American Society of Interventional Pain Physicians

2022 ASIPP® ANNUAL MEETING

MAY 5–7 | CAESARS PALACE | LAS VEGAS

IN CONJUNCTION WITH THE CALIFORNIA AND NEVADA SOCIETIES OF INTERVENTIONAL PAIN PHYSICIANS

**RAJ-RACZ DISTINGUISHED LECTURE SERIES**

# Current State and Future Developments in Neuromodulation for Chronic Pain:

# hardware, software, frequency, dose and…?

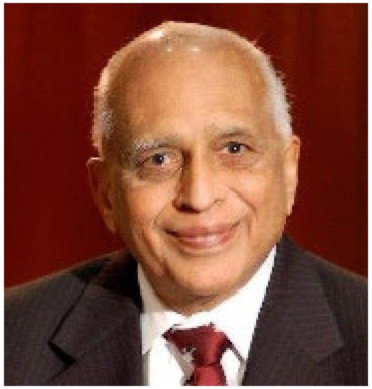
***(dedicated to 60 years of clinical neuromodulation for pain)***

**Konstantin Slavin, MD, FAANS**

Department of Neurosurgery

University of Illinois at Chicago

University of Illinois at Chicago



RAJ-RACZ DISTINGUISHED LECTURE SERIES

# Current State and Future Developments in Neuromodulation for Chronic Pain:

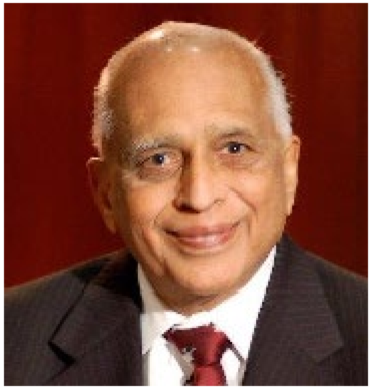
# hardware, software, frequency, dose and…?

***(dedicated to 60 years of clinical neuromodulation for pain)***


**Konstantin Slavin, MD, FAANS**

Department of Neurosurgery

University of Illinois at Chicago



# RAJ-RACZ DISTINGUISHED LECTURE SERIES

# Disclosure

- *Research / fellowship support:*

  **Abbott, Medtronic, Neuros, Stryker,**
  **(previously: Bioness, Boston Scientific, Nuvectra, Autonomic Technologies, Elan, Northstar, Pfizer)**

- *Consultant / Honoraria (current and past):*

  **Abbott, Boston Scientific, Elsevier, Karger, Integer, Medtronic, MMS/Higgs Boson, MSEI/Biotronik, Neuramodix, NeuroOne, Nevro, Nurami, Nuvectra, SPR Therapeutics, Stimwave, Thermaquil, UniQure, Vycor, Wiley-Blackwell, WISE**

# Disclosure

ins
International
Neuromodulation
Society

wssfn
World Society for Stereotactic
and Functional Neurosurgery

Progress in Neurological Surgery
Editor: **K.V. Slavin**
Karger

ASSFN
AMERICAN SOCIETY FOR STEREOTACTIC
AND FUNCTIONAL NEUROSURGERY

North American Neuromodulation Society
• est 1994 •

Cancer Pain Research
Consortium

UNIVERSITY OF ILLINOIS CHICAGO
STUDIUM DOCTRINAE
EST. UIC 1965

American Interventional
Headache Society

UIC
University of Illinois at Chicago

# Surgery for Pain

1967

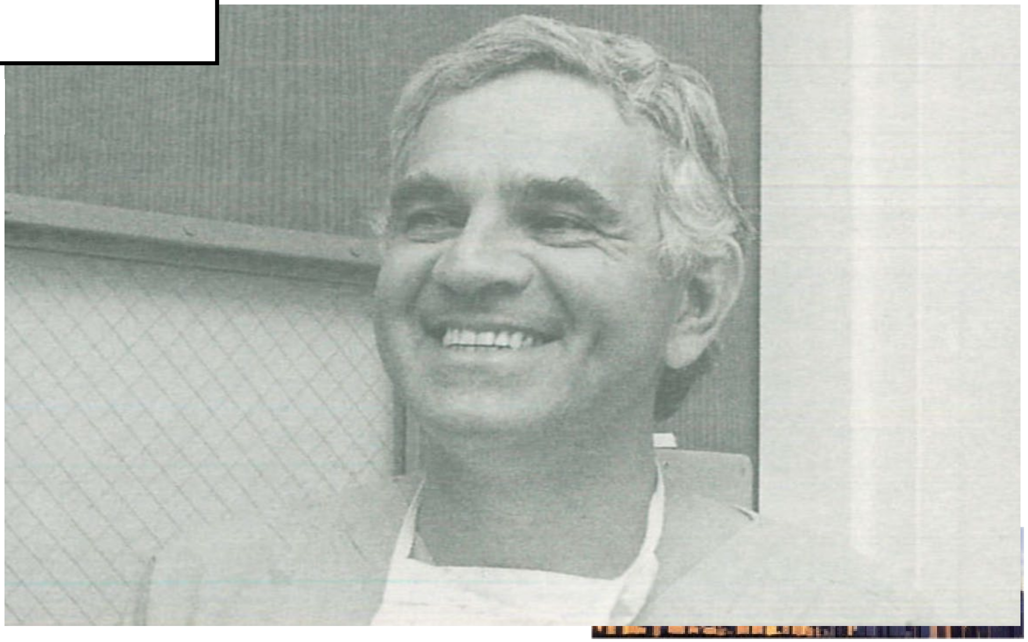
# 1967 – Microvascular decompression for treatment of trigeminal neuralgia

Journal of Neurosurgery *Jan 1967* / Vol. 26 / No. 1part2, Pages 159-162

Arterial Compression of the Trigeminal Nerve at the Pons in Patients with Trigeminal Neuralgia*

PETER J. JANNETTA, M.D.
*Principal Contributor and Leader of Discussion*

* This work was done in collaboration with Dr. R. W. Rand at U.C.L.A.



# 1967 – Clinical verification of the Gate Control Theory of Pain Processing

*Science*, New Series, Vol. 155, No. 3758 (Jan. 6, 1967), pp. 108-109

## Temporary Abolition of Pain in Man

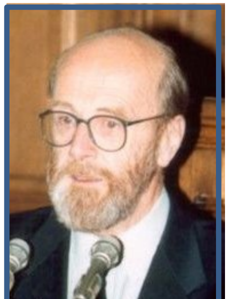

PATRICK D. WALL
*Department of Biology and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge*

WILLIAM H. SWEET
*Department of Neurosurgery, Massachusetts General Hospital, Boston, and Department of Surgery, Harvard Medical School, Boston*

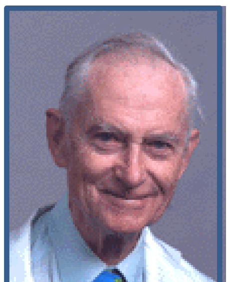


Abstract. *In eight patients with intense chronic cutaneous pain, sensory nerves or roots supplying the painful area were stimulated. Square-wave 0.1-millisecond pulses at 100 cycles per second were applied, and the voltage was raised until the patient reported tingling in the area. During this stimulation, pressure on previously sensitive areas failed to evoke pain. Four patients, who had diseases of their peripheral nerves, experienced relief of their pain for more than half an hour after stimulation for 2 minutes.*


6 JANUARY 1967



Patrick Wall, PhD 1925-2001



William H. Sweet, MD,D.Sc 1910-2001

lasted from a few seconds to a few minutes after the stimulus ended. The type of stimulation used (0.1-msec square-waves at 100 cycle/sec) was tested on ourselves before it was used in the experiment. Needle electrodes insulated except for the tip were applied to our infraorbital nerves; a tingling or buzzing sensation was evoked near threshold in the sensory region of the nerve. It was not unpleasant and always tolerable for an indefinite period. During stimulation and for a few minutes thereafter, pin prick in the tingling area did not feel sharp to either of us. In all eight patients, the sensations produced by stimulation were not painful and were acceptable for an indefinitely long time.

Science AAAS

# 1967 – Spinal Cord Stimulation

ANESTHESIA and ANALGESIA . . . *Current Researches* VOL. 46, NO. 4, JULY-AUGUST, 1967

## Electrical Inhibition of Pain by Stimulation of the Dorsal Columns: *Preliminary Clinical Report*

C. NORMAN SHEALY, M.D.*
J. THOMAS MORTIMER, M.S.†
JAMES B. RESWICK, D.Sc.†

FIGURE. Postmortem view of attached stimulating electrode in cross section.

### REPORT OF A CASE

A 70-year-old man was admitted to Lutheran Hospital in early March because of severe diffuse pain in the right lower part of the chest and the upper part of the abdomen. He had previously been demonstrated to have inoperable bronchiogenic carcinoma and was suspected of having metastasis to the pleura and liver. He ran a low-grade fever and had considerable nausea and vomiting but was thought to have a life expectancy of 1 or 2 months. We explained in detail to him and his family the experimental nature of dorsal column stimulation. A nurse anesthetist daughter was of great aid in gaining their acceptance of this treatment. On March 24, 1967, a thoracic laminectomy (D2-3) was performed and a Vitallium electrode measuring 3 by 4 mm. was approximated to the dorsal columns at D3 by suturing to dura. The spinal electrode was Vitallium covered with Dow Corning Medical Grade Adhesive and Silastic. Special subcutaneous jacks were placed inferior

### ABOUT THE AUTHORS

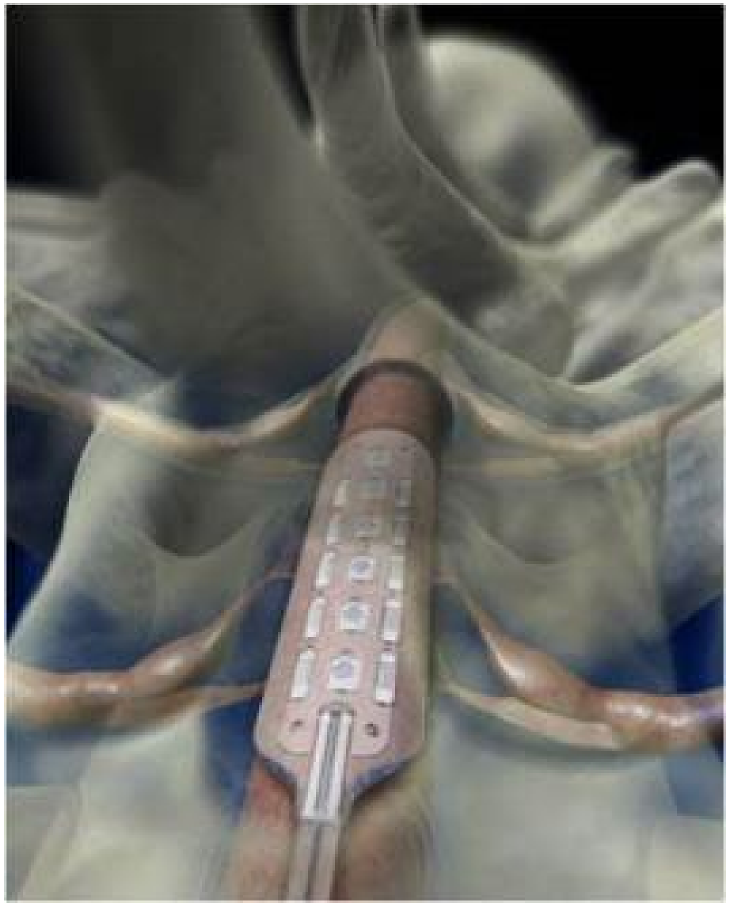
Dr. Shealy

★ C. NORMAN SHEALY, M.D. is Chief of Neurosurgery, Gundersen Clinic, La Crosse, Wisconsin, and Assistant Clinical Professor of Neurosurgery, University of Wisconsin, Madison. He graduated in 1956 from Duke University Medical School, Durham, North Carolina, interned at Duke University, and served as resident at Barnes Hospital, St. Louis, Missouri, and at Massachusetts General Hospital, Boston. Special honors achieved by Dr. Shealy include the First Annual Harold G. Wolff, M.D. Award and a Borden Award for Best Undergraduate Research.

★ J. THOMAS MORTIMER, M.S. is a graduate of Texas Technical College, Amarillo, Texas, holds the M.S. degree from Case Institute of Technology, Cleveland, Ohio, and is currently a candidate for a Ph.D. at Case. His interests are biomedical engineering and spelunking.

★ JAMES B. RESWCK, D.Sc. is Professor of Engineering at the Case Institute of Technology, Cleveland, Ohio, and since 1960 has been Director of the Engineering Design Center at Case Institute.

# 55 (?) years of clinical neuromodulation for pain (1967-2022)



# 55 (?) years of clinical neuromodulation for pain (1967-2022)

- First SCS implant
- March 24, 1967
- Norman Shealy

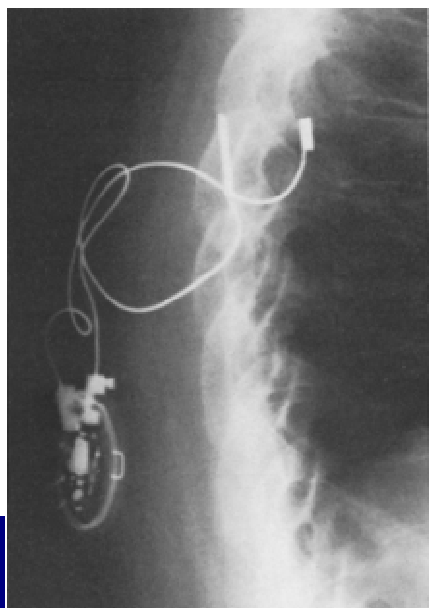
# 55 (?) years of clinical neuromodulation for pain (1967-2022)

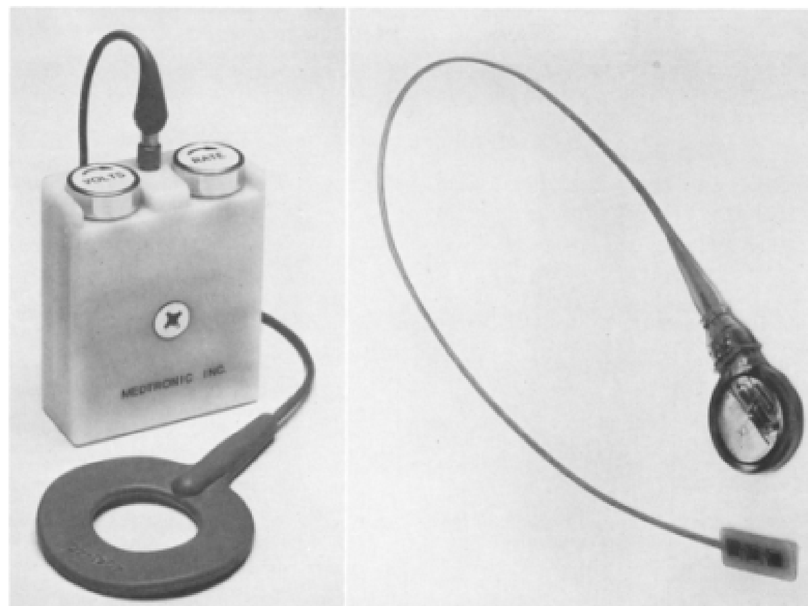
## Dorsal Column Electroanalgesia*

*J. Neurosurg. / Volume 32 / May, 1970*

C. NORMAN SHEALY, M.D., J. THOMAS MORTIMER, PH.D., AND NORMAN R. HAGFORS†

*Department of Neurosurgery, Gundersen Clinic, Ltd., La Crosse, Wisconsin and the Engineering Design Center, Case-Western Reserve University, Cleveland, Ohio*






University of Illinois at Chicago

# 60 (!) years of clinical neuromodulation for pain (1962-2022)

*American Journal of Surgery* *Vol. 114, August 1967*

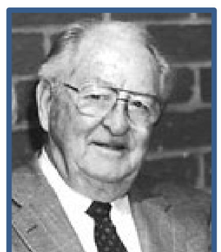
## Electrical Control of Facial Pain*

C. Hunter Shelden, M.D., Robert H. Pudenz, M.D., and James Doyle, B.S.,

*From the Department of Neurological Surgery, Institute of Medical Research, Huntington Memorial Hospital, Pasadena, California.*

* Presented at the Thirty-Eighth Annual Meeting of the Pacific Coast Surgical Association, Monterey, California, February 19–22, 1967.

The transmitter consists of a transistor oscillator operating at 14 kc., housed in a standard flashlight case. The transmitter replaces the light and reflector assembly. The unit, when energized, draws approximately 150 milliwatts of power. The implant unit, measuring $1^1/_4$ by $^3/_8$ inches, is encased in methyl methacrylate to protect the unit, allow sterilization, and facilitate attachment to the bony margins of the temporal craniotomy. It is an inductor receiver which consists of a 14 kc. resonate circuit which, when energized at a distance of $^3/_8$ inch from the transmitter, is capable of providing a potential of 10 volts.



C. Hunter Shelden, MD 1907-2003

In 1962 a method was developed for chronic depolarization, using an implanted radio receiver powered from an external source, in an attempt to reduce the sensory in-put from the face into the brain stem below the critical level at which paroxysms of pain are triggered.

The method involves the use of the implanted receiving unit connected by fine platinum wires to the mandibular branch of the trigeminal nerve just distal to the ganglion but proximal to the foramen ovale. The power is obtained from an external transmitter which is held against the intact scalp at a point in the temporal region superficial to the receiving unit itself which is located in an opening in the temporal bone.

We have employed this method with three patients with third division pain who have remained pain-free and without subjective or objective sensory loss since operation. The observation period has been four, three and a half, and three and a quarter years, respectively.

# 60 years of clinical neuromodulation for pain (1962-2022)

*Hardware*

*Procedural details*

*Indications*

*Paradigms*

# Evolution of neuromodulation for pain

***Hardware***

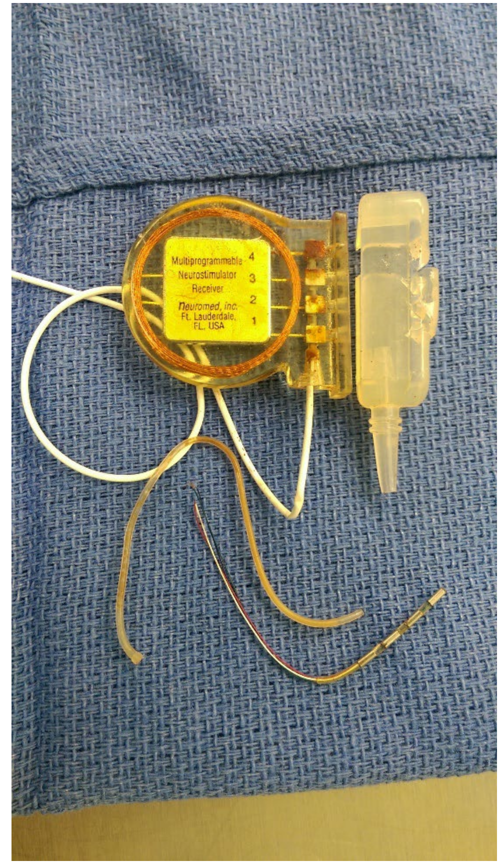
- ***Power sources***
- ***Electrodes***
- ***Accessories***
- ***Patient programmers***
- ***Physician programmers***

***Procedural details***

***Indications***

***Paradigms***

# Neuromodulation Devices


**RF receivers**

# Neuromodulation Devices


RF receivers → Implantable generators

# Neuromodulation Devices



Generators: 4 contacts → 8 contacts

University of Illinois at Chicago

# Neuromodulation Devices







Generators: 8 contacts → 16 contacts

University of Illinois at Chicago

# Neuromodulation Devices





Generators: Prime cell → Rechargeable

University of Illinois at Chicago

# Neuromodulation Devices






Generators: Large → Compact

University of Illinois at Chicago

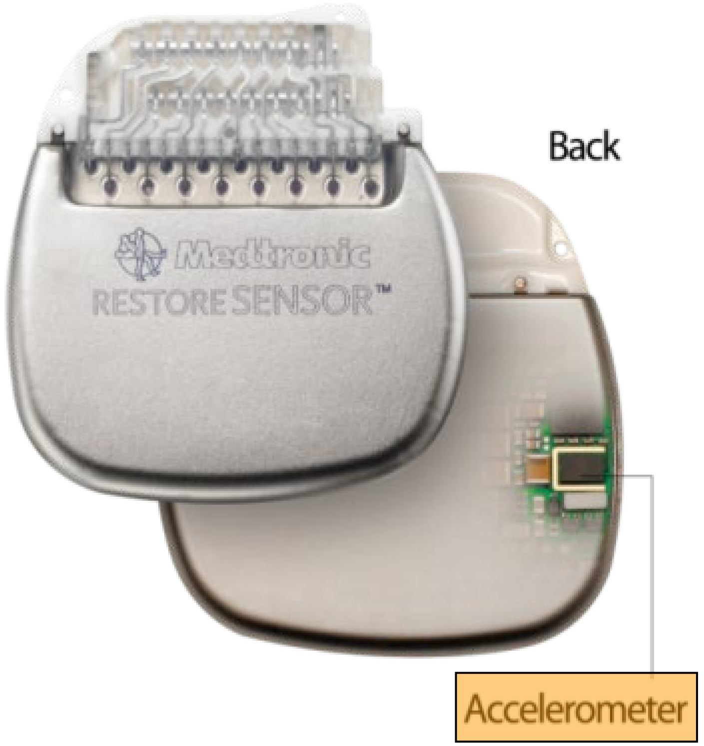
# Neuromodulation Devices



Generators: 16 contacts → 32 contacts

University of Illinois at Chicago

# Neuromodulation Devices

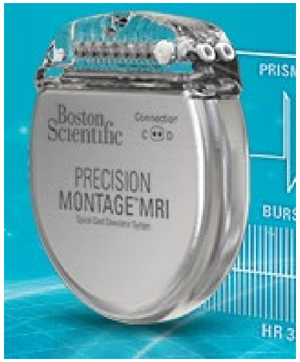




**Generators: Standard → Adaptive**

# Neuromodulation Devices









**Generators: Standard → MRI compatible**

# Neuromodulation Devices





## Generators: Rechargeable → "recharge-free"

# Neuromodulation Devices


Intellis
(Medtronic)


Proclaim DRG
(Abbott)


Wavewriter Alpha
(Boston Scientific)


Omnia
(Nevro)


Algovita
(Nuvectra)

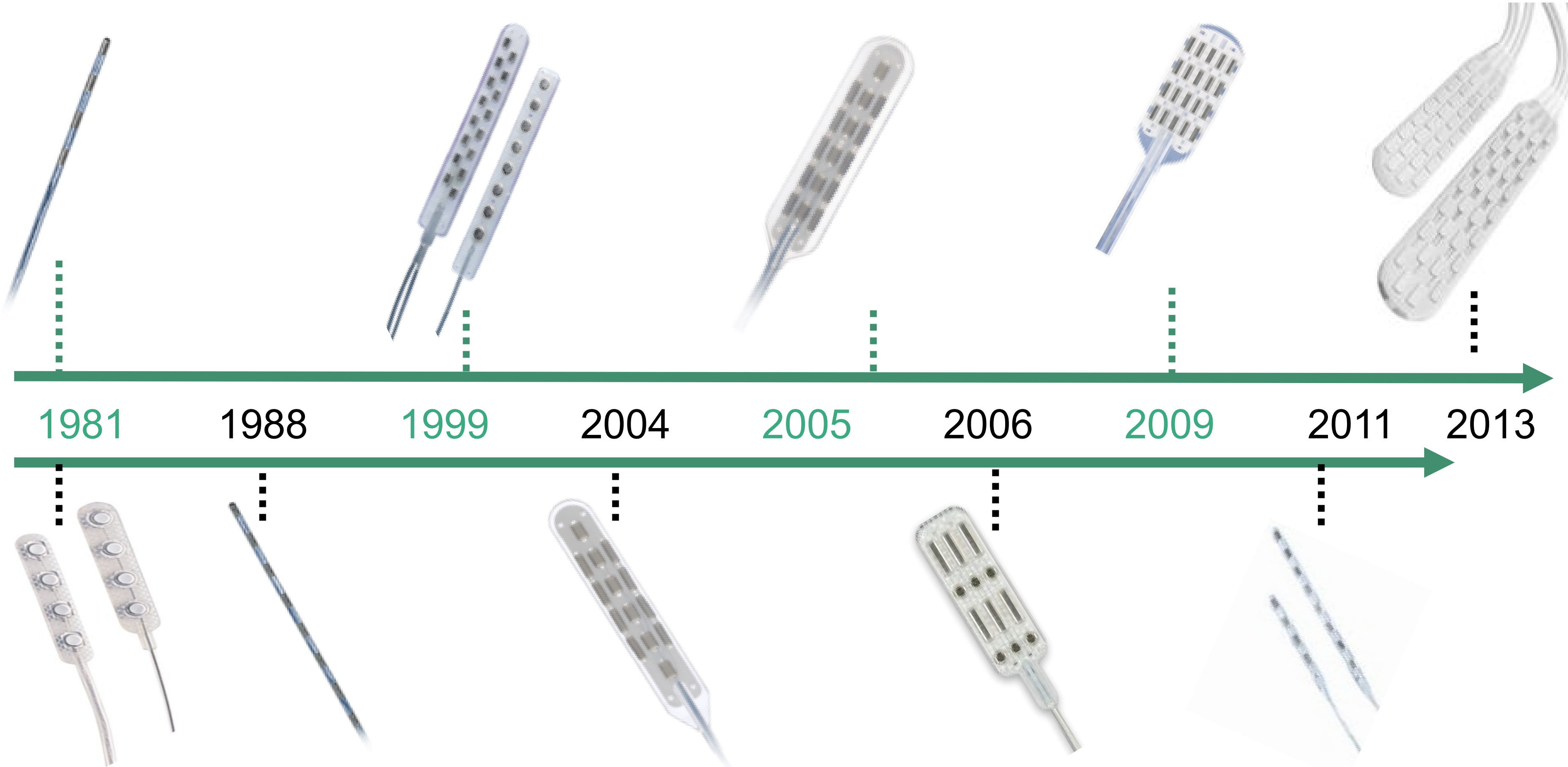
**Most recently introduced devices**


Evoke
(Saluda)


ReActiv8
(Mainstay)

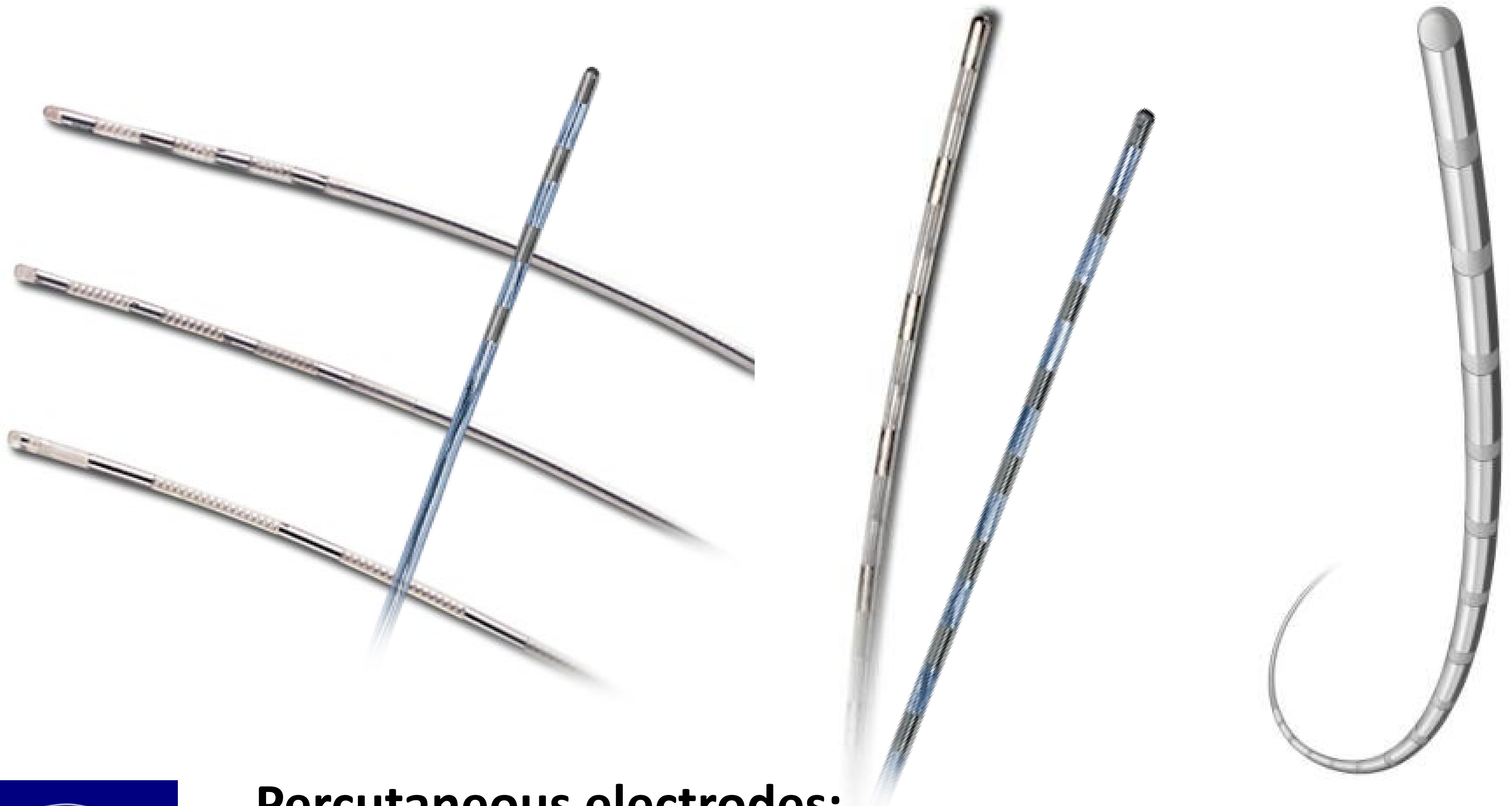
University of Illinois at Chicago

# Neuromodulation Devices




**Electrodes: 4 contacts → 8 contacts → 16 contacts →**
**→ 20 (16) contacts → 32 contacts**

# Neuromodulation Devices



**Percutaneous electrodes:**
**4 cotnacts → 8 contacts → 16 contacts**

University of Illinois at Chicago

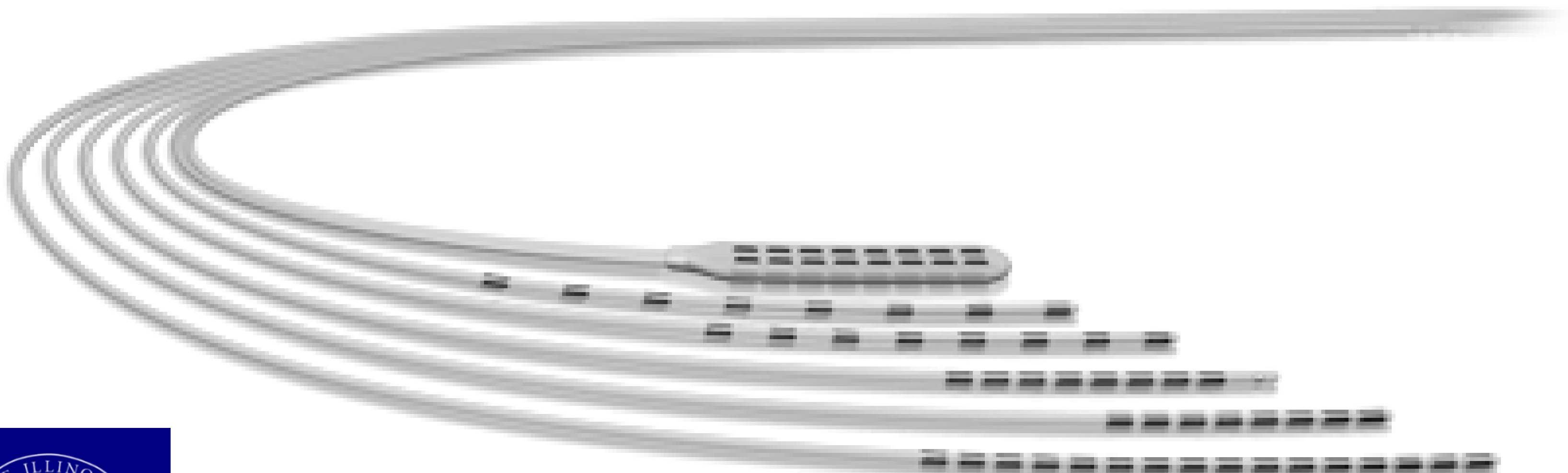
# Neuromodulation Devices

**Paddle electrodes: 4 contacts → 8 contacts →**
**→ 16 contacts → 20 (16) contacts → 32 contacts**

# Neuromodulation Devices

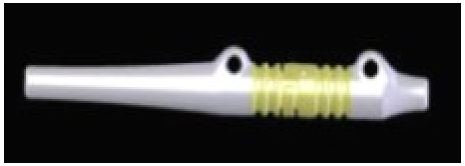
**Electrodes: 1 column → 2 columns → 3 columns →**
**→ 4 columns → 5 columns**

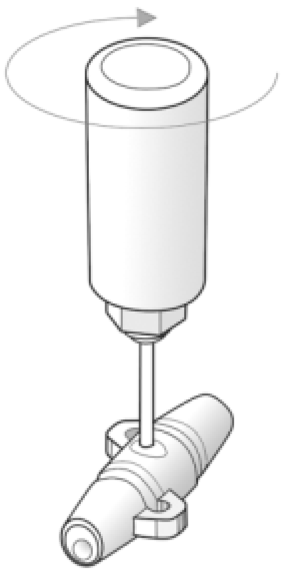
# Neuromodulation Devices



Electrodes: Wide choice

# Neuromodulation Devices



Anchors

# Neuromodulation Devices

Anchors

University of Illinois at Chicago

# Neuromodulation Devices



Patient remote controls

University of Illinois at Chicago

# Neuromodulation Devices




## Patient remote controls

# Neuromodulation Devices



## Charging systems

# Neuromodulation Devices

Clinician programmers

# Neuromodulation Devices



Clinician programmers

University of Illinois at Chicago

# Neuromodulation Devices

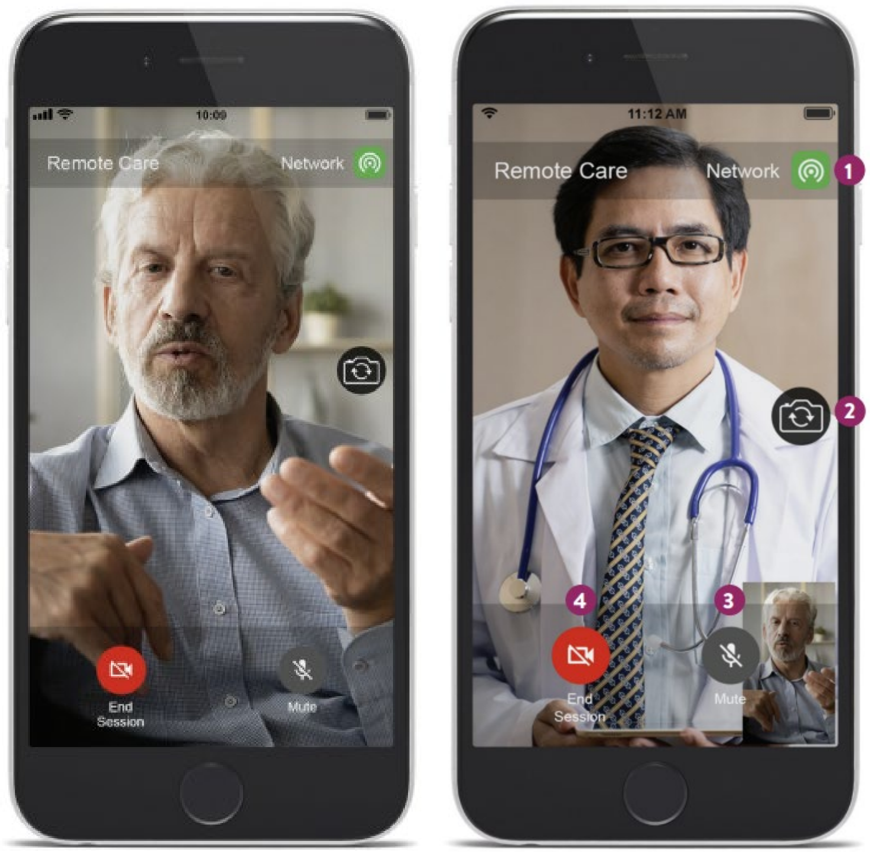




## Consumer technology-based (Apple/IOS, android)

University of Illinois at Chicago

# Neuromodulation Devices




1. Network status indicator
2. Camera reverse
3. Mute button mutes your audio to your doctor
4. Use the **'End Session'** button only in case of emergencies (for example, if significant connection issues are encountered)

GREEN
Good network connection

YELLOW
Slowed network connection

RED
Very slow network connection

## Remote programming!

# Evolution of neuromodulation for pain

*Hardware*

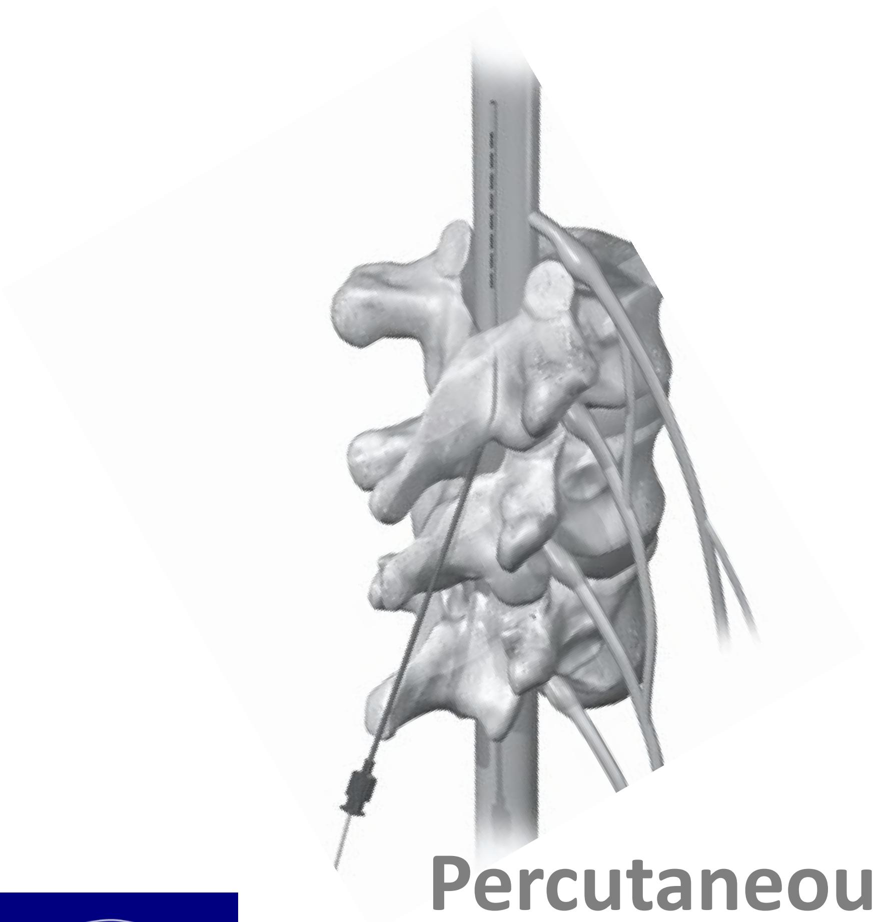
***Procedural details:***

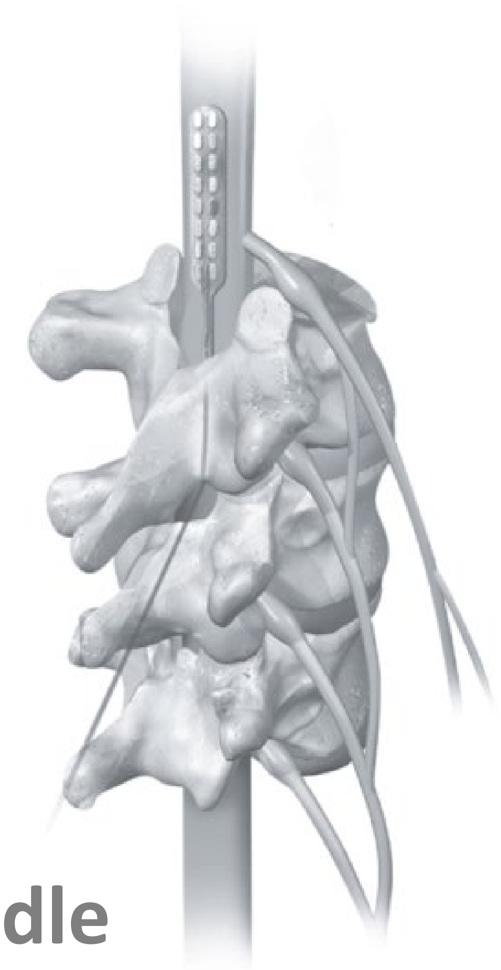
- ***Open vs. Percutaneous***
- ***Intradural vs. Extradural***
- ***Posterior vs. Anterior / Lateral placement***

*Indications*

*Paradigms*

# Evolution of spinal stimulation



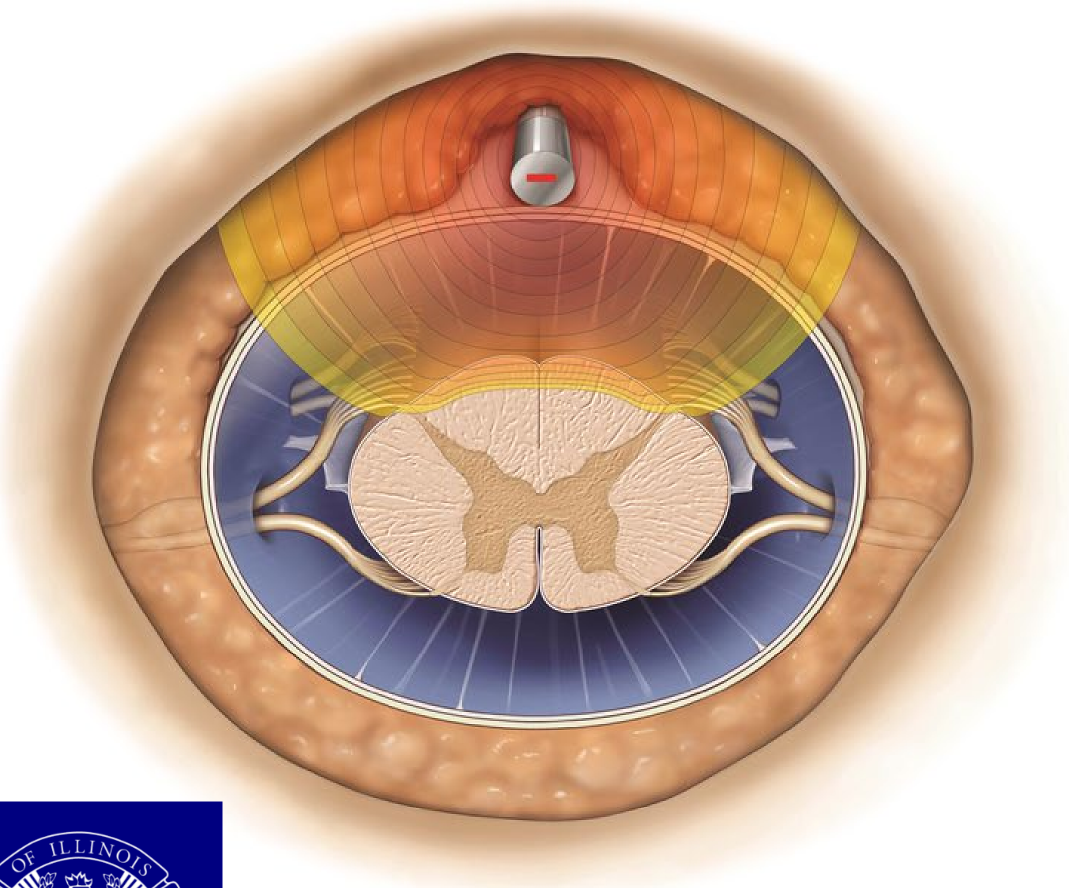


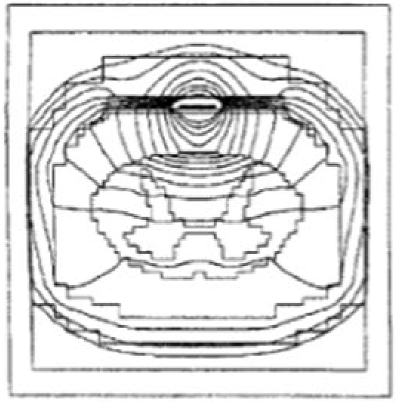
Percutaneous vs. paddle

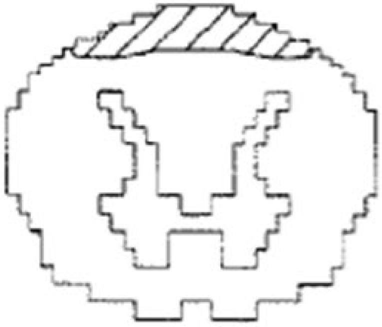
# Evolution of spinal stimulation

**vs. Percutaneous paddle**

# Neuromodulation evolution

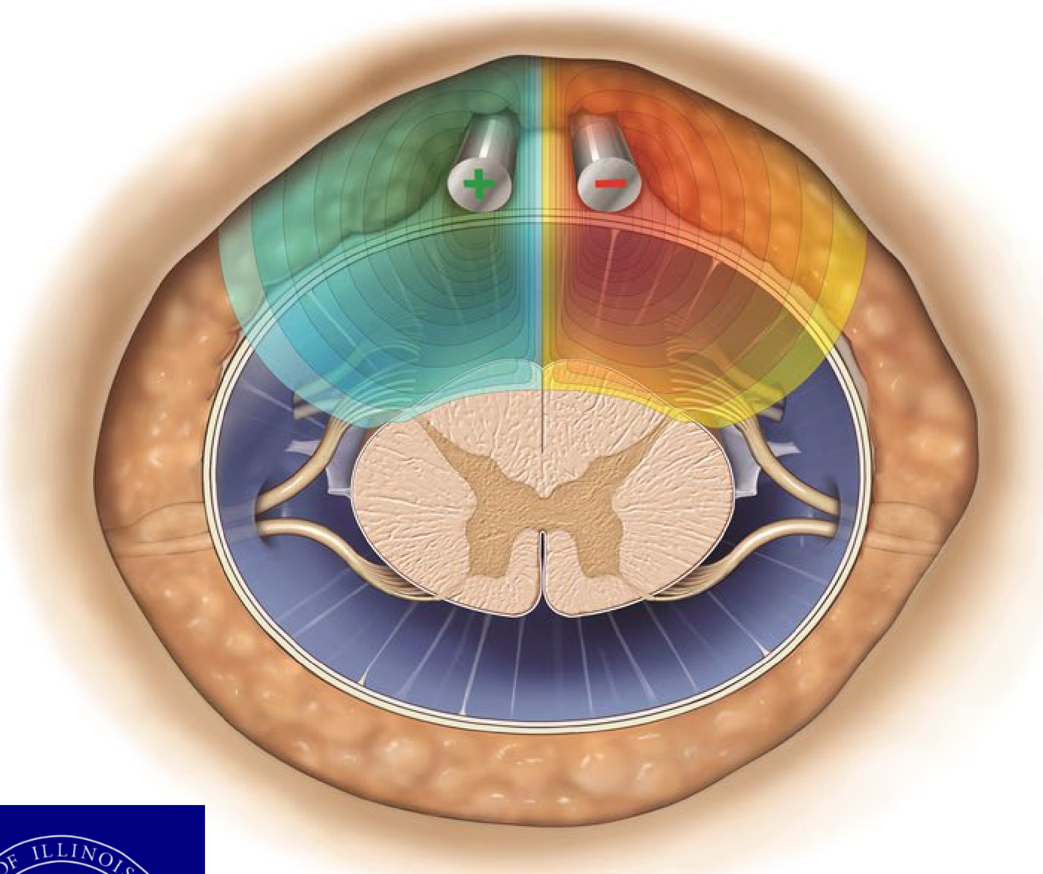


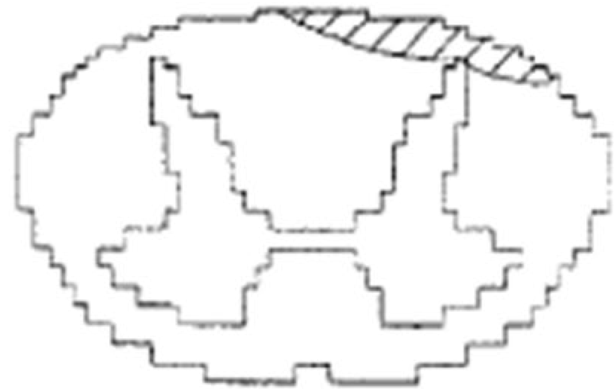




Single column

# Neuromodulation evolution

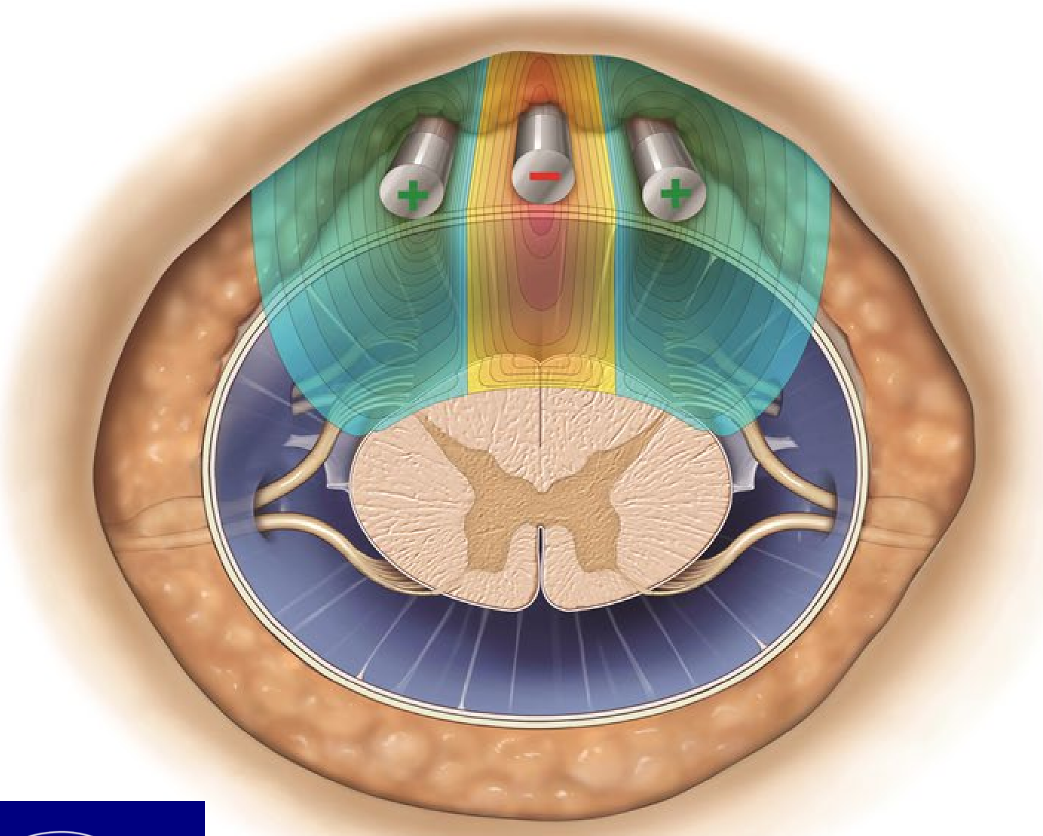


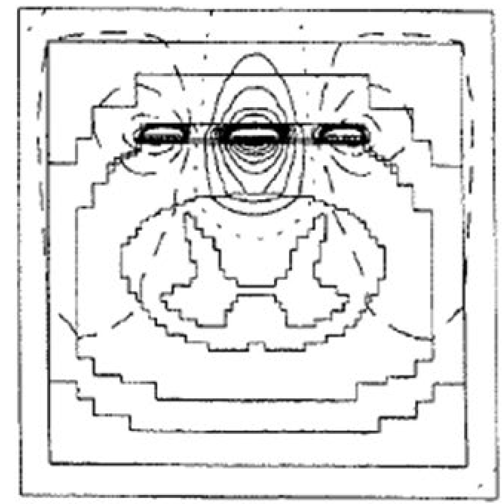


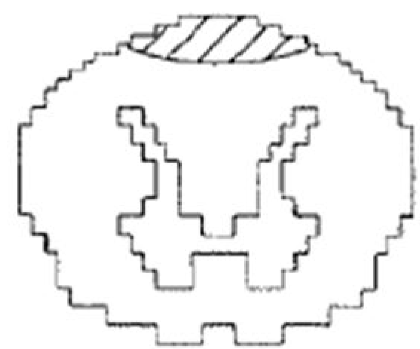
Double column

University of Illinois at Chicago

# Neuromodulation evolution

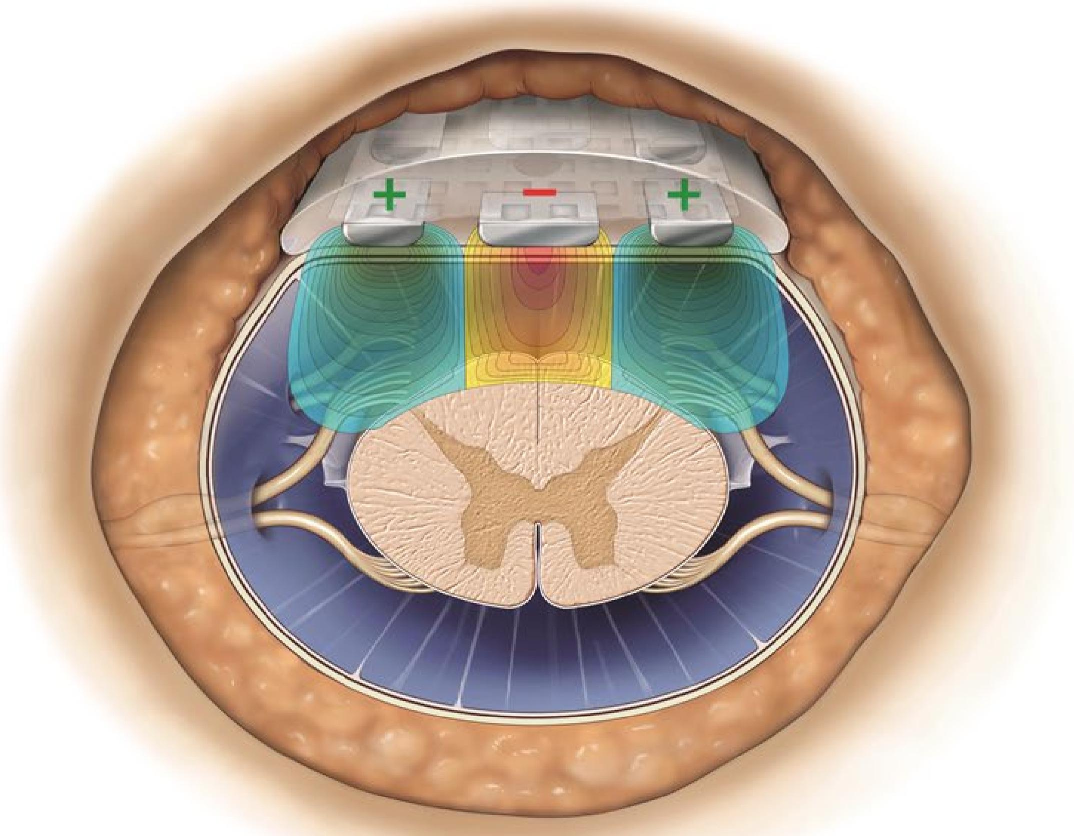






**Multi (triple) column**

# Neuromodulation evolution




Multi-column paddle

# Evolution of neuromodulation for pain

*Hardware*

*Procedural details*

***Indications***

- ***FBSS***
- ***CRPS***
- ***Neuropathy***
- ***Ischemia***
- ***....***

*Paradigms*

University of Illinois at Chicago

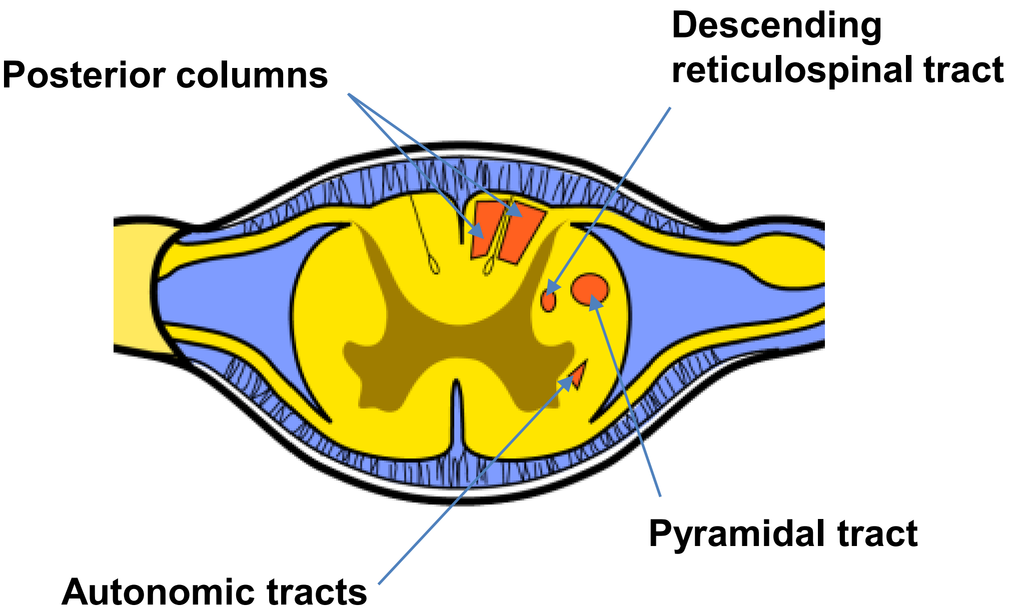
# SCS – Only For Pain?

Motor symptoms

GU symptoms

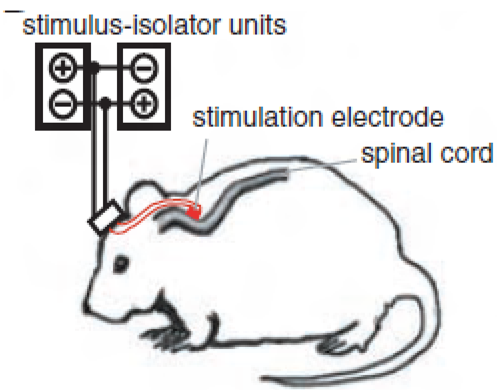
Vascular symptoms

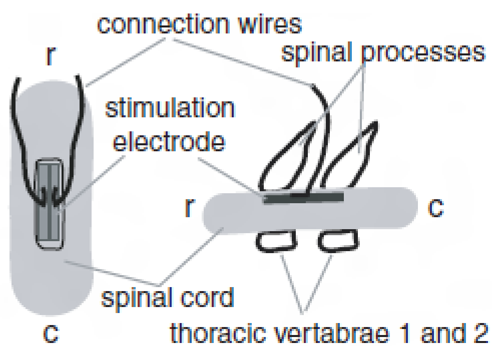
Other indications



# SCS for motor disorders

**Motor function recovery**




## Spinal Cord Stimulation Restores Locomotion in Animal Models of Parkinson's Disease

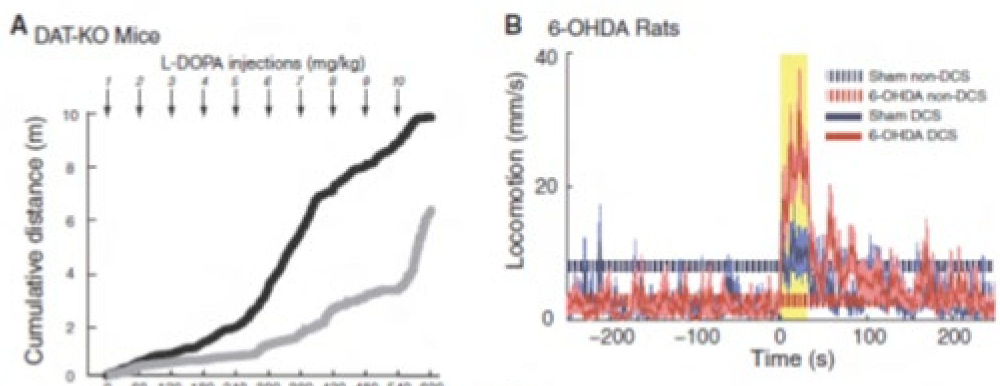

Romulo Fuentes,[1*†] Per Petersson,[1,2*] William B. Siesser,[3]
Marc G. Caron,[1,3] Miguel A. L. Nicolelis[1,4,5,6,7,8]



20 MARCH 2009 VOL 323 SCIENCE



Dopamine replacement therapy is useful for treating motor symptoms in the early phase of Parkinson's disease, but it is less effective in the long term. Electrical deep-brain stimulation is a valuable complement to pharmacological treatment but involves a highly invasive surgical procedure. We found that epidural electrical stimulation of the dorsal columns in the spinal cord restores locomotion in both acute pharmacologically induced dopamine-depleted mice and in chronic 6-hydroxydopamine–lesioned rats. The functional recovery was paralleled by a disruption of aberrant low-frequency synchronous corticostriatal oscillations, leading to the emergence of neuronal activity patterns that resemble the state normally preceding spontaneous initiation of locomotion. We propose that dorsal column stimulation might become an efficient and less invasive alternative for treatment of Parkinson's disease in the future.


inois at Chicago

# SCS for motor disorders

## Parkinson disease

### Beneficial Therapeutic Effects of Spinal Cord Stimulation in Advanced Cases of Parkinson's Disease With Intractable Chronic Pain: A Case Series

Neuromodulation 2015; 18: 751–753

Kenya Nishioka, MD, PhD*; Madoka Nakajima, MD, PhD†

**Objectives:** Pain is one of the common symptoms in patients with Parkinson's disease (PD), with a prevalence of approximately 40–85%. These symptoms affect the quality of life of PD patients. We evaluated the effect of spinal cord stimulation (SCS) to chronic pain and motor symptoms of PD.

**Materials and Methods:** Three PD patients were treated with SCS to relieve their persistent and intractable pain. One patient had failed back surgery syndrome and the other two had lumbar canal stenosis. All patients had a stooped posture and pain that was

**Results:** After SCS insertion, chronic pain in the patients decreased in both the lower back and limbs. Moreover, SCS ameliorated the symptoms of PD. One-year follow-up after SCS showed that UPDRS part III scores, rigidity, and tremor were improved without large alterations in levodopa dosage. Dementia and activities of daily living did not improve after SCS.

large alterations in levodopa dosage. Dementia and activities of daily living did not improve after SCS.

**Discussion and Conclusion:** Our results indicate that SCS may be a treatment option for both motor symptoms and chronic pain in PD, especially in cases complicated with lumbar canal stenosis or disc herniation. Further studies are needed to evaluate the efficacy of SCS in PD patients.

# Evolution of neuromodulation for pain

*Hardware*

*Procedural details*

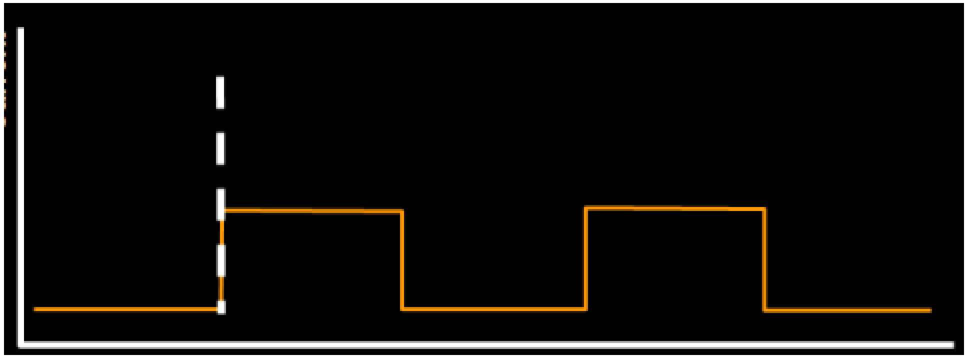
*Indications*

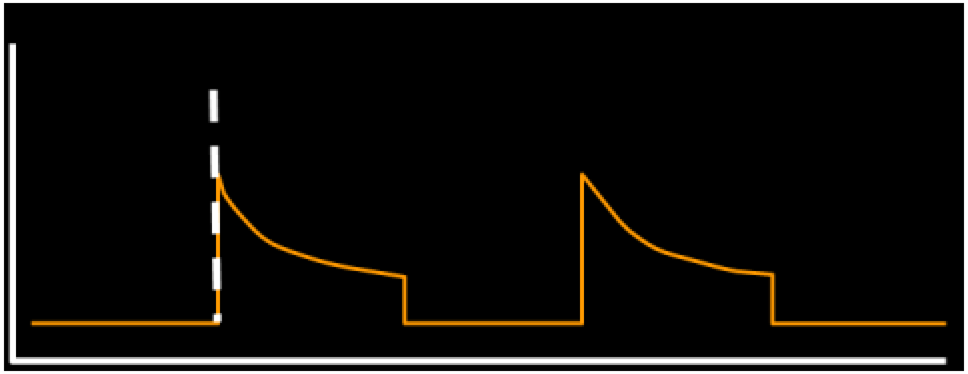
***Paradigms***

- ***constant current vs. constant voltage***
- ***extraspinal stimulation***
- ***stimulation frequency***
- ***stimulation waveform***
- ***…***

University of Illinois at Chicago

# Evolution of spinal stimulation





**Voltage or current?**

# Evolution of neuromodulation for pain

*Peripheral nerve / field*
*(regional stimulation)*

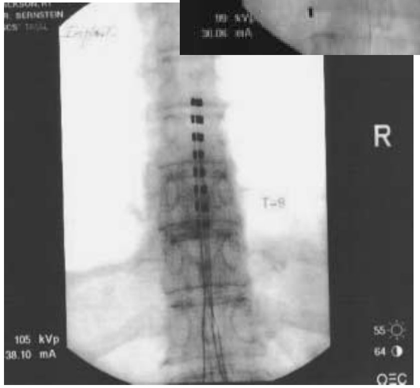
*Ganglia*

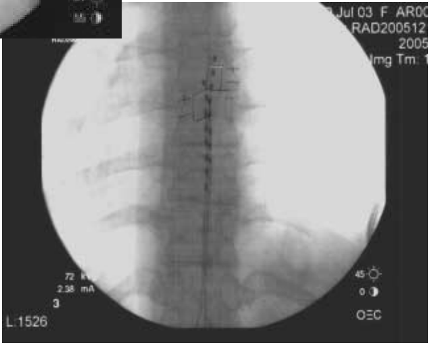
*Nerve roots*

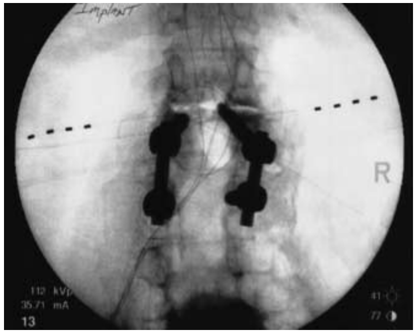
University of Illinois at Chicago

# Innovation in SCS

**Hybrid neurostimulation**
(spinal and peripheral)

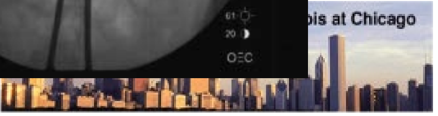



NEUROMODULATION: TECHNOLOGY AT THE NEURAL INTERFACE
Volume 11 • Number 2 • 2008
http://www.blackwell-synergy.com/loi/ner

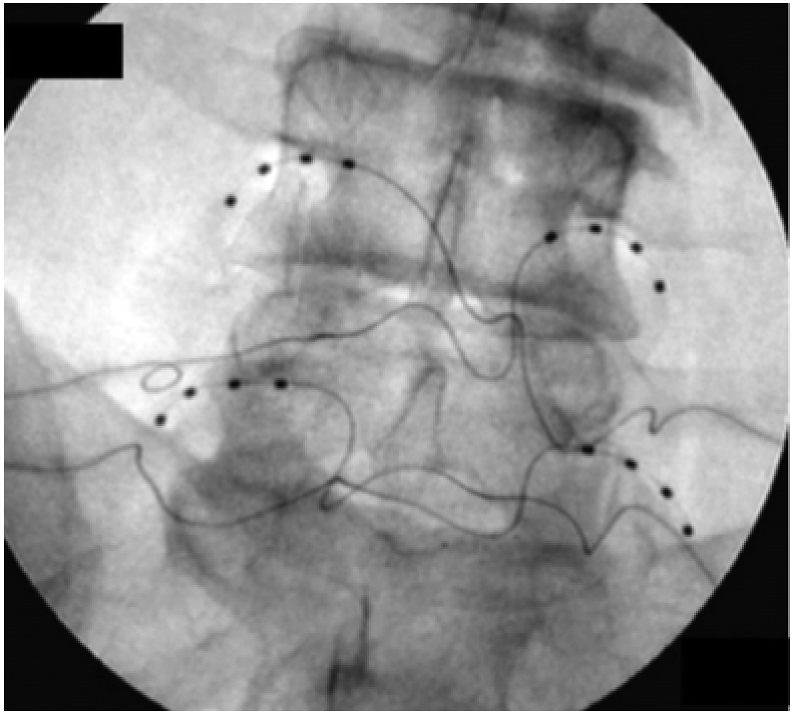
ORIGINAL ARTICLE

**Spinal Cord Stimulation in Conjunction With Peripheral Nerve Field Stimulation for the Treatment of Low Back and Leg Pain: A Case Series**

Clifford A. Bernstein, MD* • Richard M. Paicius, MD† • Stephen H. Barkow, MD, DABPM†‡ • Cheryl Lempert-Cohen, MD*



# Innovation in SCS



## DRG stimulation

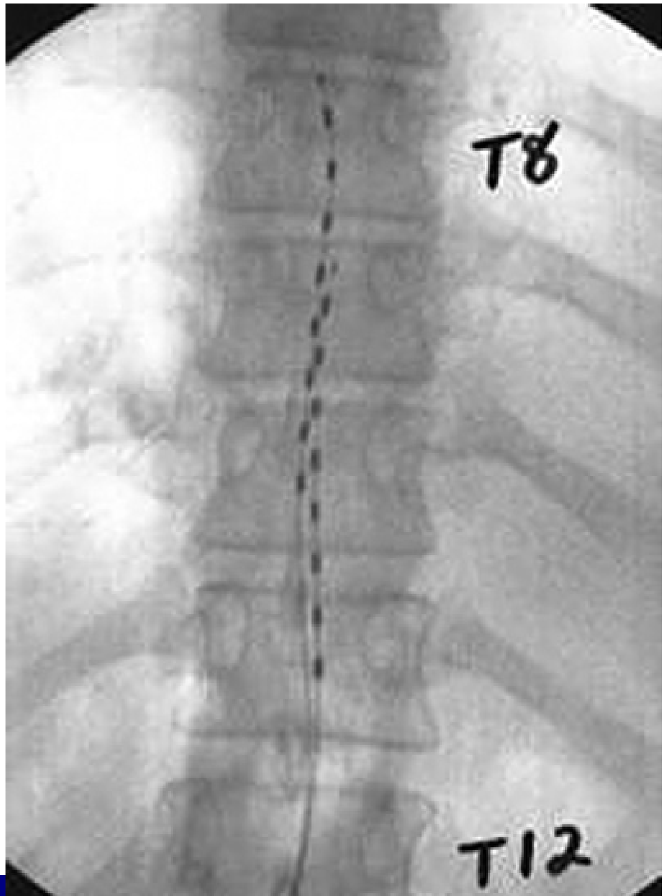

**A Prospective Study of Dorsal Root Ganglion Stimulation for the Relief of Chronic Pain**

Timothy R. Deer, MD[*], Eric Grigsby, MD[†], Richard L. Weiner, MD[‡], Bernard Wilcosky, MD[§], Jeffery M. Kramer, PhD[¶]

Neuromodulation 2013; 16: 67–72

University of Illinois at Chicago

# Innovation in SCS




**High frequency stimulation**

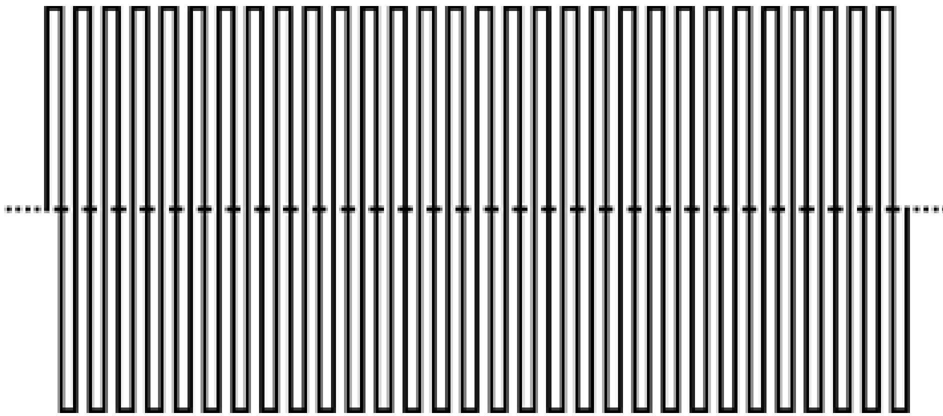

**High-Frequency Spinal Cord Stimulation for the Treatment of Chronic Back Pain Patients: Results of a Prospective Multicenter European Clinical Study**

Neuromodulation 2013; 16: 59–66

Jean-Pierre Van Buyten, MD[1*], Adnan Al-Kaisy, MD[1†], Iris Smet, MD*, Stefano Palmisani, MD[†], Thomas Smith, MD[†]

University of Illinois at Chicago

# Innovation in SCS



## SCS in kilohertz range

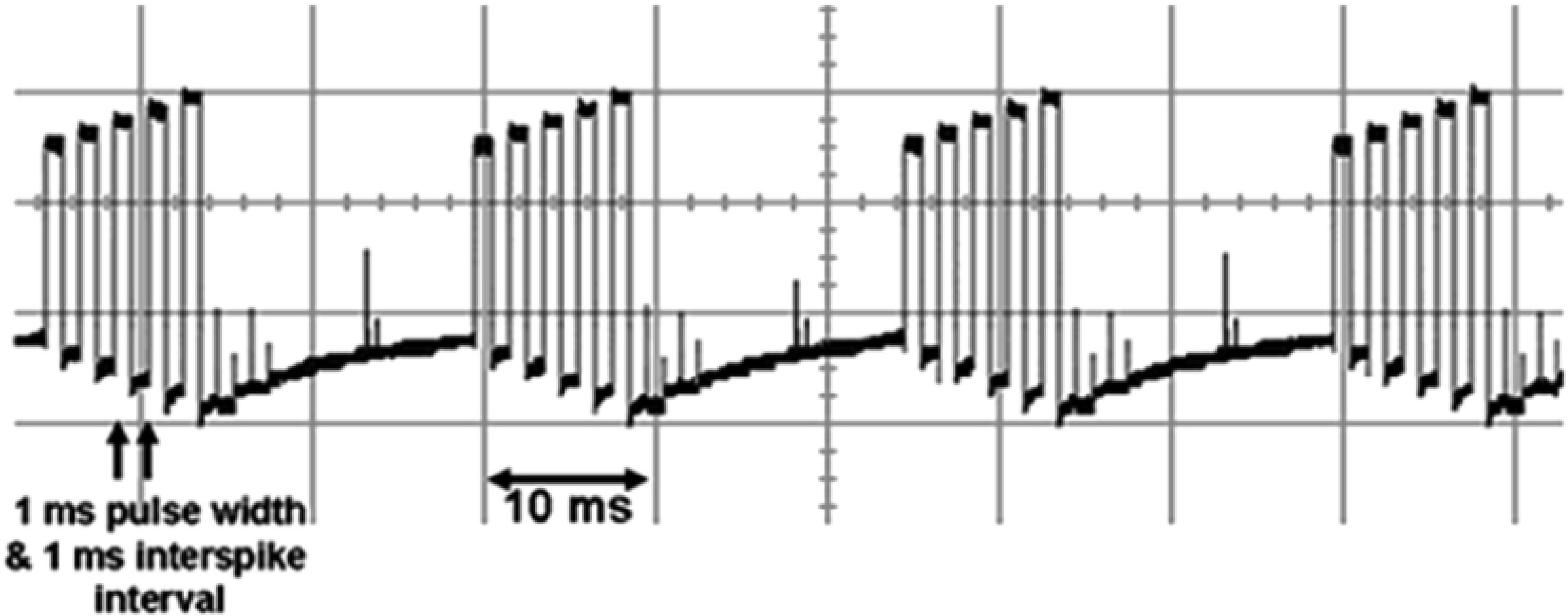
- •Frequency - 10,000 Hz
- •Amplitude – sub-perception
- •Pulse width - 30 microseconds
- •Bi-phasic pulse

**High-Frequency Spinal Cord Stimulation for the Treatment of Chronic Back Pain Patients: Results of a Prospective Multicenter European Clinical Study**

Neuromodulation 2013; 16: 59–66

Jean-Pierre Van Buyten, MD[1*], Adnan Al-Kaisy, MD[1†], Iris Smet, MD*, Stefano Palmisani, MD[†], Thomas Smith, MD[†]

# Innovation in SCS




Burst stimulation: a new form of paresthesia free spinal cord stimulation

*Plazier M[a], van der Loo E[a], Rooker S[a], Menovsky T[a], Vancamp T[b], De Ridder D[a] [[a]BRAI2N and Department Of Neurosurgery, University Hospital Antwerp, Edegem, [b]ANS Medical-Saint Jude Medical, Zaventem]*

*Surgical Neurology 71 (2009) 134–142*

Burst Spinal Cord Stimulation for Limb and Back Pain

***Dirk De Ridder[1,2], Mark Plazier[3], Niels Kamerling[3], Tomas Menovsky[3], Sven Vanneste[4]***

WORLD NEUROSURGERY 80 [5]: 642 649, NOVEMBER 2013

**Burst mode**

University of Illinois at Chicago

# Innovation in SCS

## Burst SCS

- Intra-burst frequency – 500 Hz
- Burst frequency – 40 Hzц
- Amplitude –sub-perception
- Pulse width - 1000 microseconds



Burst stimulation: a new form of paresthesia free spinal cord stimulation

*Plazier M[a], van der Loo E[a], Rooker S[a], Menovsky T[a], Vancamp T[b], De Ridder D[a] [[a]BRAI2N and Department Of Neurosurgery, University Hospital Antwerp, Edegem, [b]ANS Medical-Saint Jude Medical, Zaventem]*

*Surgical Neurology 71 (2009) 134–142*

Burst Spinal Cord Stimulation for Limb and Back Pain

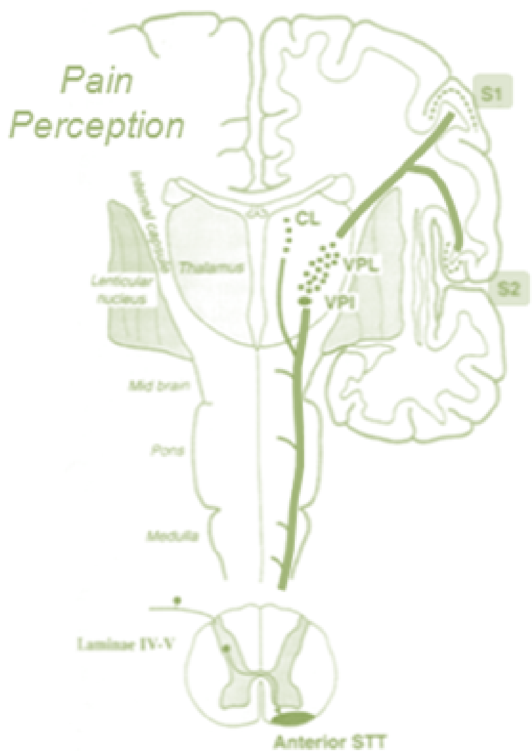
***Dirk De Ridder[1,2], Mark Plazier[3], Niels Kamerling[3], Tomas Menovsky[3], Sven Vanneste[4]***

WORLD NEUROSURGERY 80 [5]: 642 649, NOVEMBER 2013

# Innovation in SCS

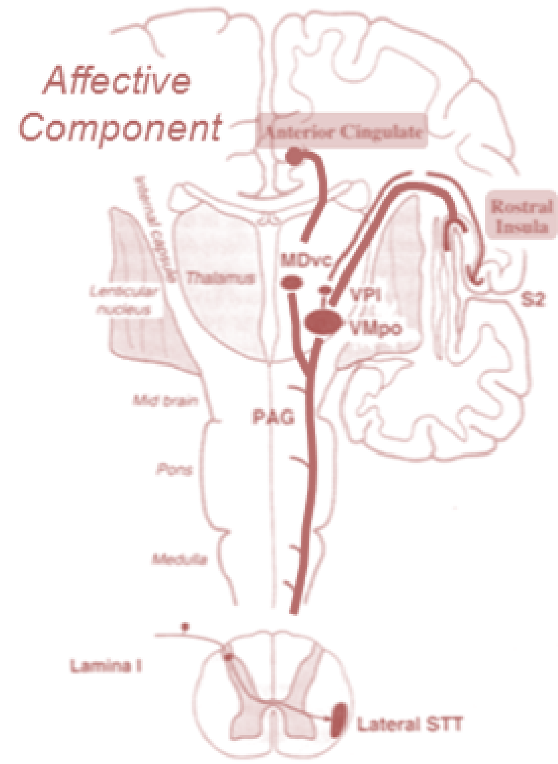
**PAIN**

Latheral pathway




**SUFFERING**

Medial pathway

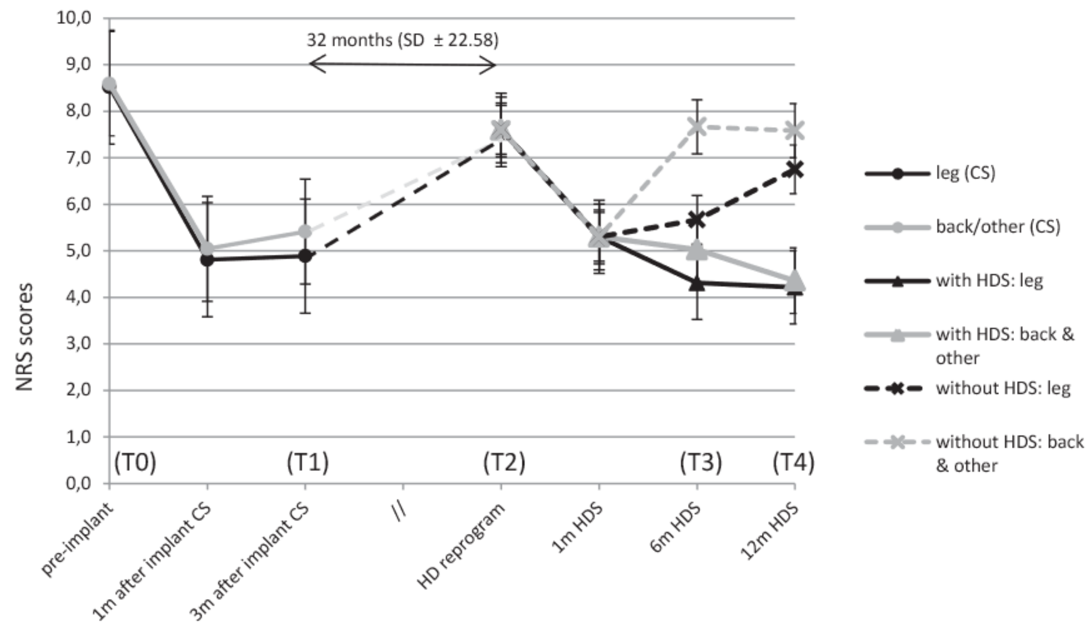



**Burst mode**

University of Illinois at Chicago

# Innovation in SCS

"High-density" – stimulation with conventional devices with higher frequency and longer pulse widths




**Altering Conventional to High Density Spinal Cord Stimulation: An Energy Dose-Response Relationship in Neuropathic Pain Therapy**


**Frank Wille, MD*†; Jennifer S. Breel, MPA*†; Eric W.P. Bakker, PhD‡; Markus W. Hollmann, MD, PhD†**

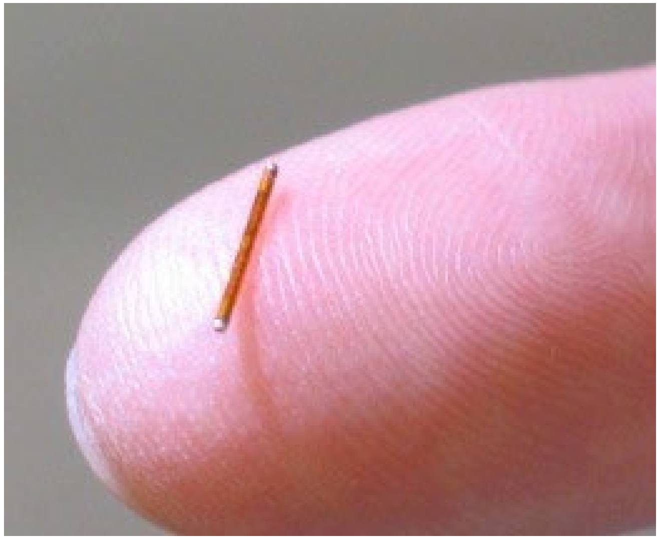


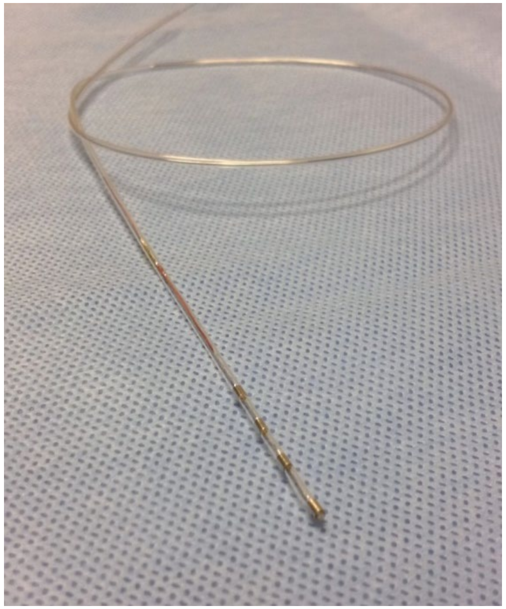
Neuromodulation 2017; 20: 71–80

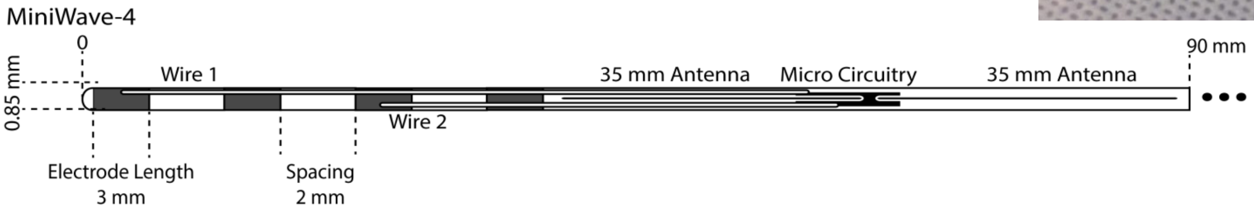
# Innovation in SCS

**Wireless device**

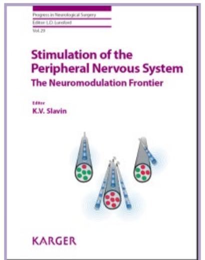
Nanotechnology in action








From Yearwood T, et al.
PNS; 2015



# Innovation in SCS

**Closed loop approach**

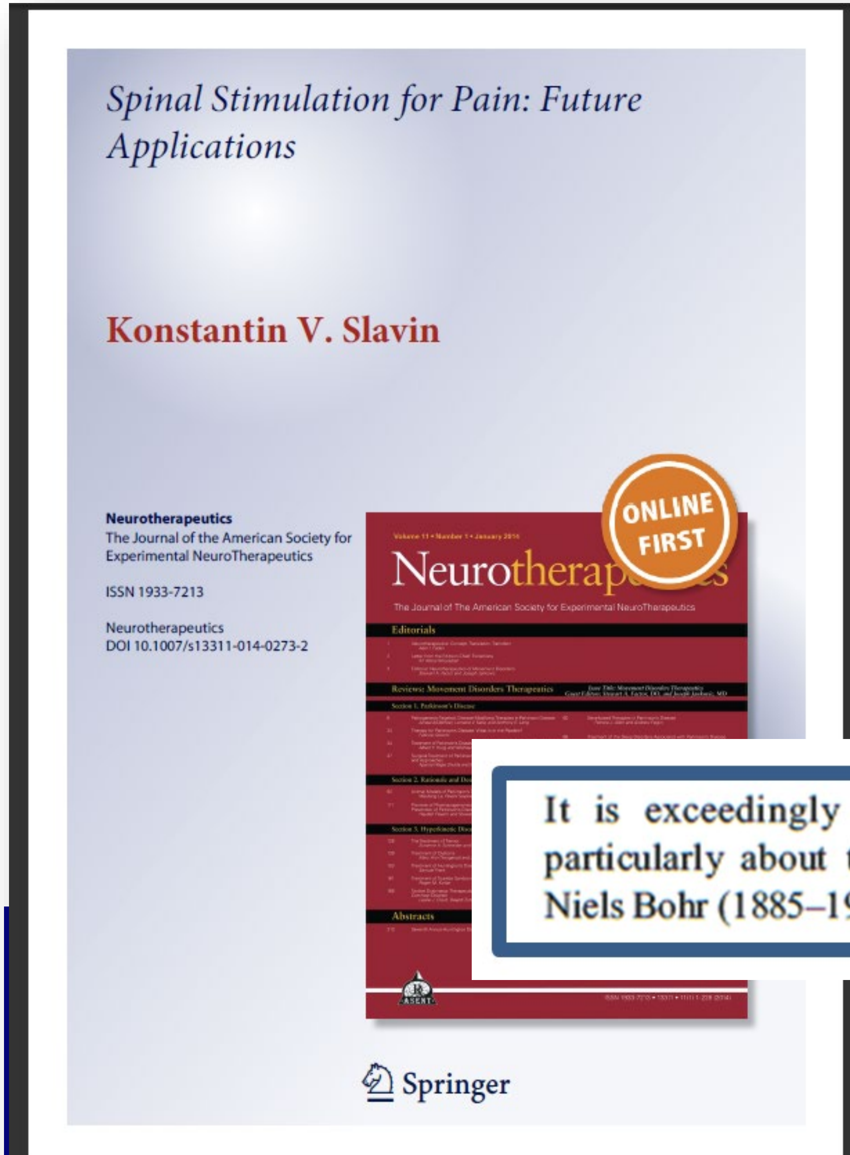
Real time therapy adjustment based on evoked compound action potentials

# Comparative analysis of spinal neurostimulation for pain

# Prospective (*) controlled (#) randomized (^) multi-center (!) studies:

1. **Accurate** (Spinal Modulation / Abbott) *#^!
   DRG stimulation – compared to conventional SCS
2. **SENZA** (Nevro) *#^!
   High-frequency SCS – compared to conventional SCS
3. **SUNBURST** (St. Jude Medical / Abbott) *#^!
   Burst SCS – compared to conventional SCS
4. **HD Stim** (Medtronic) *
   High-density SCS (after failed conventional SCS)
5. **SubPSCS** (Boston Scientific) *!
   Subperception SCS (in successful conventional SCS)
6. **PROCO** (Boston Scientific) *#^
   Comparative assessment of different high frequencies
7. **EVOKE** (Saluda) *#^!
   Comparative analysis of closed loop vs. open loop SCS
8. **AVALON** (Saluda) *!
   Closed-loop stimulation – open label study

# The Future…






Neurotherapeutics
DOI 10.1007/s13311-014-0273-2

REVIEW

## Spinal Stimulation for Pain: Future Applications

Konstantin V. Slavin



**Abstract** With continuous progress and rapid technological advancement of neuromodulation it is conceivable that within next decade or so, our approach to the electrical stimulation of the spinal cord used in treatment of chronic pain will change radically. The currently used spinal cord stimulation (SCS), with its procedural invasiveness, bulky devices, simplistic stimulation paradigms, and frustrating decline in effectiveness over time will be replaced by much more refined and individually tailored modality. Better understanding of underlying mechanism of action will allow us to use SCS in a more rational way, selecting patient-specific targets and techniques that properly fit each patient with chronic pain based on pain characteristics, distribution, and cause. Based on the information available today, this article will summarize emerging applications of SCS in the treatment of pain and theorize on further developments that may be introduced in the foreseeable future. An overview of clinical and technological innovations will serve as a basis for better understanding of SCS landscape for the next several years

It is exceedingly difficult to make predictions, particularly about the future.
Niels Bohr (1885–1962)

K. V. Slavin (✉)
Department of Neurosurgery, University of Illinois at Chicago, 912 South Wood Street (MC 799), Chicago, IL 60612, USA
e-mail: kslavin@uic.edu

Published online: 03 April 2014

### Introduction

Epidural electrical stimulation of the dorsal columns of spinal cord [usually referred to as spinal cord stimulation (SCS)] is, today, an arguably most commonly performed surgical intervention for the treatment of chronic pain. Since its inception in 1967 by Shealy et al. [1–3], SCS evolved in both conceptual and practical dimensions. The systems became more complex, and the choice of individual components gave clinicians many options with different degrees of invasiveness, selectivity, longevity, and adjustability.

The number of clinical indications for SCS remained relatively stable over the years—the dominant categories remain chronic radiculopathy (such as in failed back surgery syndrome), complex regional pain syndromes (type 1 and 2), and pain due to ischemia (coronary or in extremities) [2–5]. Some indications have faded away (cancer pain, pain associated with spasticity, postherpetic neuralgia, brachial plexus avulsion, phantom pain after amputations) [3, 6], while others seem to be growing (low back pain, headaches) [7, 8]. Radiofrequency-coupled systems became replaced by implantable pulse generators, and simple electrode combinations became supplemented by complex multicontact configurations. Within the last decade, there has been the introduction of rechargeable generators, multicolumn electrode leads, independent current delivery, percutaneously insertable paddle leads, long-range telemetry, self-adjustable stimulation, and magnetic resonance imaging (MRI) compatibility—and this is only a partial list of major innovations.

If such an exponential pace of innovative trend continues, one may expect even more revolutionary developments within a short period of time. But as (in the absence of crystal ball) any futuristic predictions have little validity, this article will be dedicated to those recent developments that are likely to enjoy widespread acceptance once the neuromodulation community-at-large becomes convinced in their benefits and



cago

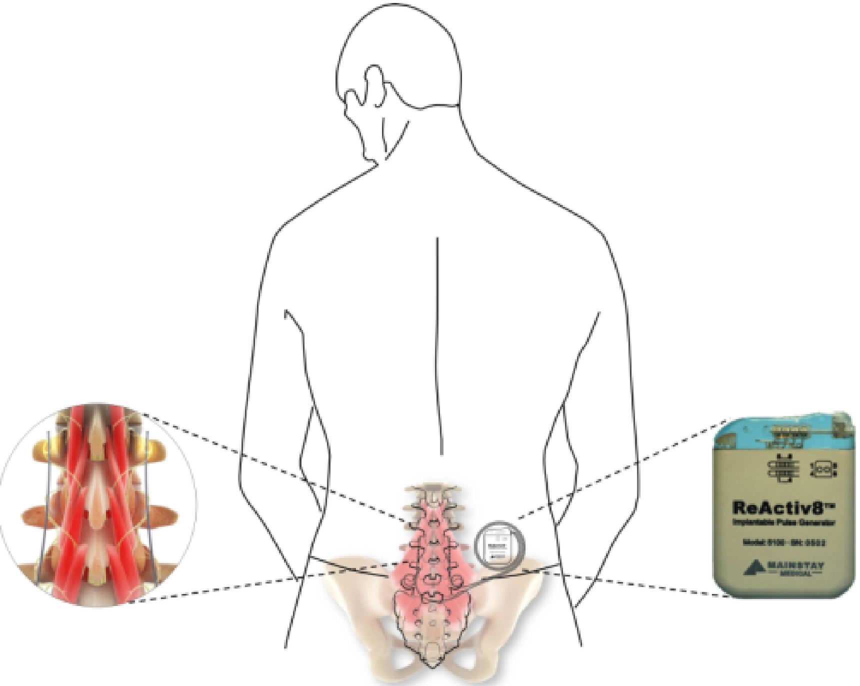
# The Future of Neuromodulation for Pain…

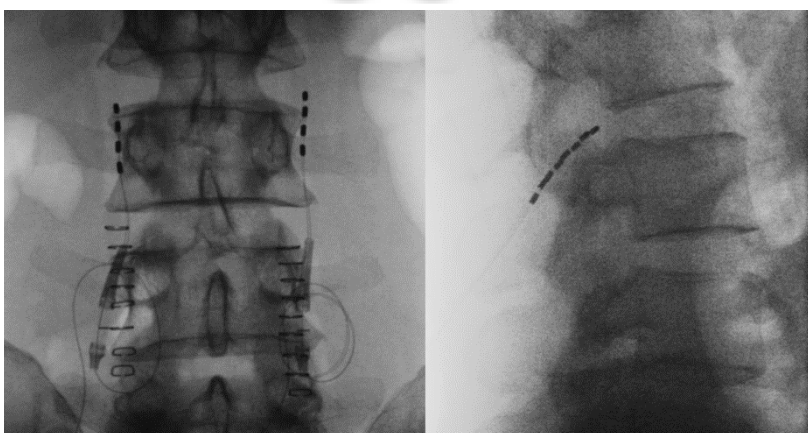
is bright!

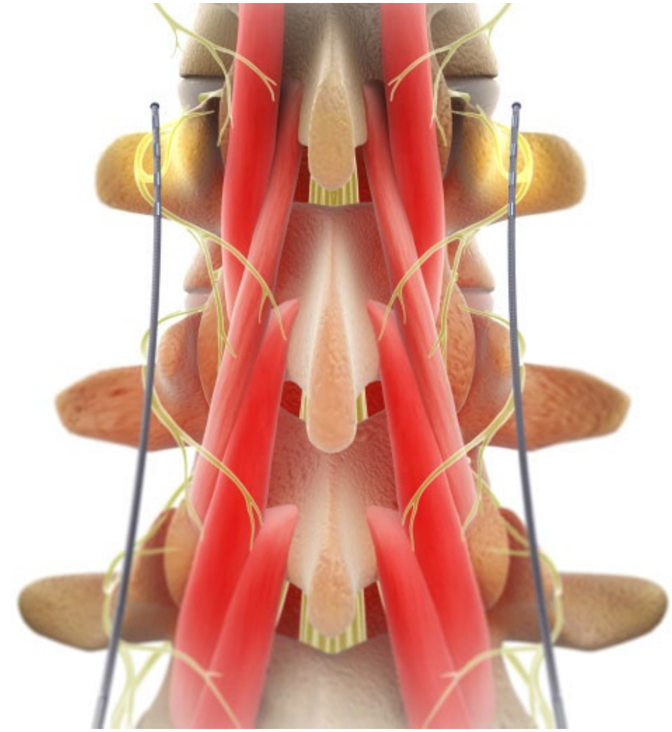
# Future of neuromodulation for pain

# Future of neuromodulation for pain

## Extra-spinal stimulation?





**Chronic Low Back Pain: Restoration of Dynamic Stability**

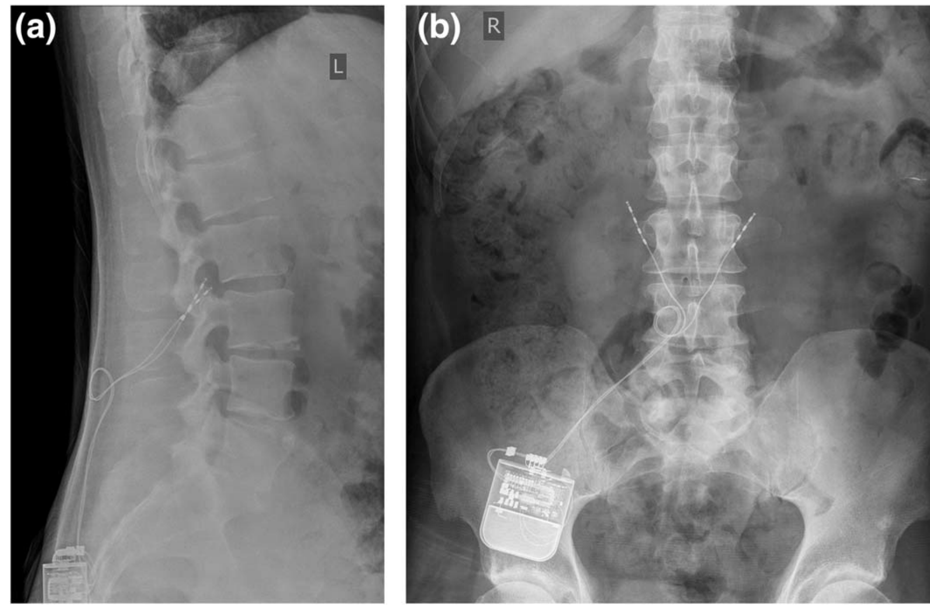
Neuromodulation 2015; 18: 478–486

Kristiaan Deckers, MD*; Kris De Smedt, MD†; Jean-Pierre van Buyten, MD‡; Iris Smet, MD‡; Sam Eldabe, MD§; Ashish Gulve, MD§; Ganesan Baranidharan, MD¶; José de Andrès, MD, PhD**; Chris Gilligan, MD††; Kristen Jaax, MD, PhD‡‡; Jan Pieter Heemels, MS‡‡; Peter Crosby, MS‡‡

# Medial branch stimulation – multifidus activation – "restoration of dynamic stability"

University of Illinois at Chicago

# Medial Branch Stimulation with Implanted Electrodes



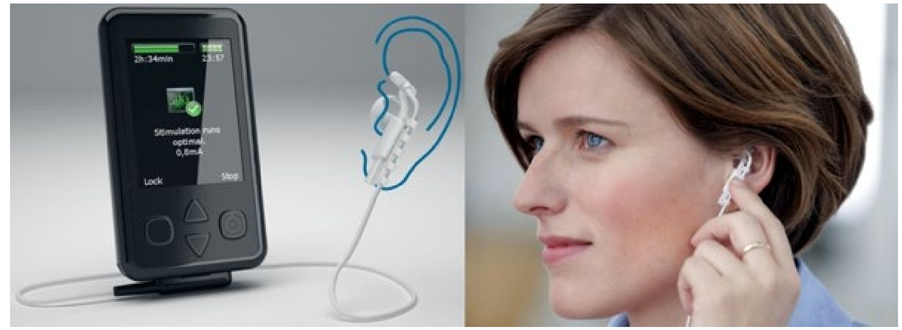

Neuromodulation 2018; 21: 48–55

## New Therapy for Refractory Chronic Mechanical Low Back Pain—Restorative Neurostimulation to Activate the Lumbar Multifidus: One Year Results of a Prospective Multicenter Clinical Trial

Kristiaan Deckers, MD[*]; Kris De Smedt, MD[*]; Bruce Mitchell, MD[†];
David Vivian, MD[†]; Marc Russo, MD[‡]; Peter Georgius, MD[§];
Matthew Green, MD[¶]; John Vieceli, MSc[¶]; Sam Eldabe, MD[**];
Ashish Gulve, MD[**]; Jean-Pierre van Buyten, MD, PhD[††]; Iris Smet, MD[††];
Vivek Mehta, MD[‡‡]; Shankar Ramaswamy, MD[‡‡];
Ganesan Baranidharan, MD[§§]; Richard Sullivan, MD[¶¶]; Robert Gassin, MD[¶¶];
James Rathmell, MD[***]; Chris Gilligan, MD[***]

# Future of neuromodulation for pain

# Non-invasive neuromodulation?





# FDA-approved devices

University of Illinois at Chicago

# At-Home Cortical Stimulation for Neuropathic Pain: a Feasibility Study with Initial Clinical Results

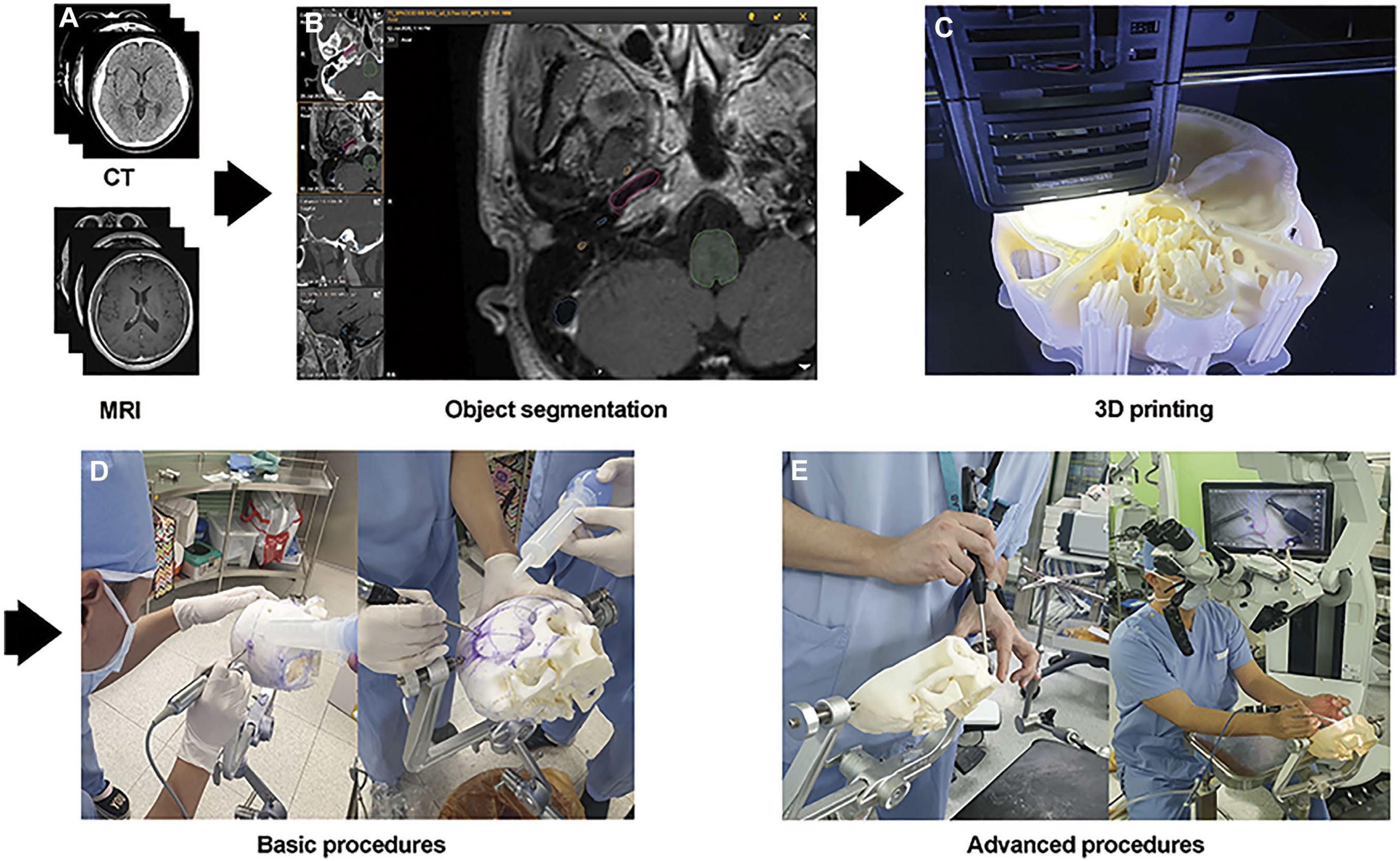
Neurotherapeutics (2019) 16:1198–1209

Luis Garcia-Larrea [1,2] • Caroline Perchet [1] • Koichi Hagiwara [1] • Nathalie André-Obadia [1,3]

University of Illinois at Chicago

# Future of neuromodulation for pain

# Augmented reality for simulation?




# Cadaver-Free Neurosurgical Simulation Using a 3-dimensional Printer and Augmented Reality

Min Ho Lee, MD*

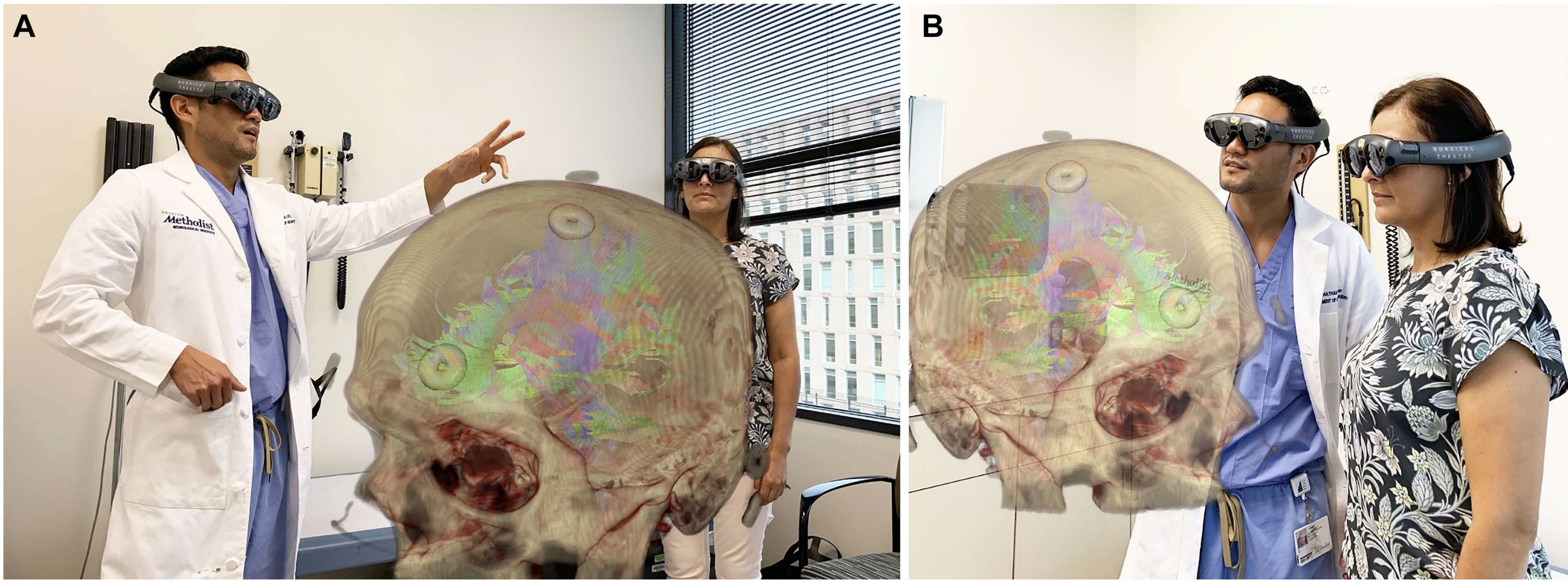
Tae-Kyu Lee, MD, PhD,

*Operative Neurosurgery 00:1–7, 2022*

University of Illinois at Chicago

# Future of neuromodulation for pain

# Virtual reality for surgical planning?




Jonathan J. Lee, MD*
Maxim Klepcha, MBE‡
Marcus Wong, MD*
Phuong N. Dang, PhD‡
Saeed S. Sadrameli, MD*
Gavin W. Britz, MD, MPH,

# The First Pilot Study of an Interactive, 360° Augmented Reality Visualization Platform for Neurosurgical Patient Education: A Case Series

*Operative Neurosurgery 00:1–7, 2022*

UIC University of Illinois at Chicago

# Future of neuromodulation for pain

# Out-of-box thinking!

# Out-of-box thinking

super-miniaturized

autonomous devices


StarTribune

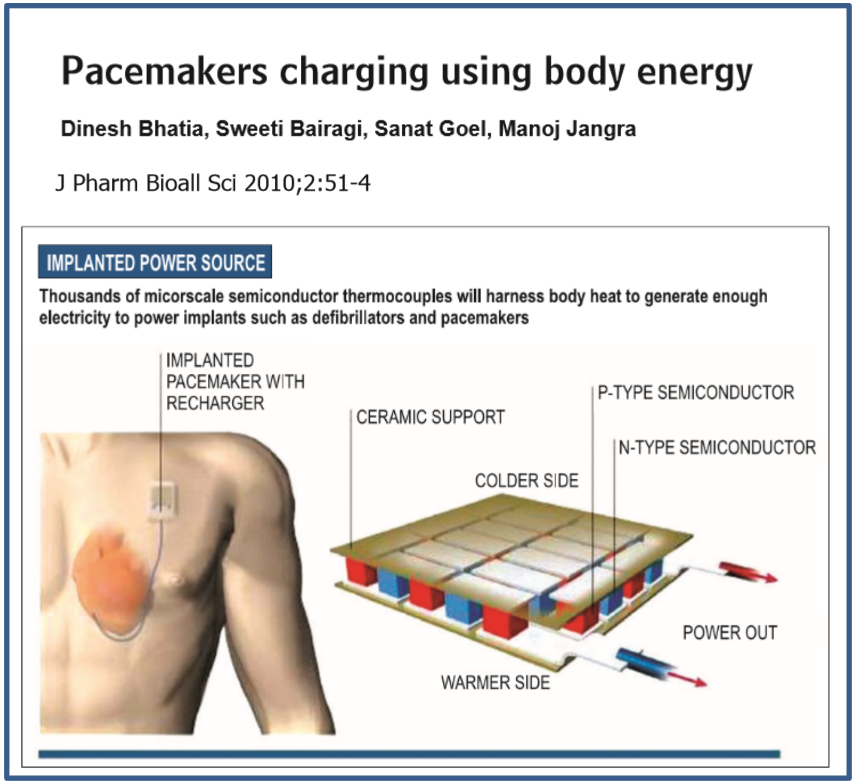
**Medtronic gets OK to sell next generation of pacemakers that fit inside the heart**

By JOE CARLSON , STAR TRIBUNE
January 31, 2020 - 8:13 PM

# Out-of-box thinking

body-heat

powered devices



Pacemakers charging using body energy

Dinesh Bhatia, Sweeti Bairagi, Sanat Goel, Manoj Jangra

J Pharm Bioall Sci 2010;2:51-4

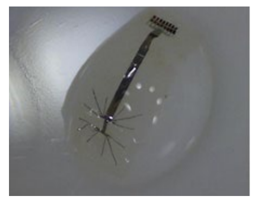
IMPLANTED POWER SOURCE

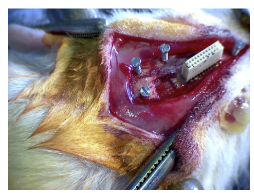
Thousands of micorscale semiconductor thermocouples will harness body heat to generate enough electricity to power implants such as defibrillators and pacemakers

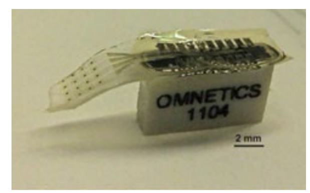
# Out-of-box thinking

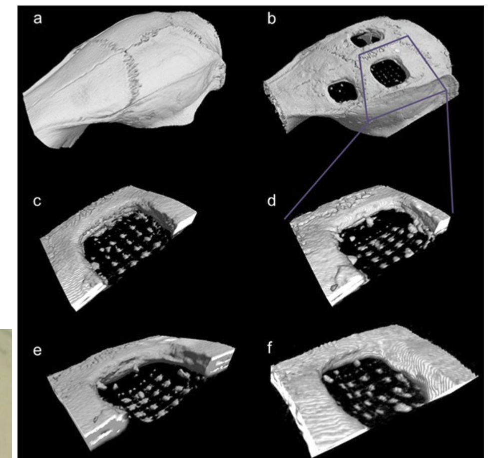
dissolvable

hardware








**Resorbable scaffold based chronic neural electrode arrays**

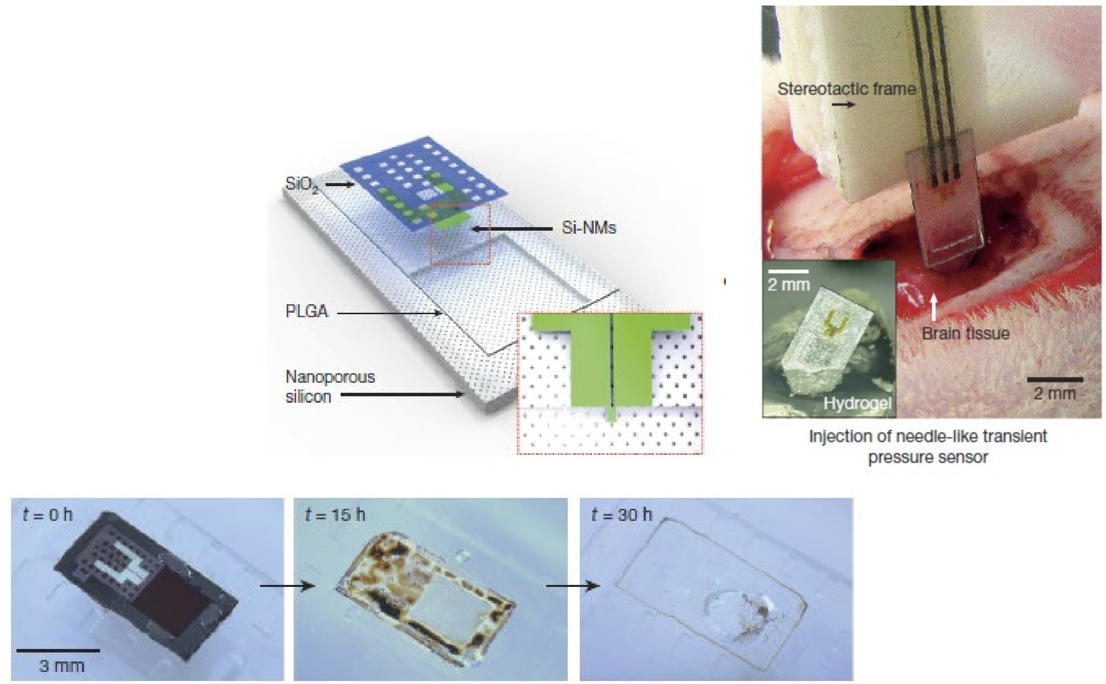
Frederik Ceyssens · Kris van Kuyck ·
Greetje Vande Velde · Marleen Welkenhuysen ·
Linda Stappers · Bart Nuttin · Robert Puers

Biomed Microdevices (2013) 15:481–493

# Out-of-box thinking

dissolvable

hardware




Injection of needle-like transient pressure sensor

## Bioresorbable silicon electronic sensors for the brain

Seung-Kyun Kang[1,2]*, Rory K. J. Murphy[3]*, Suk-Won Hwang[4]*, Seung Min Lee[1,2]*, Daniel V. Harburg[1,2], Neil A. Krueger[1], Jiho Shin[2,5], Paul Gamble[3], Huanyu Cheng[6], Sooyoun Yu[2,5], Zhuangjian Liu[7], Jordan G. McCall[8], Manu Stephen[3], Hanze Ying[1], Jeonghyun Kim[1,2], Gayoung Park[9,10], R. Chad Webb[1,2], Chi Hwan Lee[11], Sangjin Chung[1,2], Dae Seung Wie[12], Amit D. Gujar[3], Bharat Vemulapalli[3], Albert H. Kim[3], Kyung-Mi Lee[10], Jianjun Cheng[1], Younggang Huang[13], Sang Hoon Lee[14], Paul V. Braun[1,2,15], Wilson Z. Ray[3] & John A. Rogers[1,2,15]

4 FEBRUARY 2016 | VOL 530 | NATURE

doi:10.1038/nature16492

University of Illinois at Chicago

WIKISTIM

Neuromodulation Data Extracted & Categorized

# Thank you for your attention!

kslavin@uic.edu

+1-800-597-5970

University of Illinois at Chicago