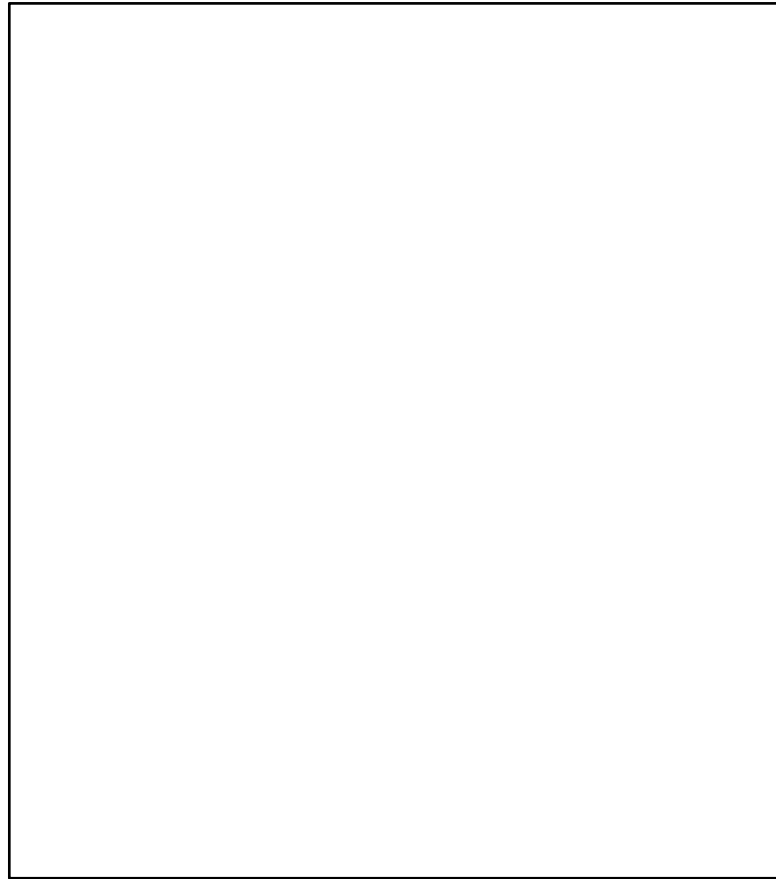
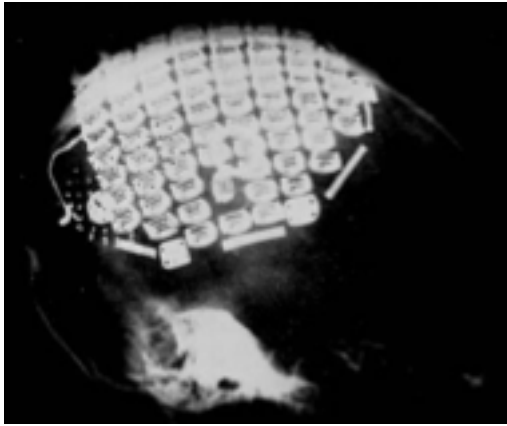
Optic Nerve

Lateral Geniculate

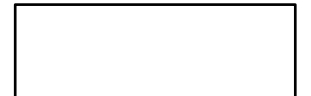
Visual Cortex



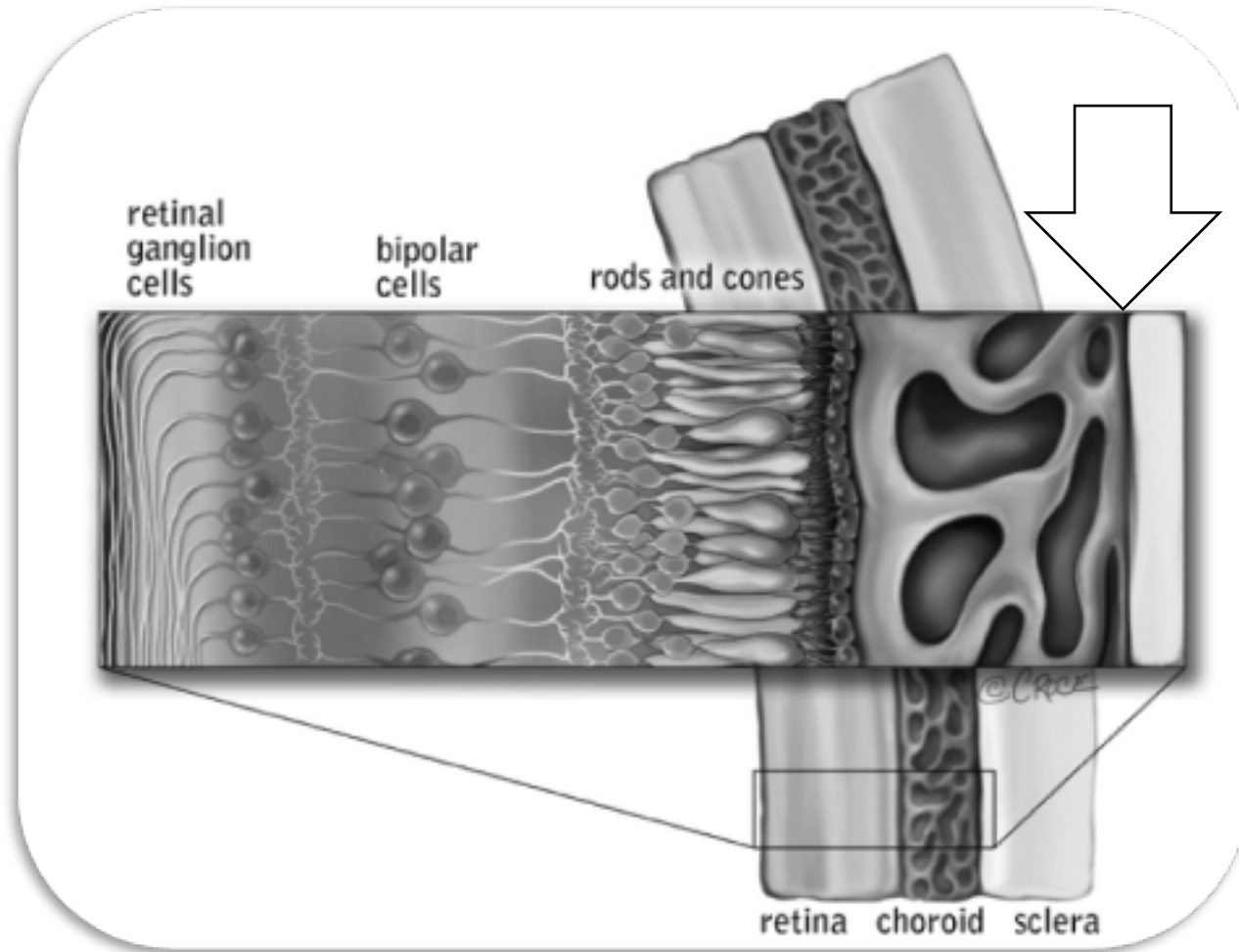
# The original bionic eyes



**Brindley, Lewin & Donaldson 1968**



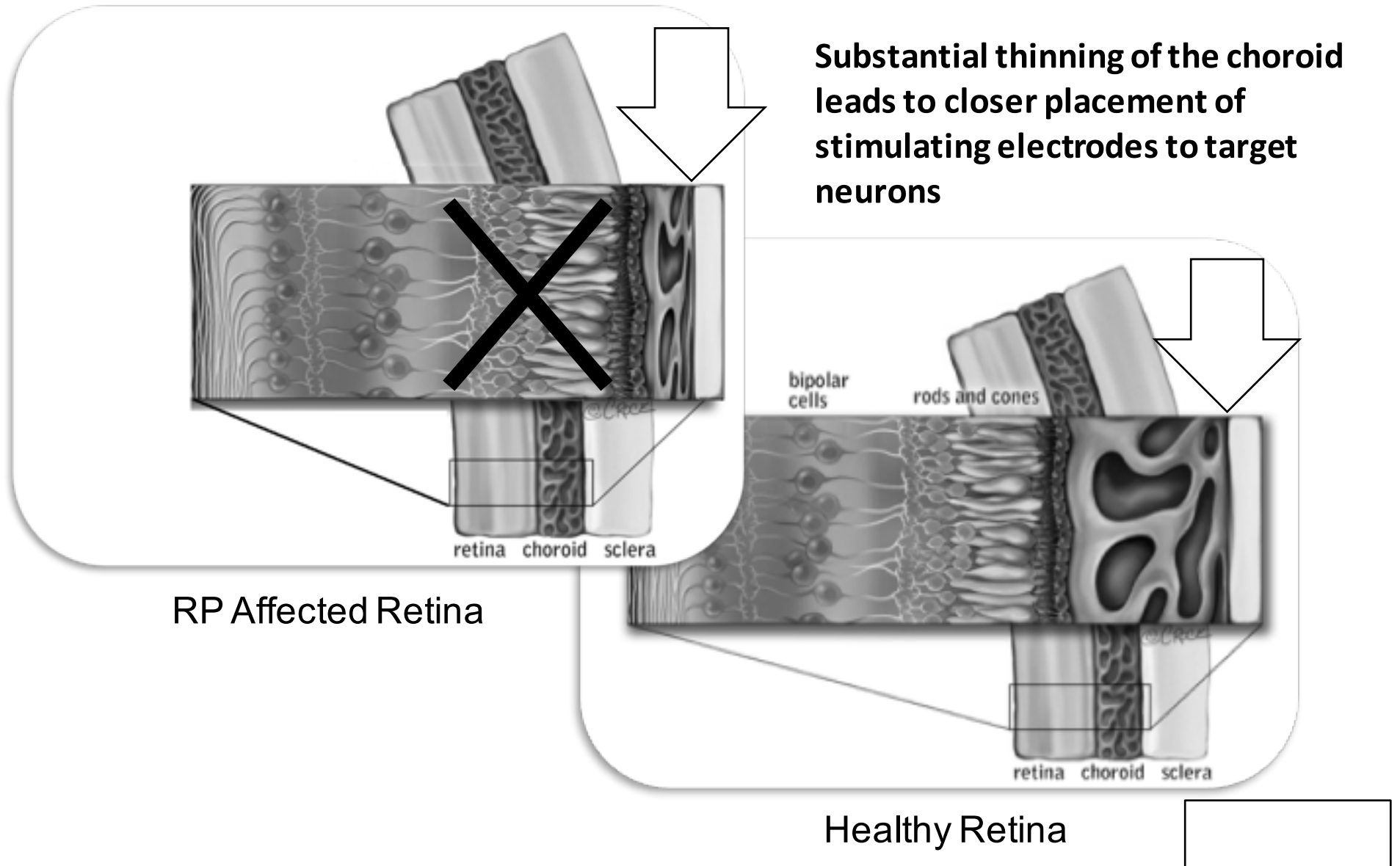
# Retinal prosthesis location



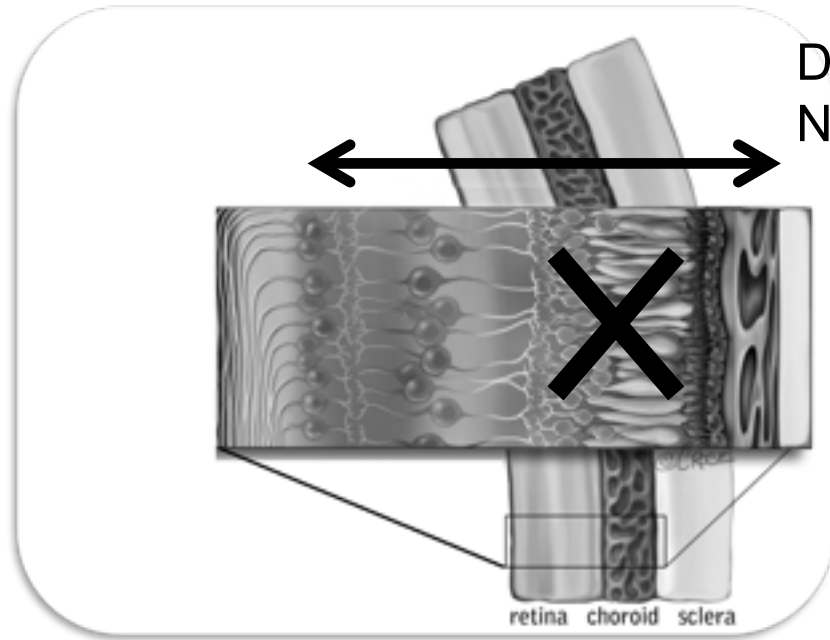
**Placement of a stimulating electrode array in the supra-choroidal space**



# Retinal prosthesis location



# Retinal prosthesis location



DISTANCE TO TARGET NEURONS (RGCs/BPCs)

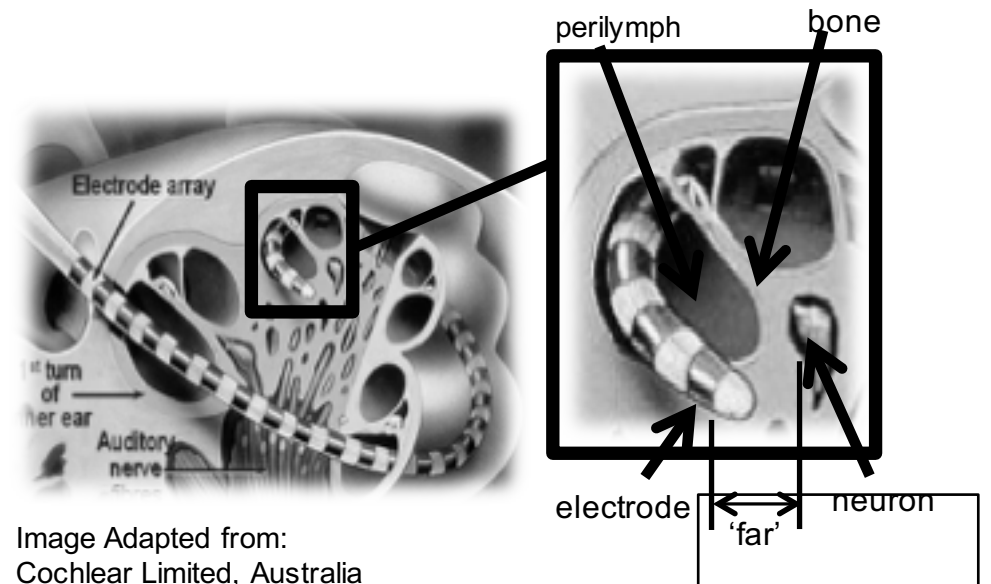
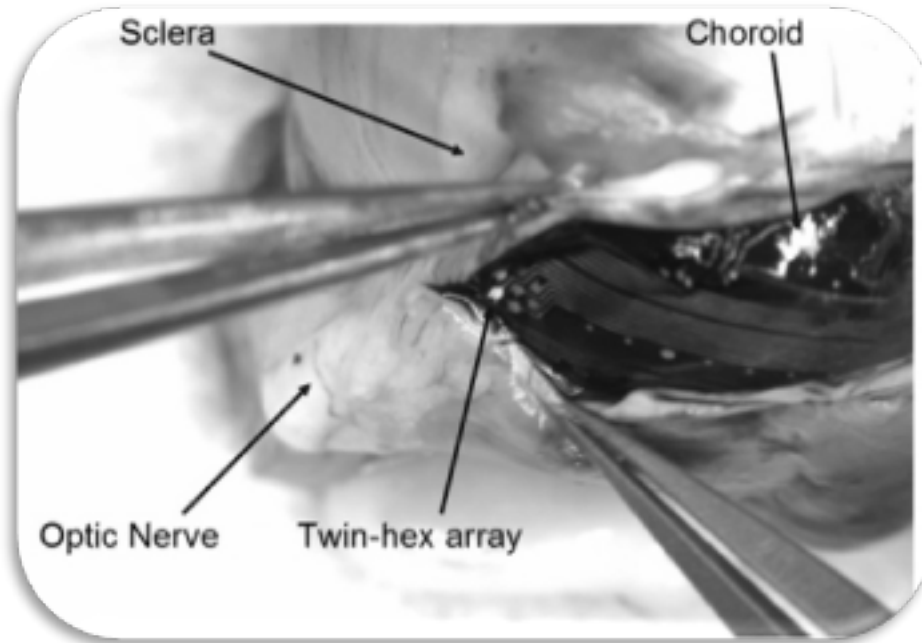
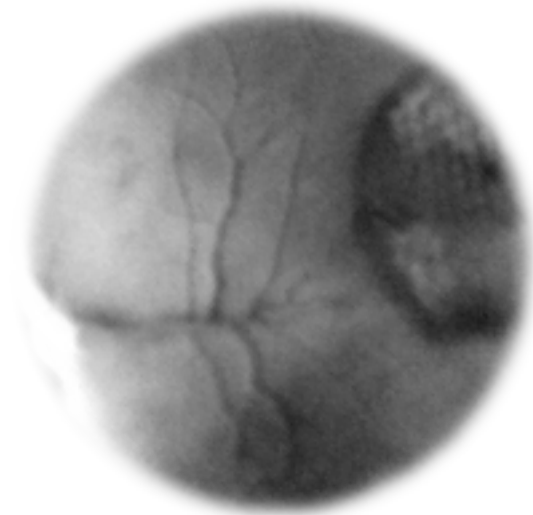


Image Adapted from:  
Cochlear Limited, Australia

# The implant method

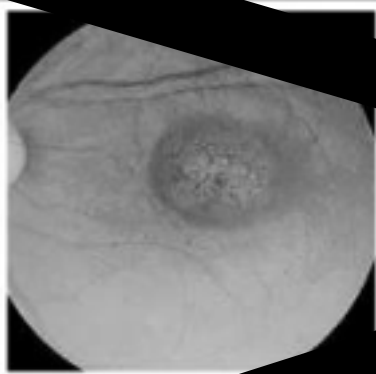


- **Array sits within a stable “pocket”**
- **Significantly simplified surgical approach**
- **Protection of neurons from stimulation by-products due to physical separation (behind choroid)**
- **Can co-exist with residual vision (potential for AMD therapy)**





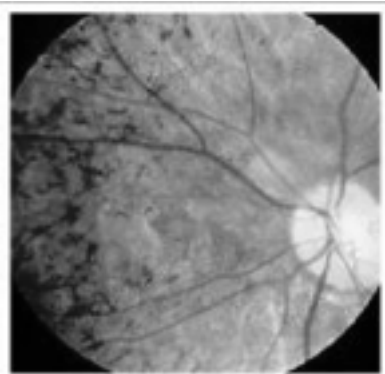
# Degenerative Diseases



Age-related macular degeneration (AMD)

AMD is a leading cause of blindness in the elderly population

?



Retinitis pigmentosa (RP)

RP is one of the leading causes of blindness in young people

**\*\* Both leave behind a viable optic nerve \*\***



# Degenerative Diseases



**Bionic eye improves macular degeneration patient's sight**

21 July 2015 Last updated at 17:59 BST

Surgeons in Manchester have performed the world's first bionic eye implant in a patient with the most common cause of sight loss in the developed world.

Ray Flynn, 80, has dry age-related macular degeneration which has led to the total loss of his central vision.

Degenerative Diseases

~~Age-related macular degeneration (AMD)~~  
AMD is a leading cause of blindness in the elderly population.

Retinitis pigmentosa (RP)  
RP is one of the leading causes of blindness in young people.

**"Both leave behind a viable optic nerve"** UNOW



**British pensioner gets bionic eye in operation which could help millions with age-related sight loss**

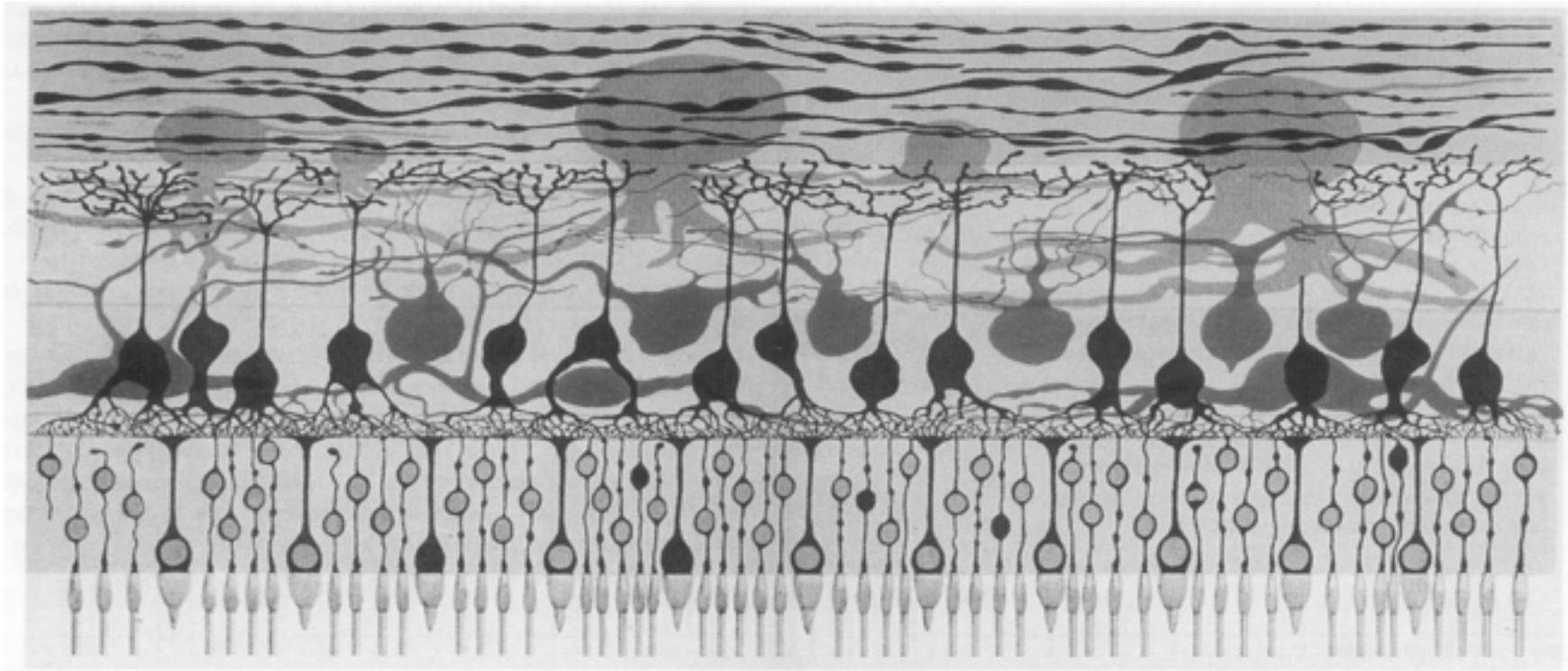
AM By Nick Grimm  
Updated 22 Jul 2015, 2:07pm

**British doctors have given an 80-year-old man a new bionic eye in a procedure which could go on to help millions of people suffering from the most common cause of sight loss.**

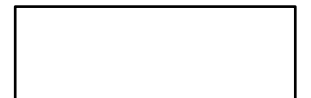
While he is not the first to benefit from the technology, Ray Flynn was the first bionic eye recipient with dry age-related macular degeneration — a condition affecting millions of people worldwide.



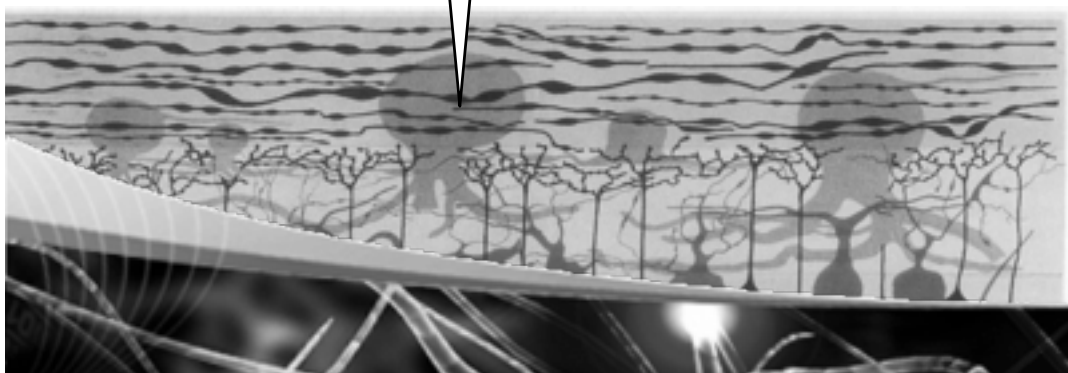
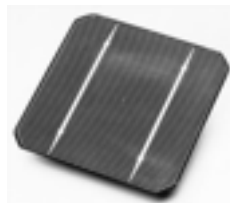
## The Perfect Intervention (using electrical stimulation)



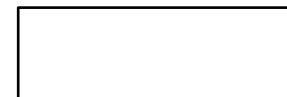
Tartuferi  
1887



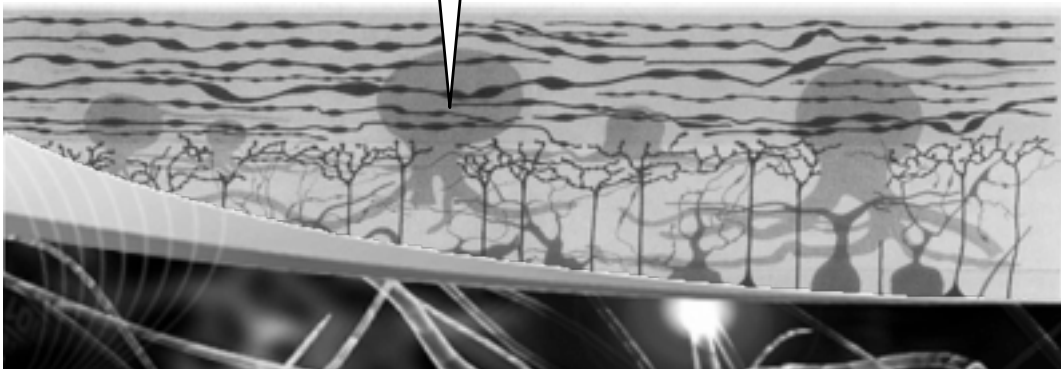
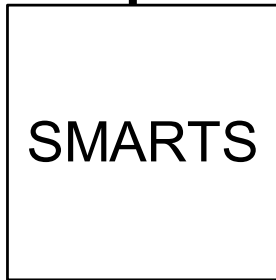
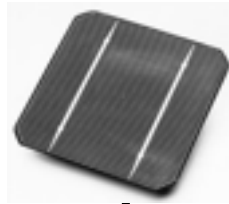
# The Perfect Intervention (using electrical stimulation)



Tartuferi  
1887



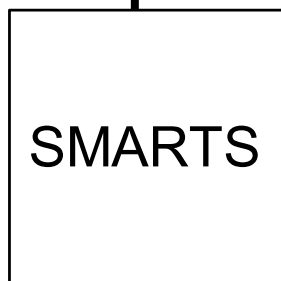
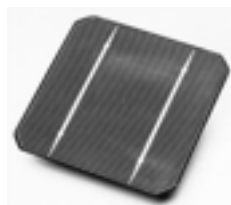
# The Perfect Intervention (using electrical stimulation)



Tartuferi  
1887

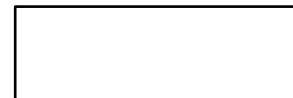
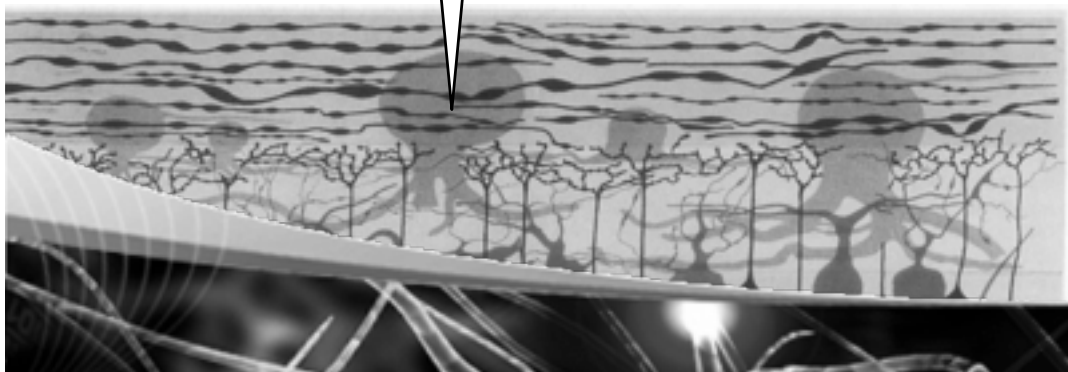


# The Perfect Intervention (using electrical stimulation)

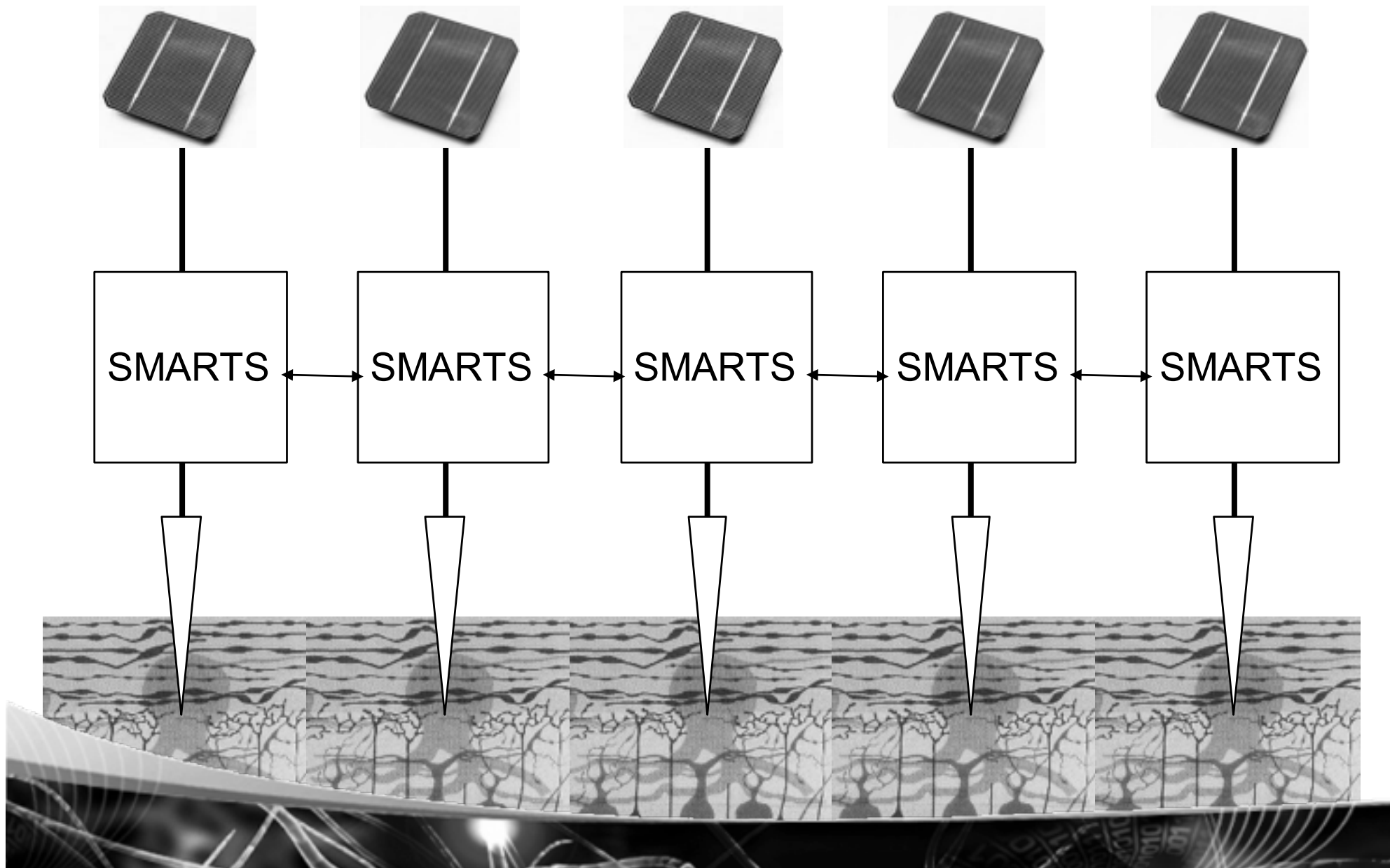


```
int off_rgc(void)
{
    if(on_to_off)
    {
        send_lots_of_spikes();
        tell_neighbours();

        tell_cell_down_the_road();
    }
    else
        send_slow_spikes();
}
```

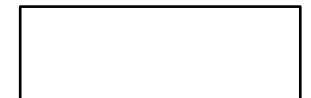
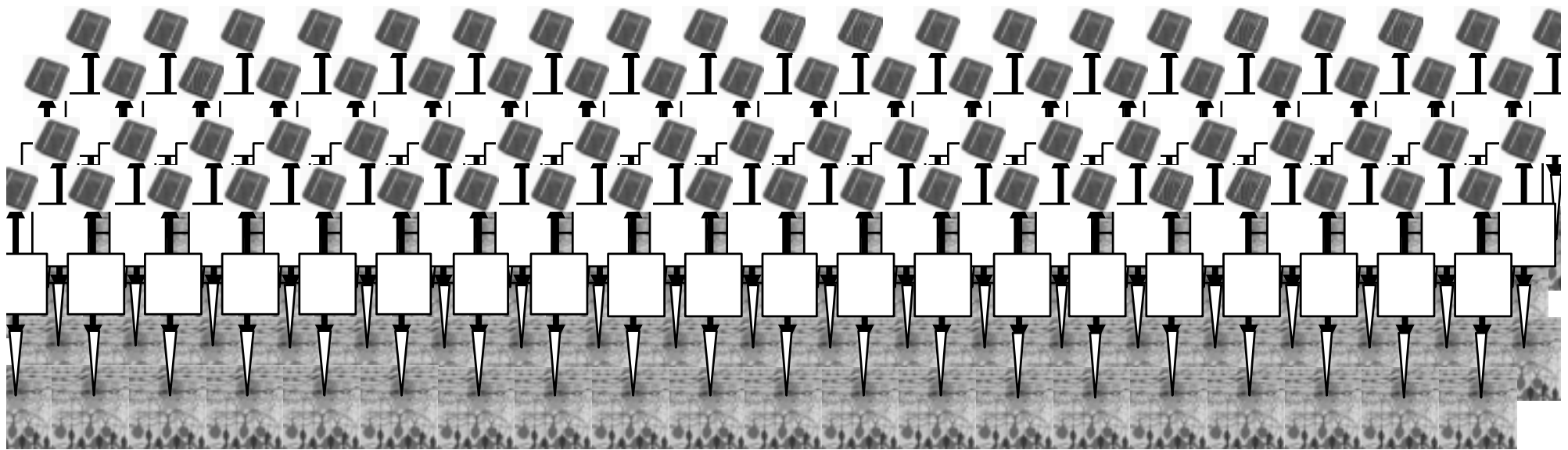


# The Perfect Intervention (using electrical stimulation)



**The Perfect Intervention  
(using electrical stimulation)**

... for about 1,000,000 RGCs

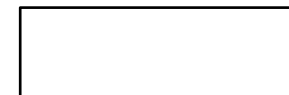
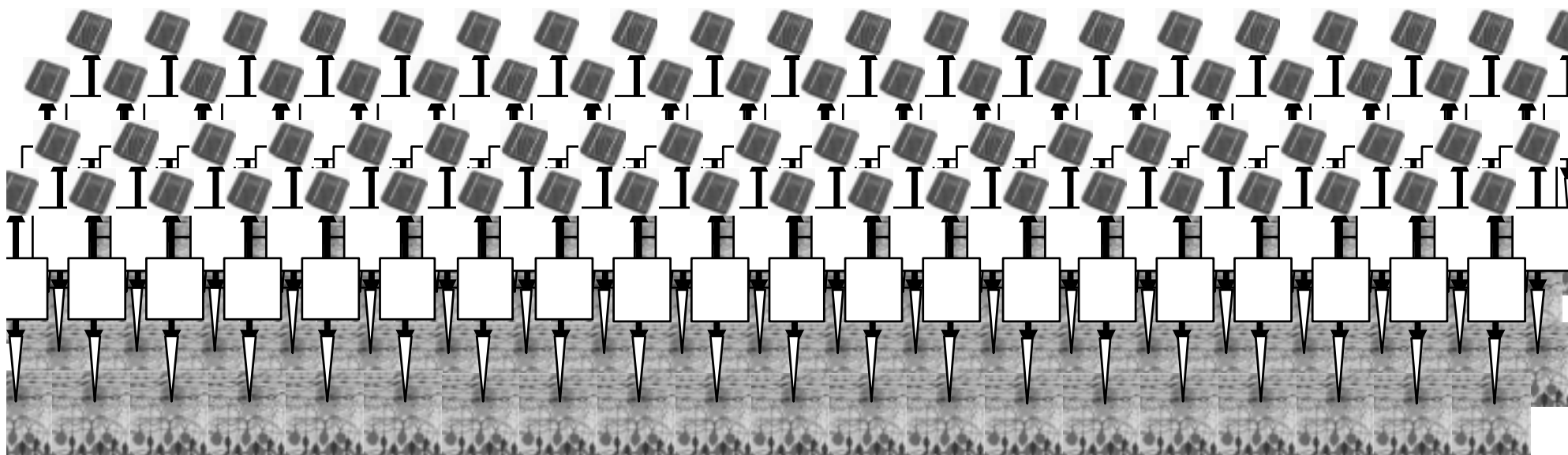




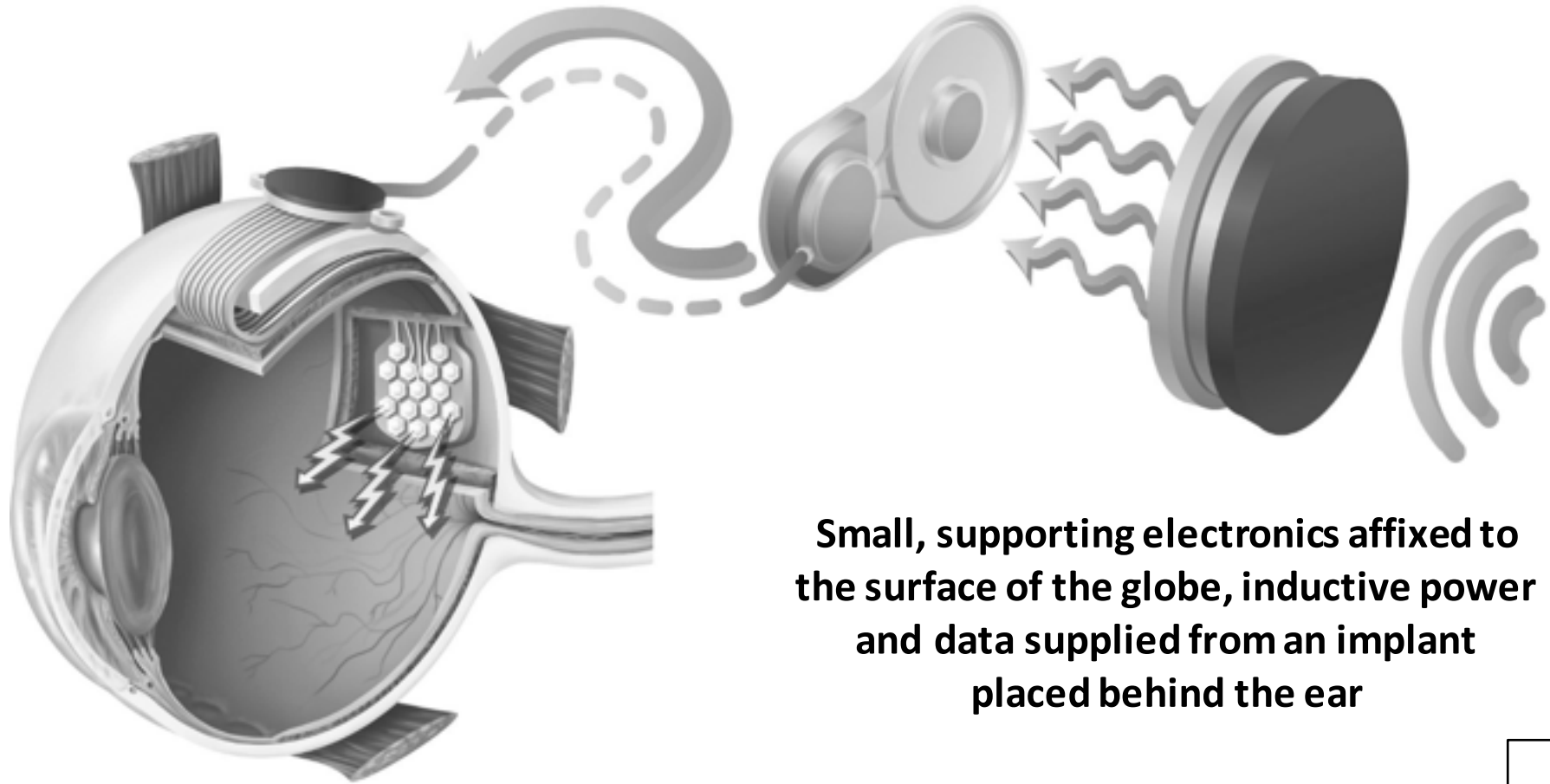
# The Perfect Intervention (using electrical stimulation)



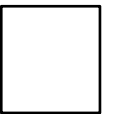
... for about 1,000,000 RGCs



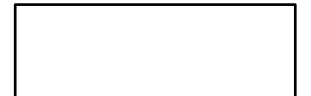
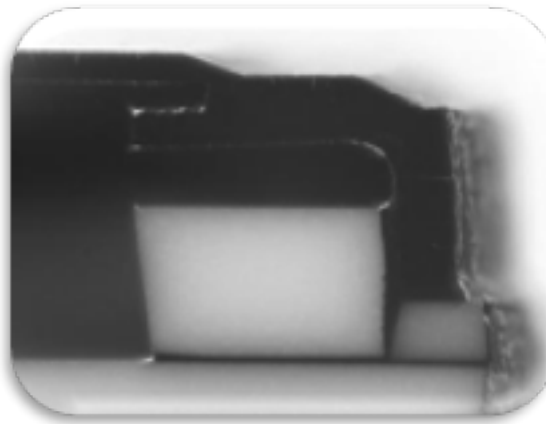
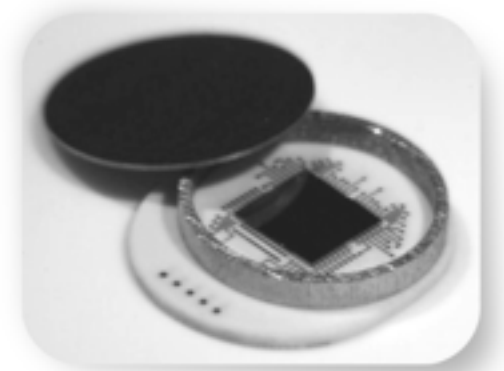
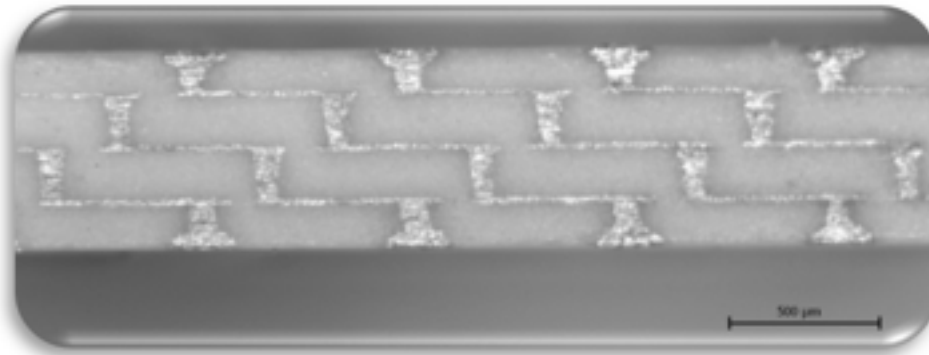
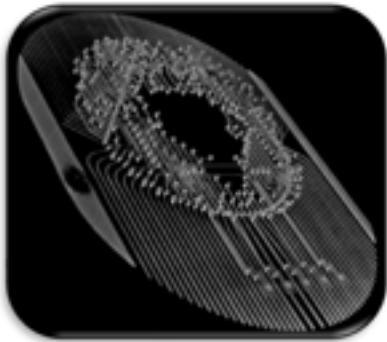
# The idea



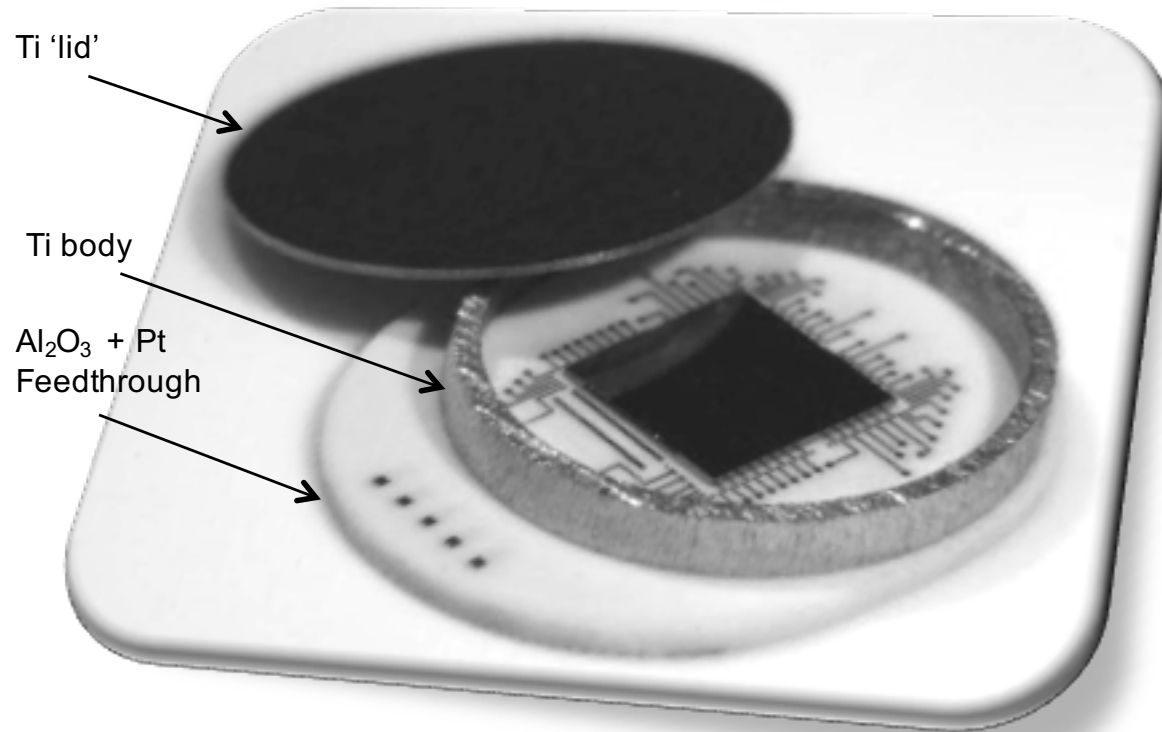
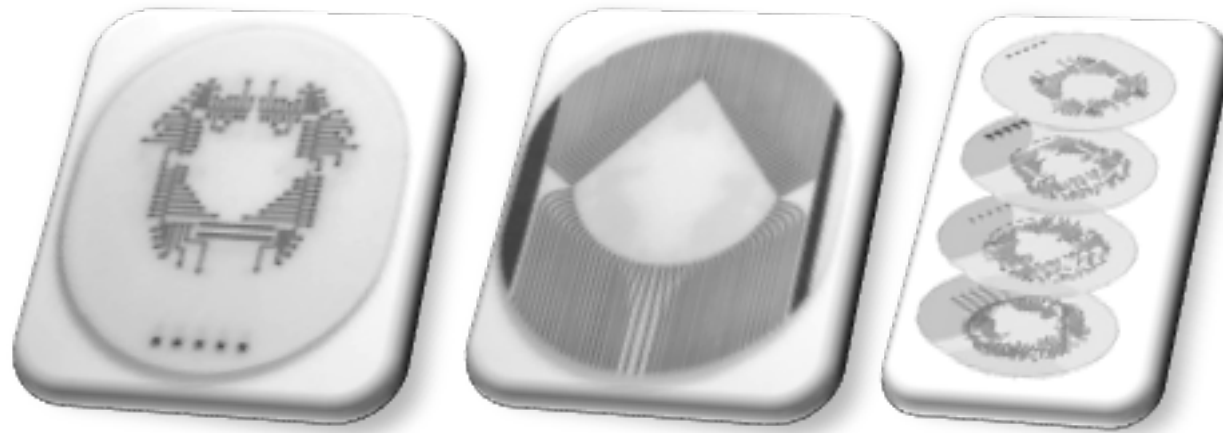
**Small, supporting electronics affixed to the surface of the globe, inductive power and data supplied from an implant placed behind the ear**



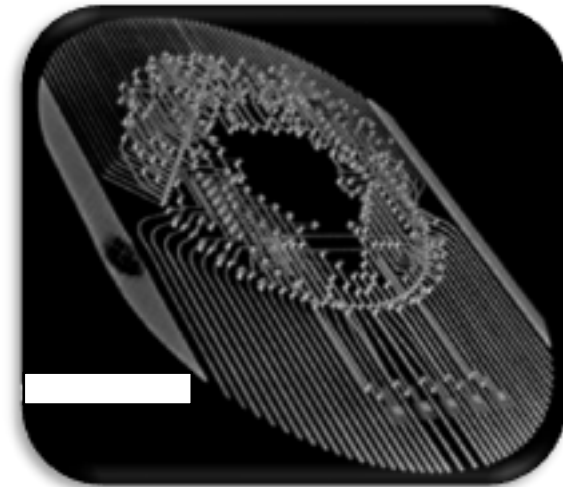
# Hermetic Encapsulation



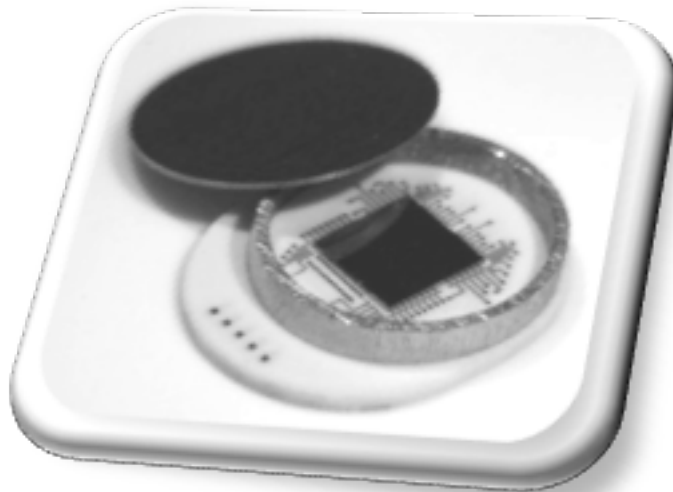
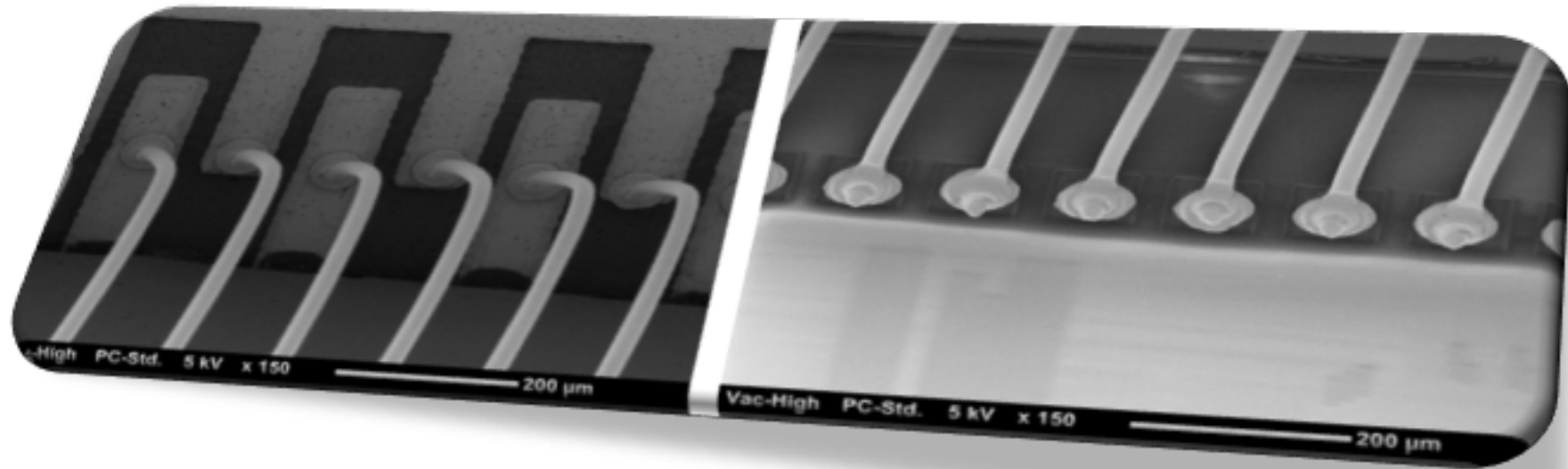
# Hermetic Encapsulation



- Layered,  $\text{Al}_2\text{O}_3$  and Pt feedthrough system with 102 feedthroughs (tested to 1141)
- Volume + Hermeticity -> 50+ years lifetime
- Flip-chip bonded with no additional components (e.g. capacitors, etc.)
- Biostable materials, each with long-term implantation histories
- Laser micromachined vias/pads/tracks

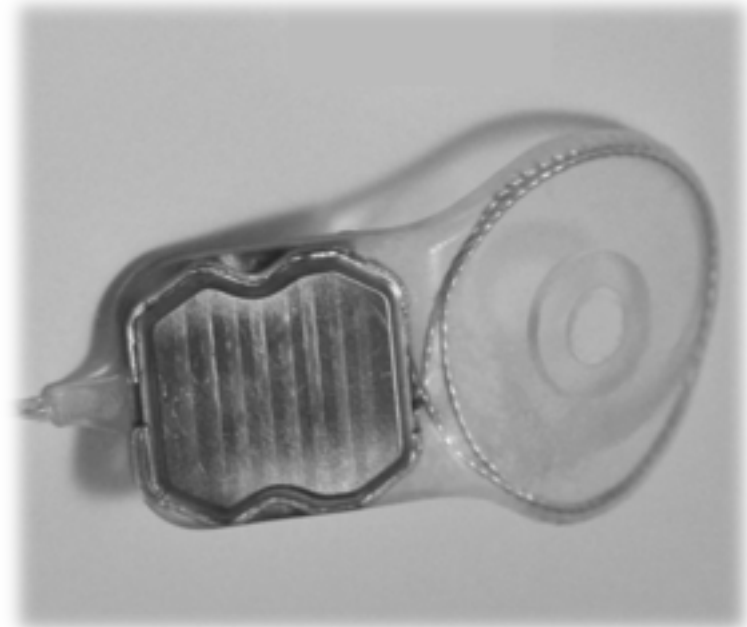
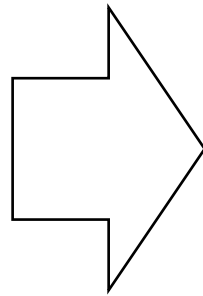
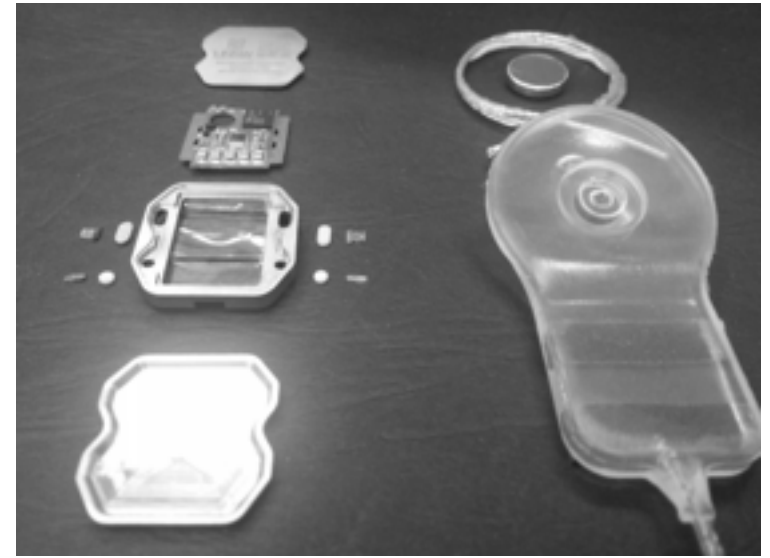


# Chip Integration with encapsulation

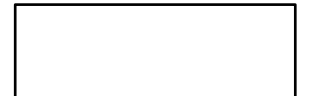
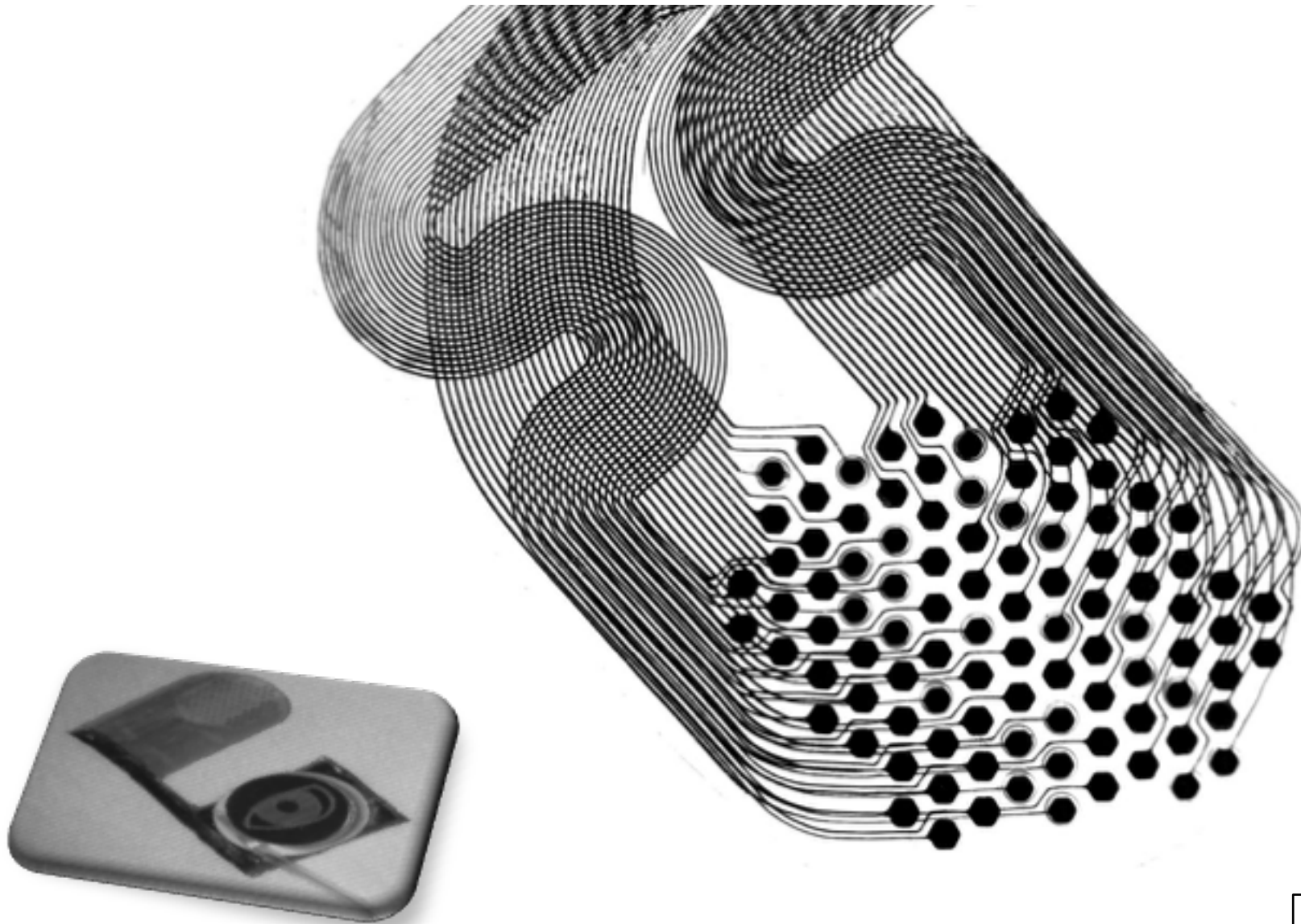


# Telemetry Implant:

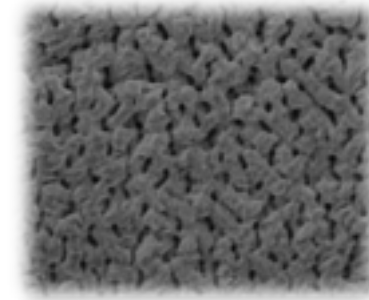
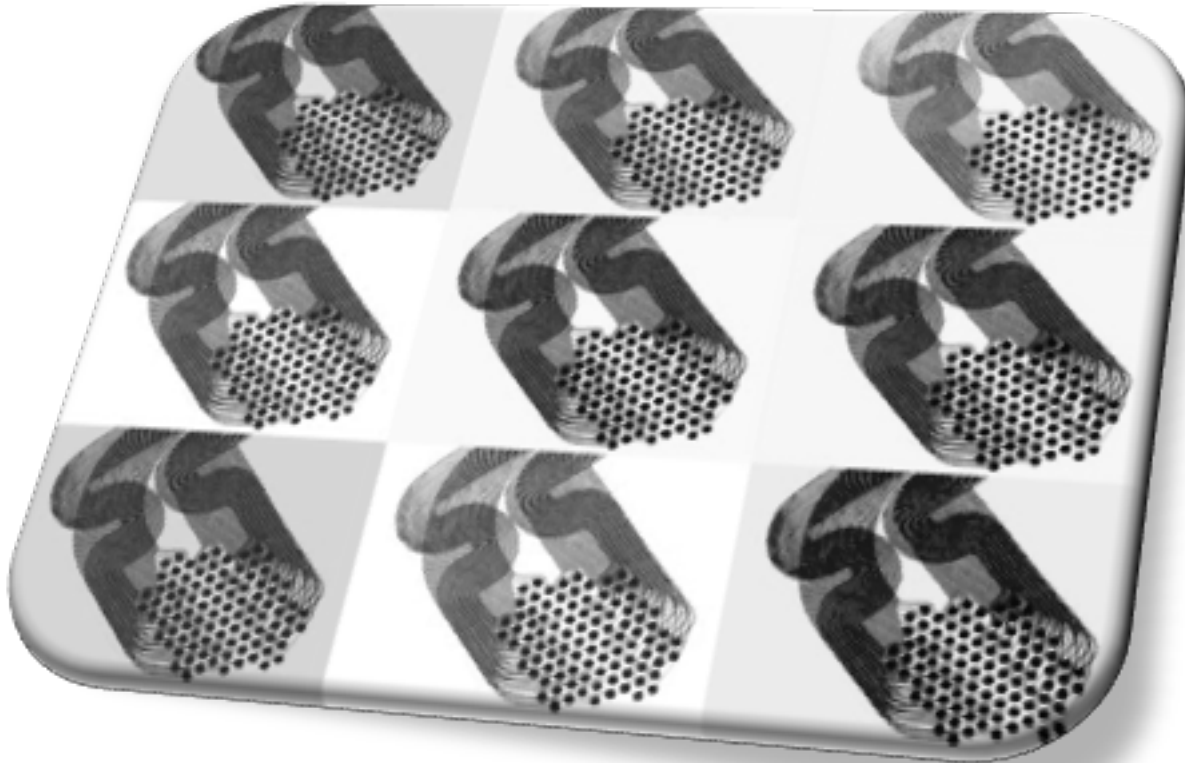
From concept to design, manufacture and test



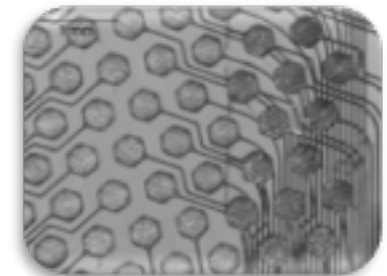
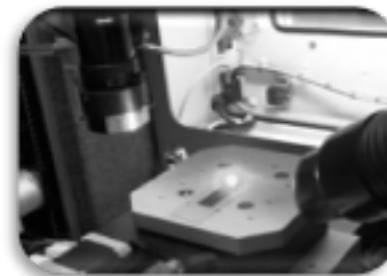
# Electrode Array



# Electrode Array

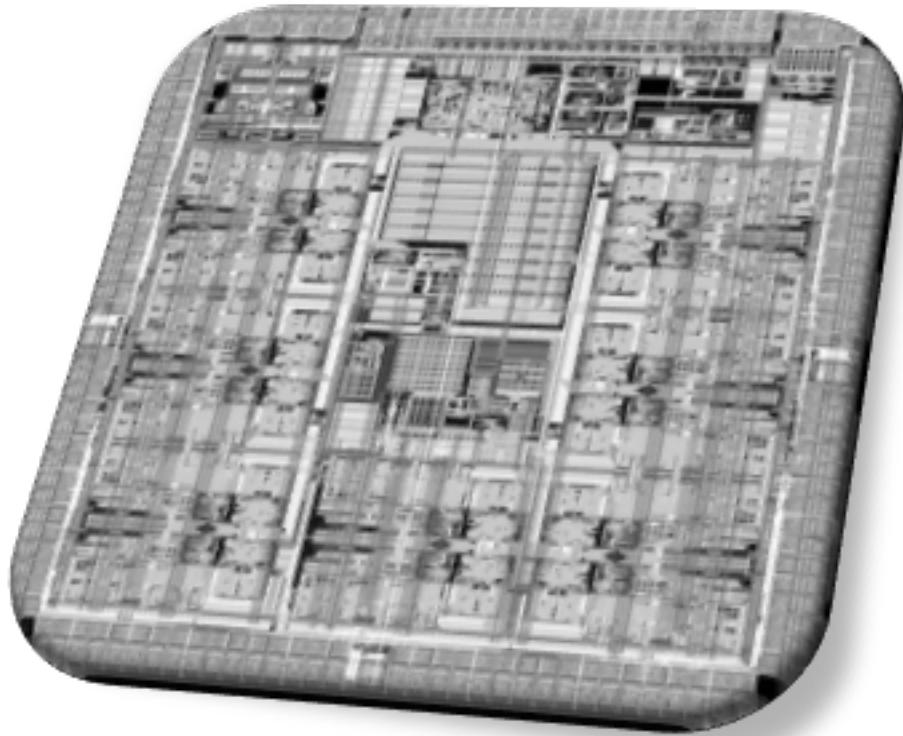


- Appropriate physical and electrochemical size of electrodes;
- Minimization of the scleral wound (currently 3.1 mm;
- Appropriate robustness.





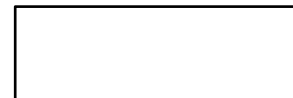
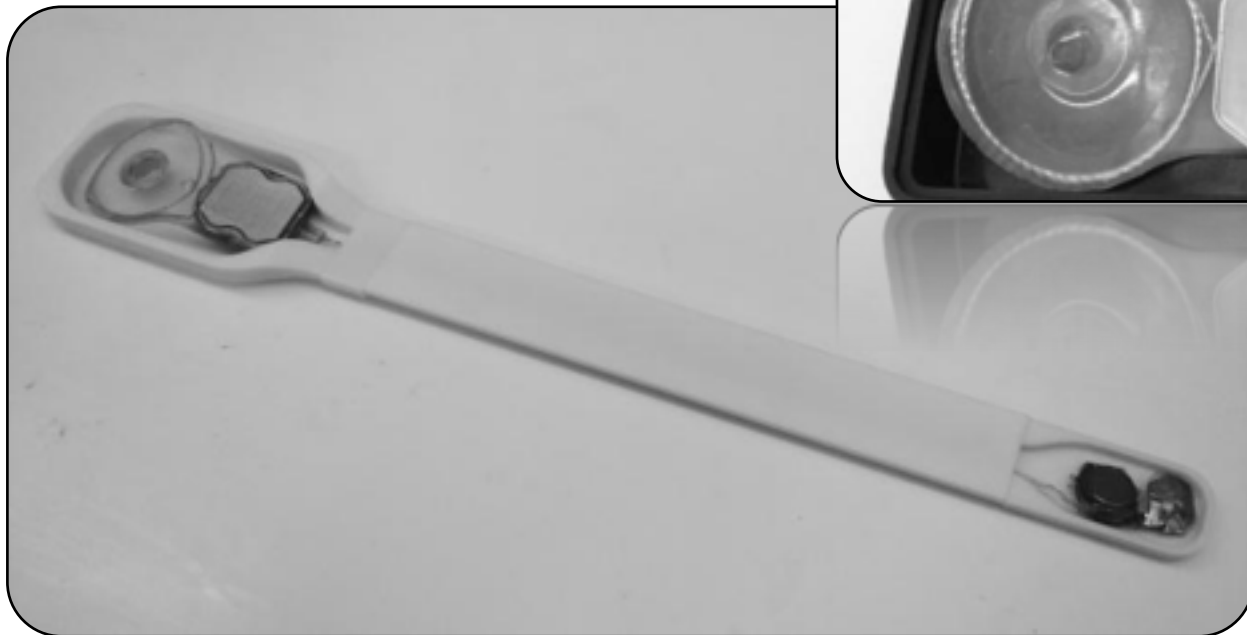
# Microelectronics



- Robust safety features
- Parallel stimulation capabilities
- Focal activation via hexapolar multiplexing
- Threshold reduction through Quasi-monopolar stimulation
- Reverse telemetry
- high compliance voltage for stimulation from the suprachoroidal space



# Phoenix<sup>99</sup>



# Surgical collaborators

Vitreo-retinal, orbital plastic and ENT surgical expertise



Vitreoretinal surgeon:  
Dr. Adrian Fung

Save Sight Institute (USyd)



Orbital surgeon:  
Dr. Krishna Tumuluri

RPA (USyd)



ENT surgeon:  
(cochlear implant)  
A/Prof. Melville da Cruz

Westmead (USyd)



# Human Cadaver Study - Surgical Development

Full procedure documented and refined in multiple studies in human cadaver subjects

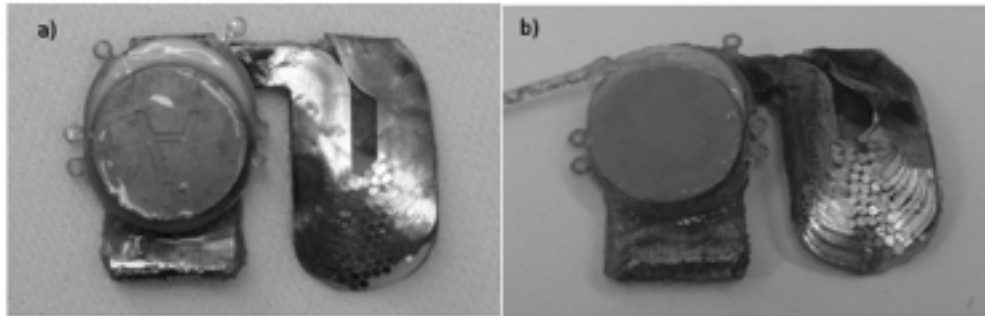


Figure 1 Image and schematic of Visual Stimulator with for the left eye.

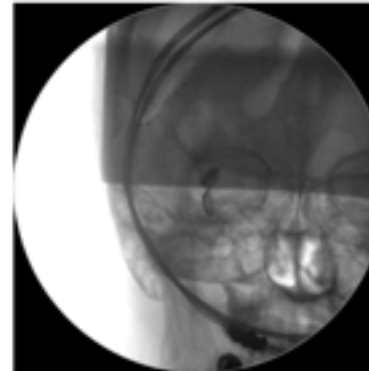


Figure 2 X-ray image of implanted right eye, showing array implanted temporally, capsule implanted in the supratemporal quadrant.

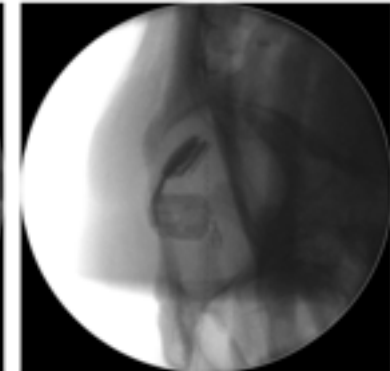


Figure 3 Zoomed in image on the implanted right eye Visual Stimulator, showing the undamaged suprachiasmatic array.

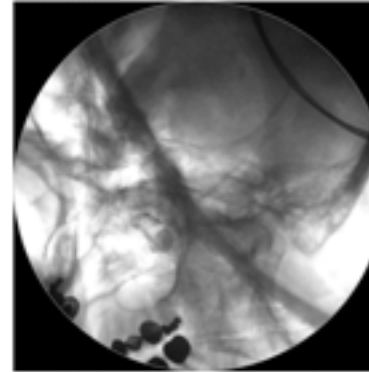


Figure 4 X-ray image of implanted left eye, showing array implanted supratemporal, capsule implanted temporally.

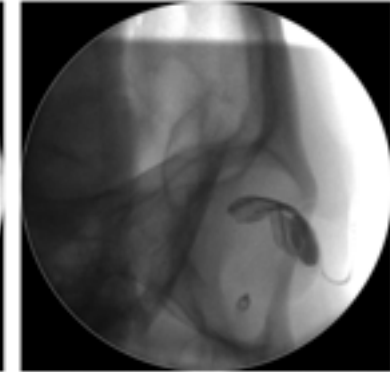


Figure 5 Zoomed in image on the implanted left eye Visual Stimulator, showing undamaged suprachiasmatic array and tail end of capsule side.

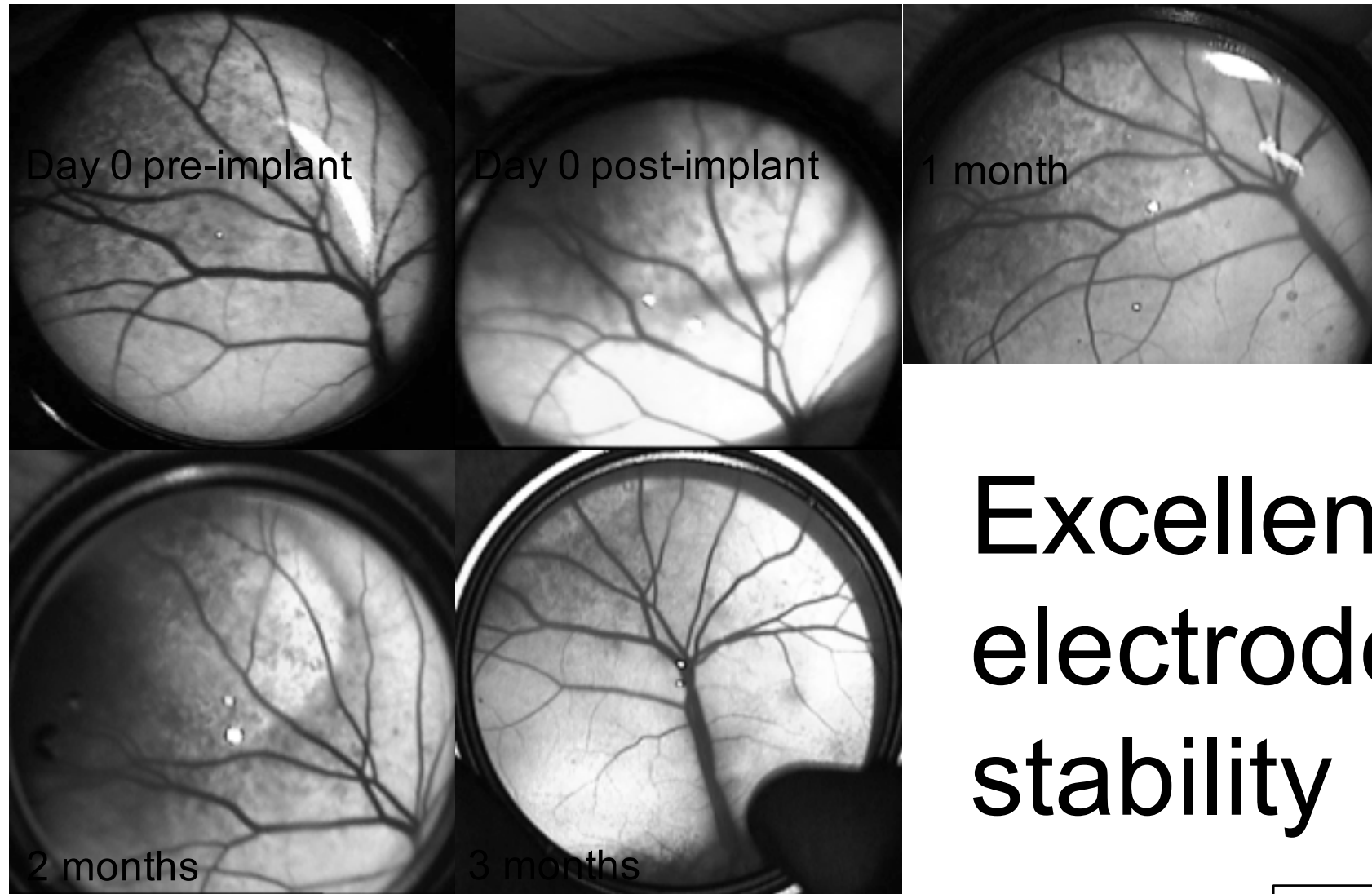


# Passive and active implants in sheep

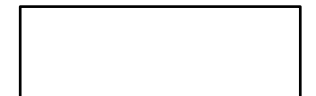
Excellent surgical recovery,  
no significant complications



# Indirect Ophthalmoscopy

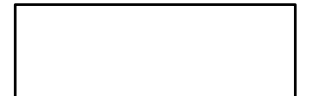


**Excellent  
electrode  
stability**



## Infrared Imaging

From L to R, images acquired at day 0, 2 months and 3 months post implant. Landmarks confirm robust stability.



# X-ray Imaging

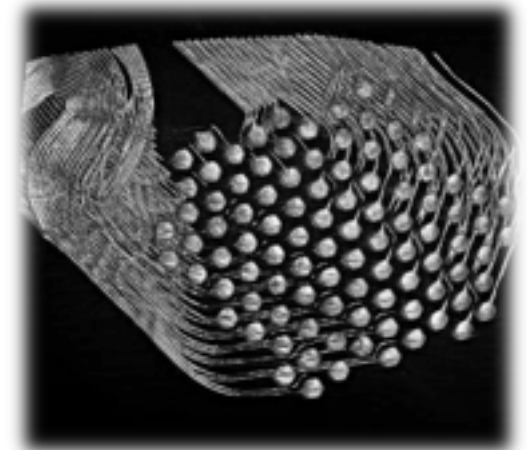
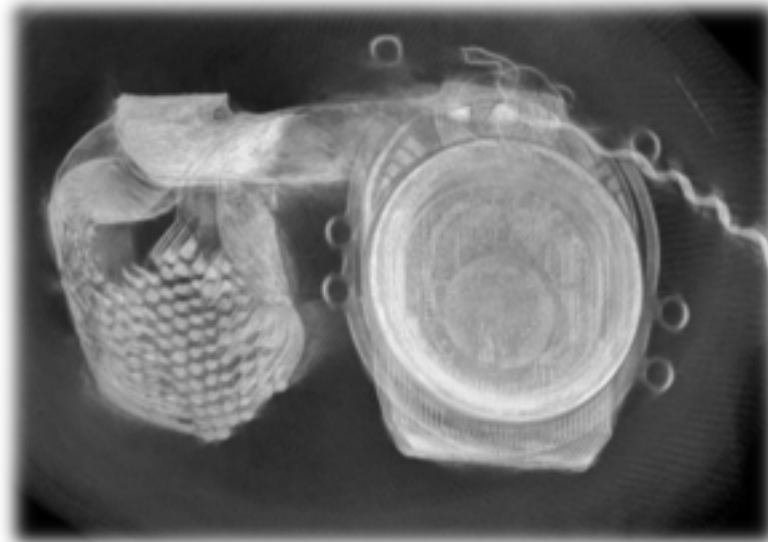
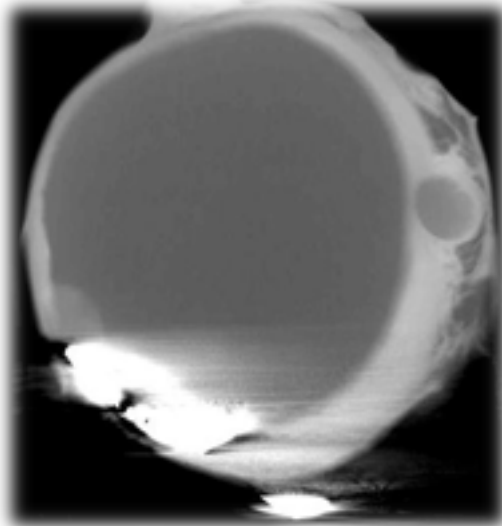
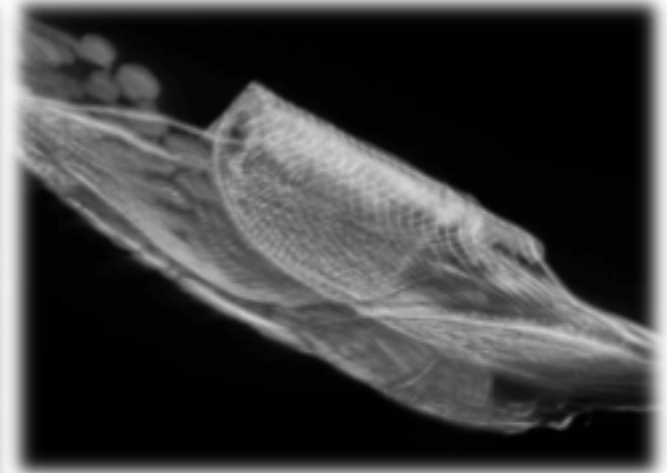
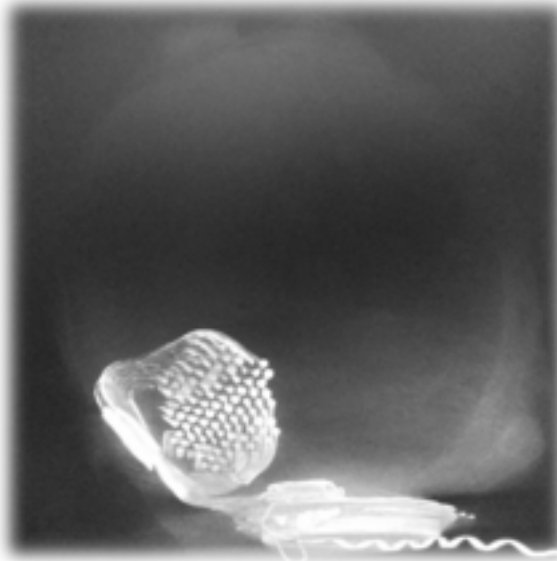
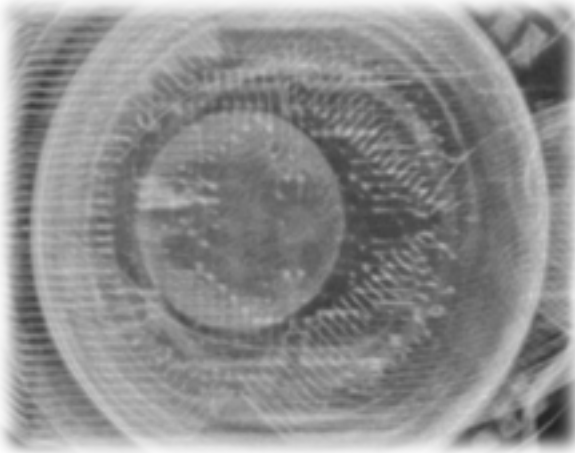
1 month

3 months





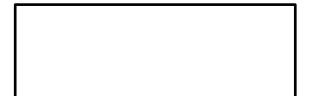
# Implant integrity



# Testing Efficacy – Sheep behaviour:



# Testing Efficacy – Sheep behaviour:

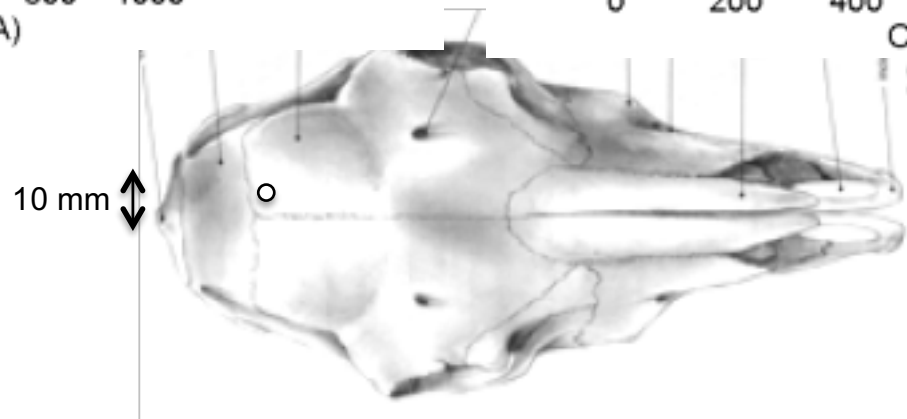
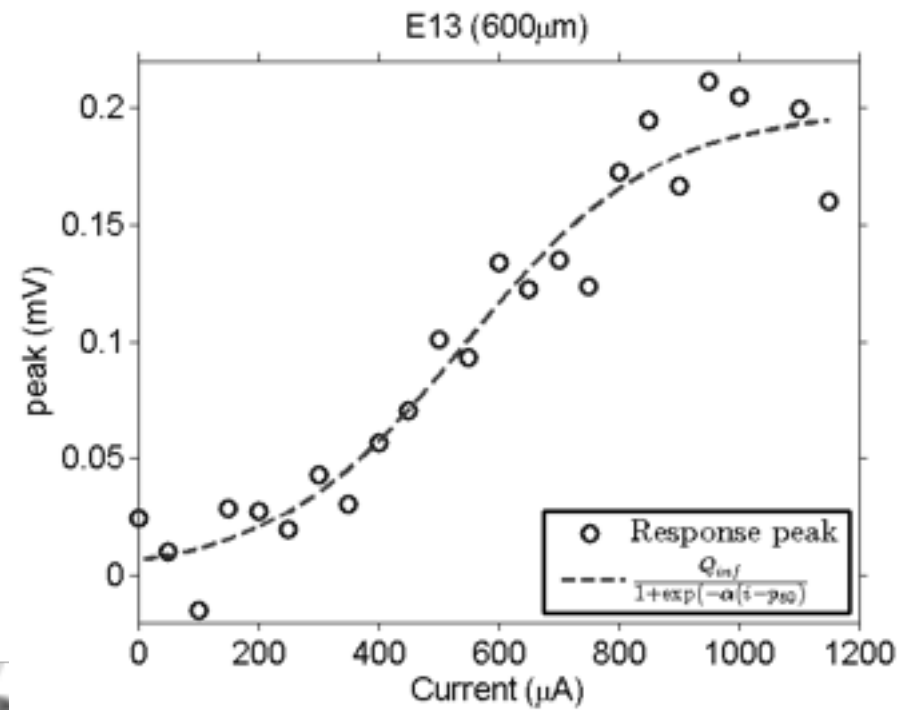
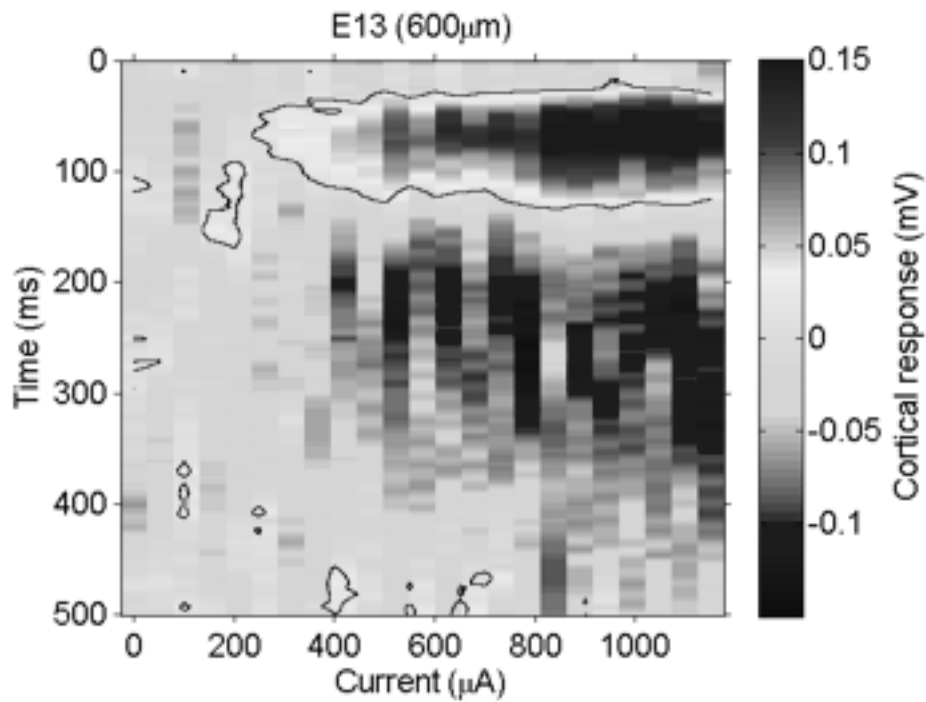


# Sheep behavior:

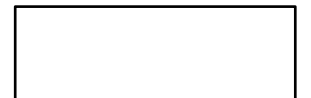
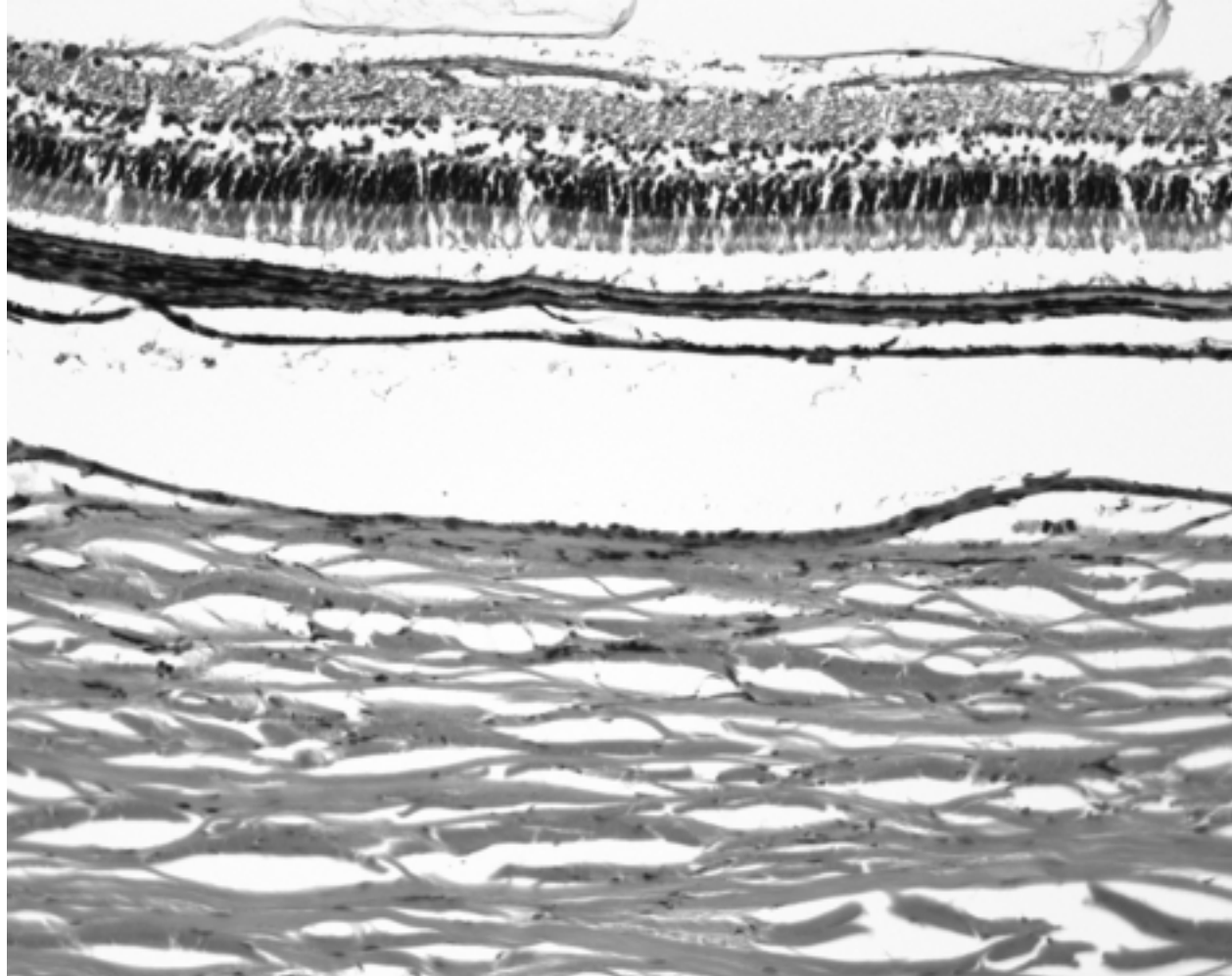


# Cortical Activation (Sheep):

“Human-sized” implant in sheep (array more anterior)







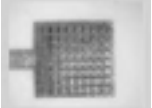



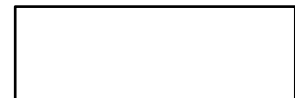
# Histology (Sheep):



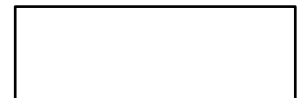
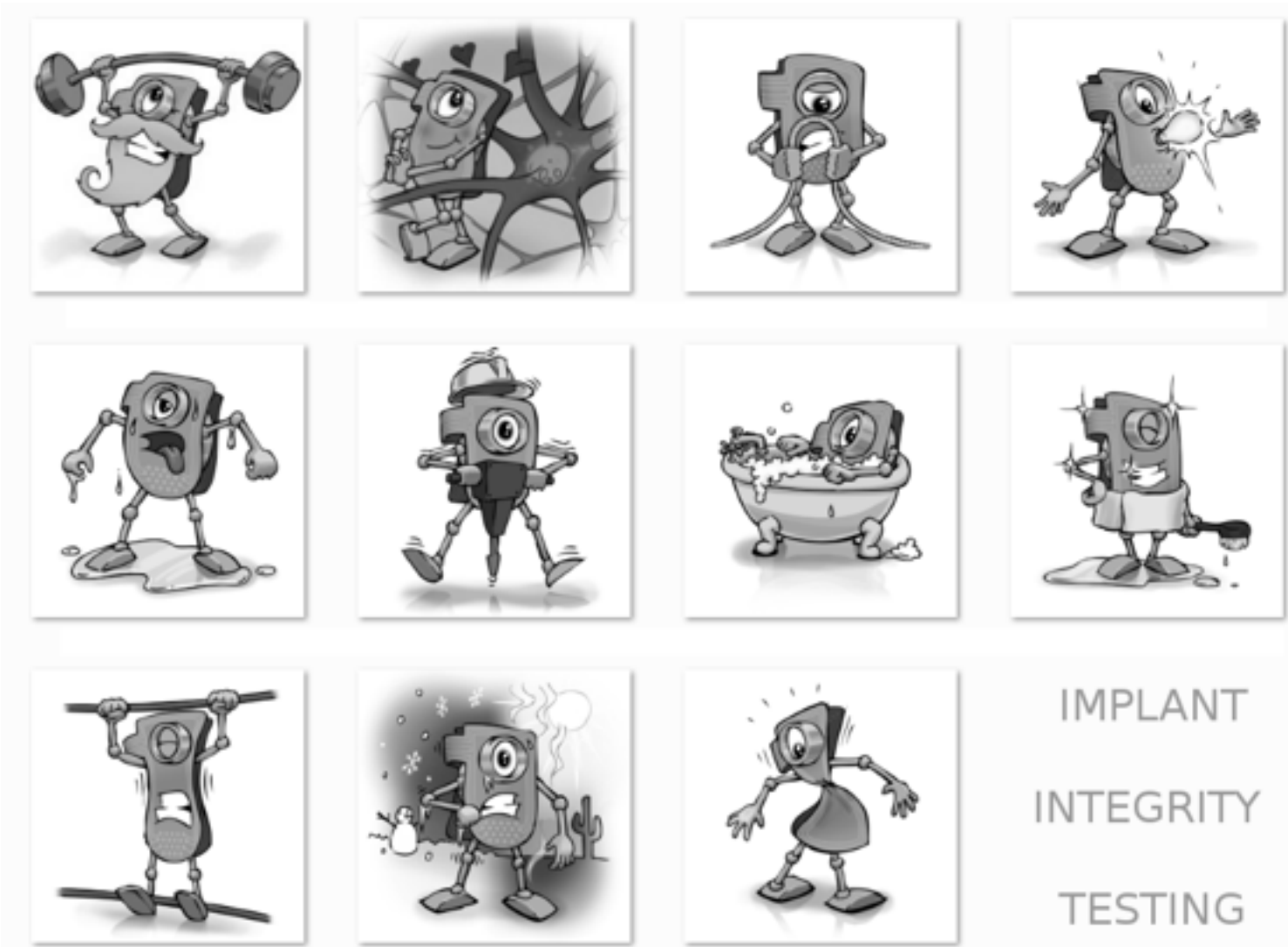
# Phoenix99 vs Other Global Efforts



System	Organisation	Stimulation channels	Adhere to UNSW design Philosophy	1 electrode 1 percept	Charge containment	Processing algorithm upgrade possible	Coexist w/residual vision (e.g. AMD)	Simplified Surgery	Human Tested
	BVA Wide View	98	✓	✓	✓	✓	✓	✓	<b>X</b> ✓
	Epi-Ret 3	25	<b>X</b>	✓ -	<b>X</b>	✓	<b>X</b>	<b>X</b>	✓
	Boston Retinal Implant Project	16	✓ -	✓	<b>X</b>	✓	✓ -	<b>X</b>	<b>X</b>
	Second Sight (ARGUS II)	60	✓	✓ -	<b>X</b>	✓	<b>X</b>	<b>X</b>	✓
	Retina AG	1.5k	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	✓ -	<b>X</b>	✓
	IMI	49	<b>X</b>	✓ -	<b>X</b>	✓	<b>X</b>	<b>X</b>	✓
	Nidek	64	<b>X</b>	✓ -	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>	<b>X</b>
	Osaka University	49	✓	✓ -	<b>X</b>	✓	✓	✓	✓

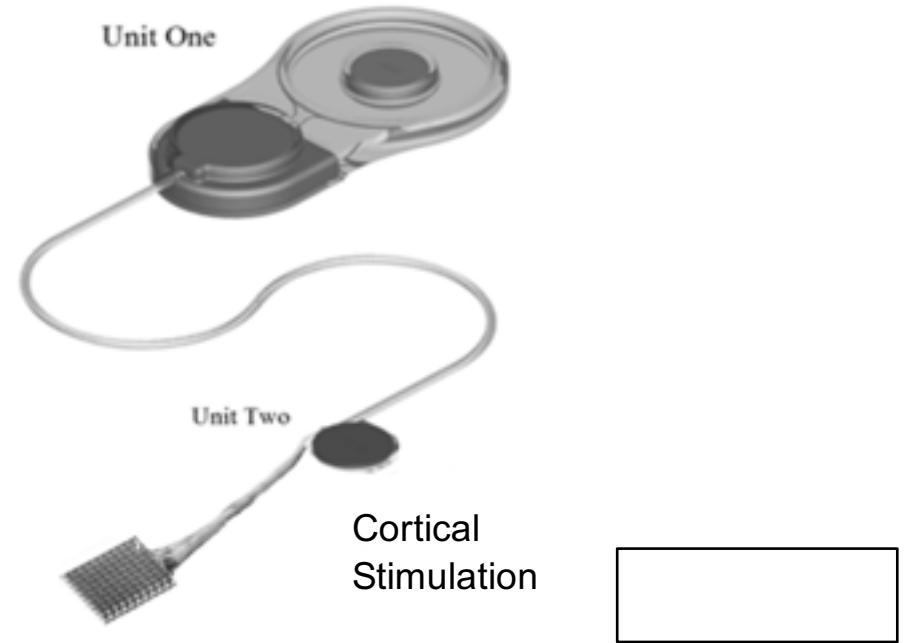
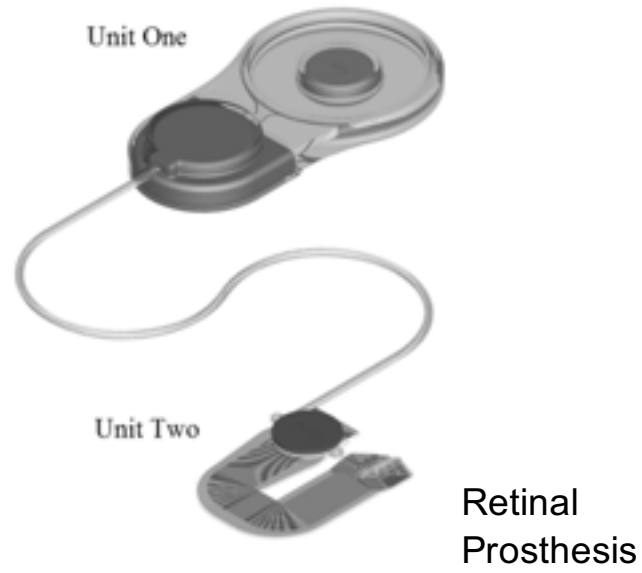
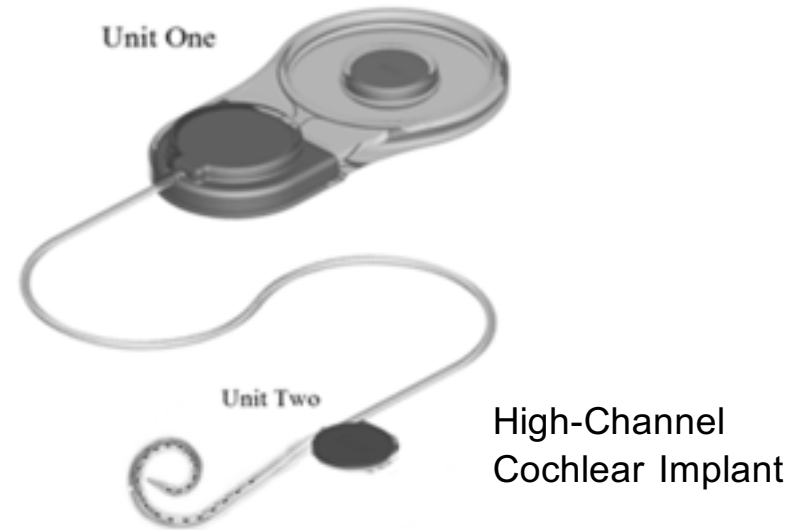
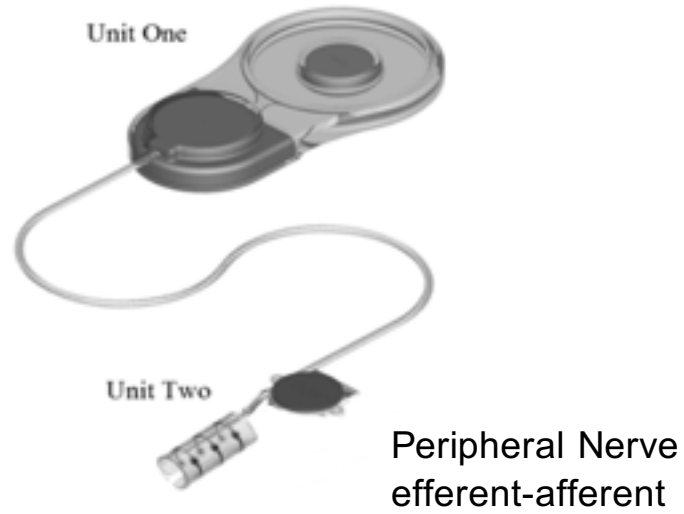


# Implant in Training





# Leveraging the Technology



Managing expectations...



ALL THE **EXCITEMENT**  
ALL THE **REALISM**  
ALL THE **'BIONIC' ACTION!**

YOU WORK HIS **POWERFUL 'BIONIC' ARM!**  
It actually lifts the engine block that comes with Colonel Austin!

Col. Steve Austin

**THE SIX MILLION DOLLAR MAN**  
ACTION FIGURE

**A BACK PACK RADIO THAT REALLY WORKS!**  
A working crystal set that picks up the AM radio broadcasts, works without batteries.

**BIONIC TRANSPORT and REPAIR STATION**  
Closed it's a space ship 17 1/2" tall, opened it's a repair station with "X-Ray", Diagnostic Computer, Magnifying Glass, and a "Bionic" Medical Center!  
Also serves as carrying case for Six Million Dollar Man.

**SEE THROUGH HIS BIONIC EYE!**  
See everything, through a wide-angle lens just as Colonel Steve Austin sees through his own Bionic Eye!

18" TALL

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**THE SIX MILLION DOLLAR MAN BIONIC ACTION CLUB**  
P.O. Box 1408, Cincinnati, Ohio 45201  
Enclosed is \$10 for postage and handling.  
Please email me in the Six Million Dollar Man "Bionic" Action Club and send me my official membership certificate, autographed color picture of Colonel Steve Austin, membership card, and decal of Six Million Dollar Man Seal.

NAME \_\_\_\_\_  
ADDRESS \_\_\_\_\_  
CITY \_\_\_\_\_ STATE \_\_\_\_\_ ZIP \_\_\_\_\_

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Thank You!

