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

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

The Project has been realised with the support of the European Union and has been co-financed by the European Social Fund ***

**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 PROSTHESES

Neurális interfészek és protézisek

LECTURE 3

FUNCTIONAL MUSCLE AND NERVE STIMULATION

(Funkcionális izom- és idegingerlés)

DOMONKOS HORVÁTH, BÁLINT PÉTER KEREKES and GYÖRGY KARMOS

FUNCTIONAL ELECTRICAL STIMULATION

- Definition: functional electrical stimulation is a technique that uses electrical currents to activate nerves innervating extremities affected by paralysis
- Most common origins of paralysis:
  - Spinal cord injury
  - Head injury
  - Stroke
  - Other neurological disorders
- Types of paralysis:
  - Paraplegia: both upper or both lower limbs are paralyzed
  - Tetraplegia: all four limbs are paralyzed
  - Hemiplegia: left or right side of the body is paralyzed

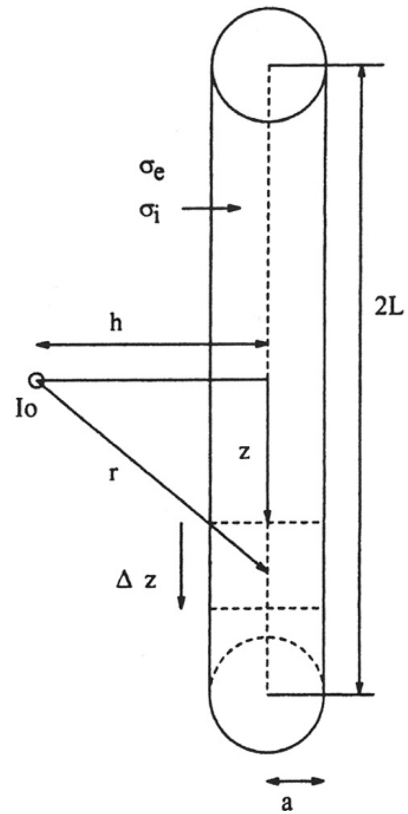
FUNCTIONAL ELECTRICAL STIMULATION (FES)

- Nerve stimulation: achieved by passing current between two or more electrodes implanted into the body or placed on the skin surface
- Design: appropriate spatial and temporal patterns of stimulation must be determined in order to produce real functional nerve activation
- Both nerve responses and stimulus properties must be understood for effective design

PROPERTIES OF ELECTRICAL STIMULATION

- In FES, stimulation is extracellular, i. e. stimulating electrodes are placed outside the neurons and nerves

I_0: single current point source placed at a distance h from a circular cylindrical fiber
$2L$: length of fiber
a: radius of fiber
σ_i: intracellular conductivity
σ_e: extracellular conductivity
z: fiber centerline axis
Δz: fiber element for numerical calculations



http://www.ece.mcmaster.ca/~ibruce/courses/ECE795_2008/ECE795_lecture09.pdf

PROPERTIES OF ELECTRICAL STIMULATION

- The effect of the point source can be described with the following equation:

$$\phi_a = \frac{I_0}{4\pi\sigma_e r}$$

- Φ_a: extracellular potential field
- I_0: current strength
- σ_e: extracellular medium conductivity
- r: distance from the source to an arbitrary field point
- Effect of the fiber on the field is ignored.

PROPERTIES OF ELECTRICAL STIMULATION

- Transmembrane current induced by the stimulation must be equal to the intrinsic ionic current plus the capacitive current of the membrane.
- This can be fitted into the following equation:

$$r_i i_m = \frac{\partial^2 \phi_i}{\partial z^2}$$

- r_i: intrinsic membrane resistance
- i_m: transmembrane current
- Φ_i: membrane potential
- z: coordinate along the fiber centerline axis (see Slide 5)
- See reformatted equation with ionic and capacitive membrane currents on next slide.

PROPERTIES OF ELECTRICAL STIMULATION

- Replacing Φ_i by $v_m+\Phi_e$ and i_m by $i_{ion}+c_m\partial v_m/\partial t$ in the previous equation gives the following:

$$r_i\frac{\partial v_m}{\partial t} = \frac{1}{c_m}\left(-i_{\text{ion}}r_i + \frac{\partial^2 v_m}{\partial z^2} + \frac{\partial^2 \phi_e}{\partial z^2}\right)$$

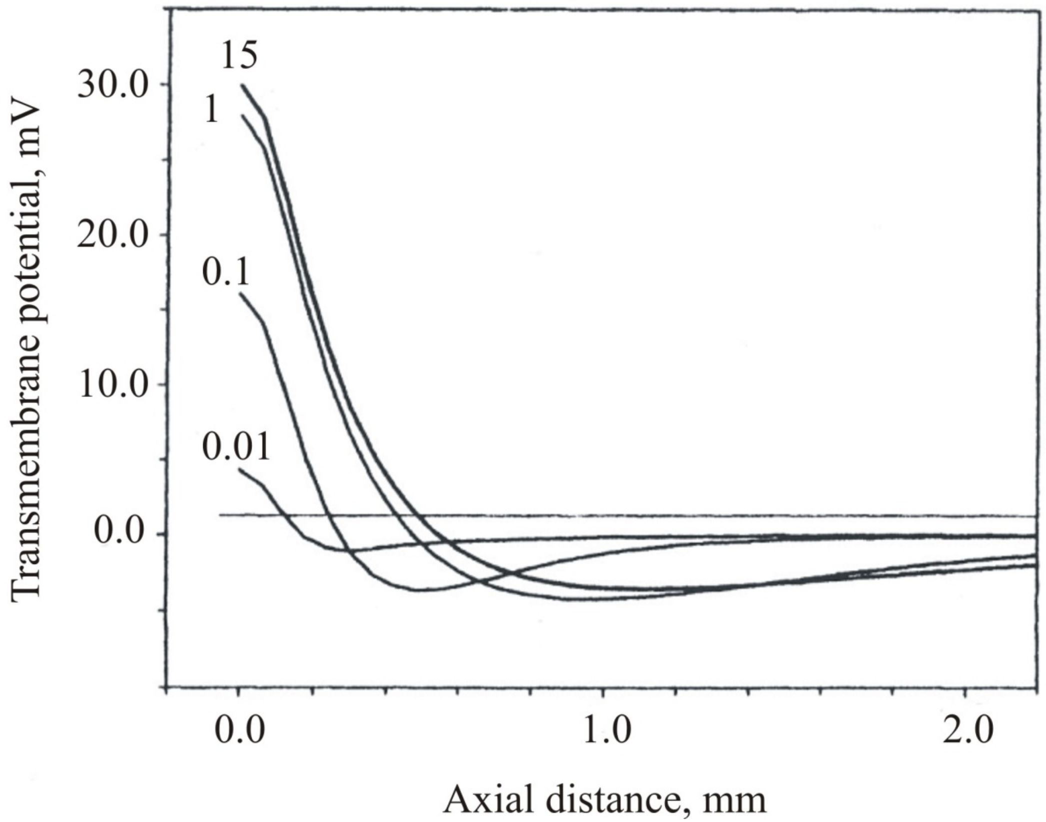
- At rest, v_m=0 for all z
- This means: $\partial^2 v_m/\partial z^2=0$ and $i_{ion}=v_m/r_m$
- As a consequence, the first application of stimulus can be described as follows:

$$r_i\frac{\partial v_m}{\partial t} = \frac{1}{c_m}\frac{\partial^2 \phi_e}{\partial z^2}$$

PROPERTIES OF ELECTRICAL STIMULATION

- According to the previous equation, excitation is possible at the region where $\partial^2\Phi_e/\partial z^2$ is positive because this makes $\partial v_m/\partial t$ initially positive.
- Thus, it is also true conversely that regions where $\partial^2\Phi_e/\partial z^2$ is negative are hyperpolarized because this makes $\partial v_m/\partial t$ initially negative.
- Because of its role in the activation or inhibition of the membrane section, the function $\partial^2\Phi_e/\partial z^2$ is called the activating function

PROPERTIES OF ELECTRICAL STIMULATION



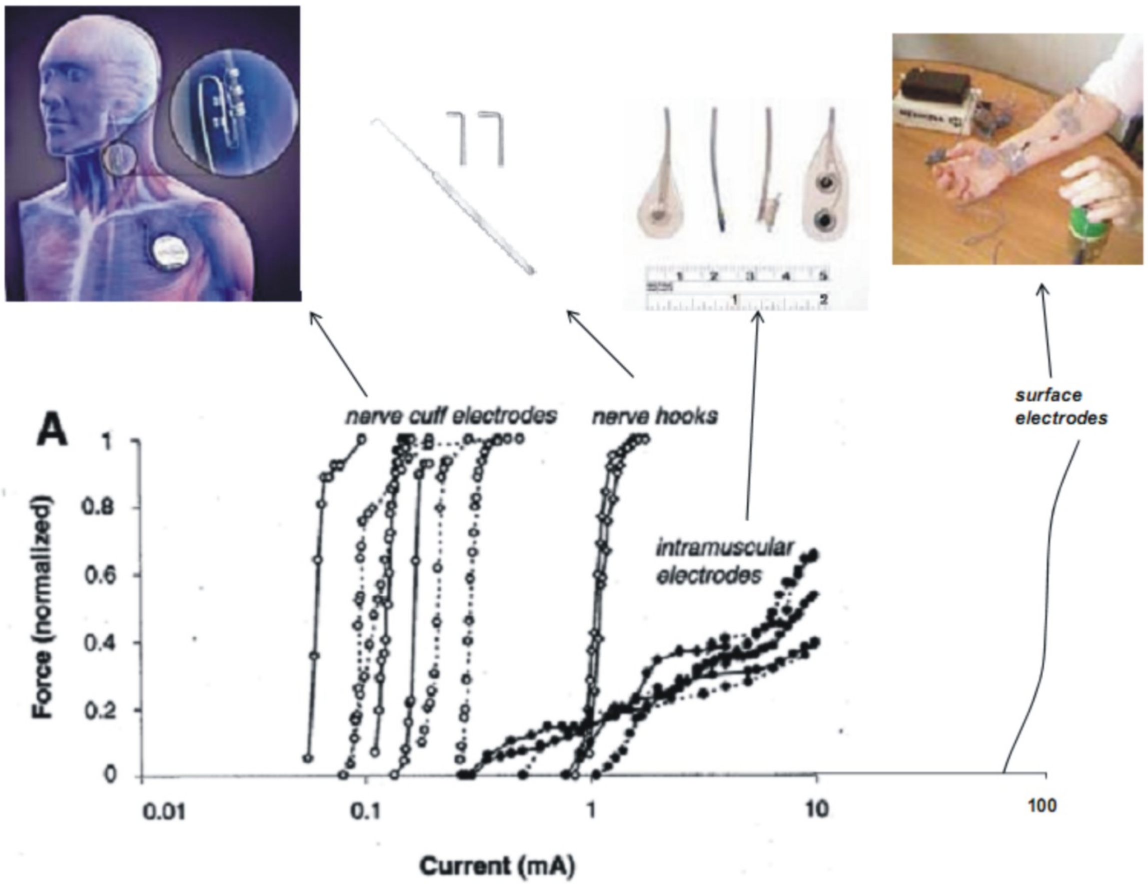
http://www.ece.mcmaster.ca/~ibruce/courses/ECE795_2008/ECE795_lecture09.pdf

Time evolution of induced transmembrane voltage along a fiber. Different curves represent different stimulus durations in milliseconds. Fiber structure is shown on Slide 5, h=0.02 cm.

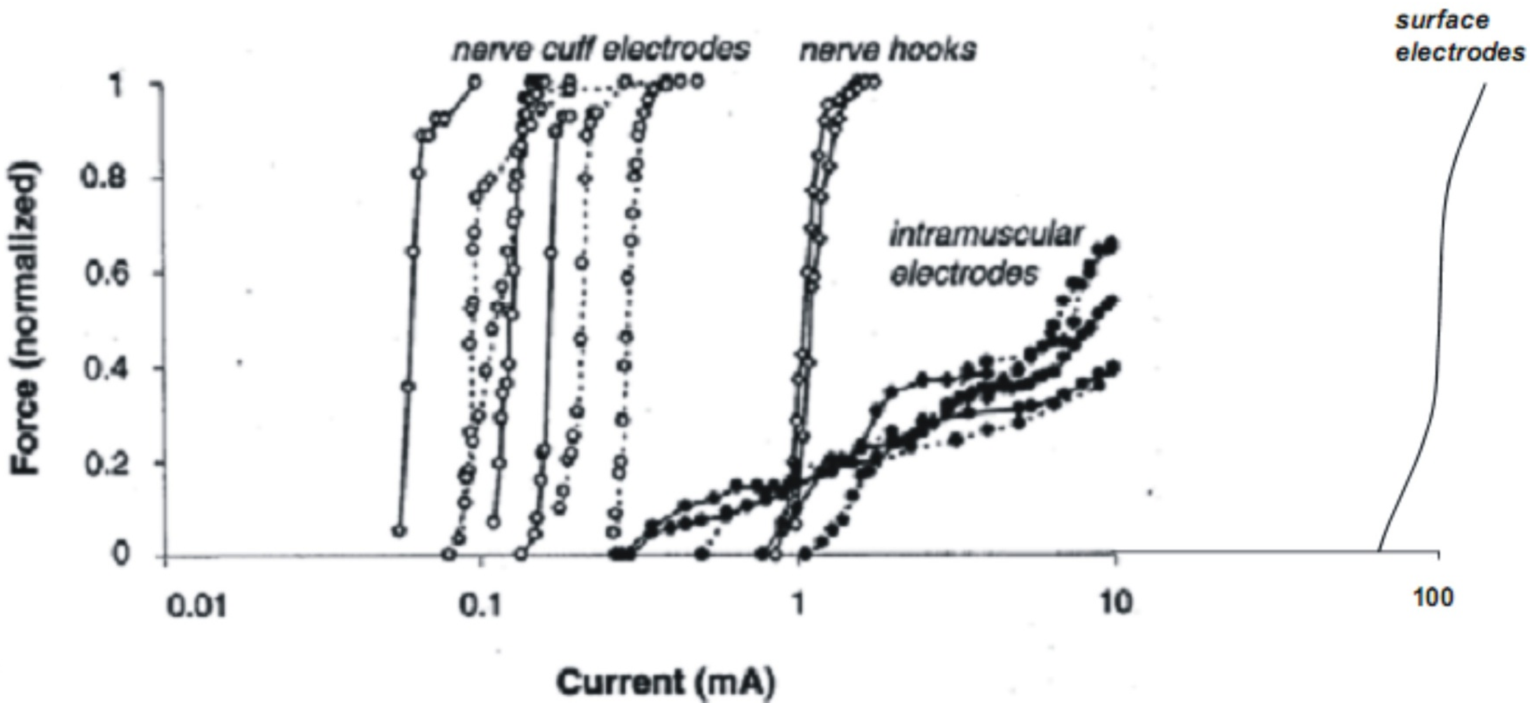
PROPERTIES OF ELECTRICAL STIMULATION

- Conclusion: a space clamped membrane patch and a whole fiber react differently on different durations of an external point stimulus
- Space clamped membrane patch: threshold potential relatively independent of stimulus duration
- Whole fiber: higher threshold for shorter stimulus duration. This effect is stronger when the source is close and weakens when the source is move further from the fiber.
- These effects result from the hyperpolarized regions flanking the depolarized region.
- The flanking hyperpolarized regions can block action potential generation along the fiber.

TYPES OF ELECTRICAL NERVE STIMULATION

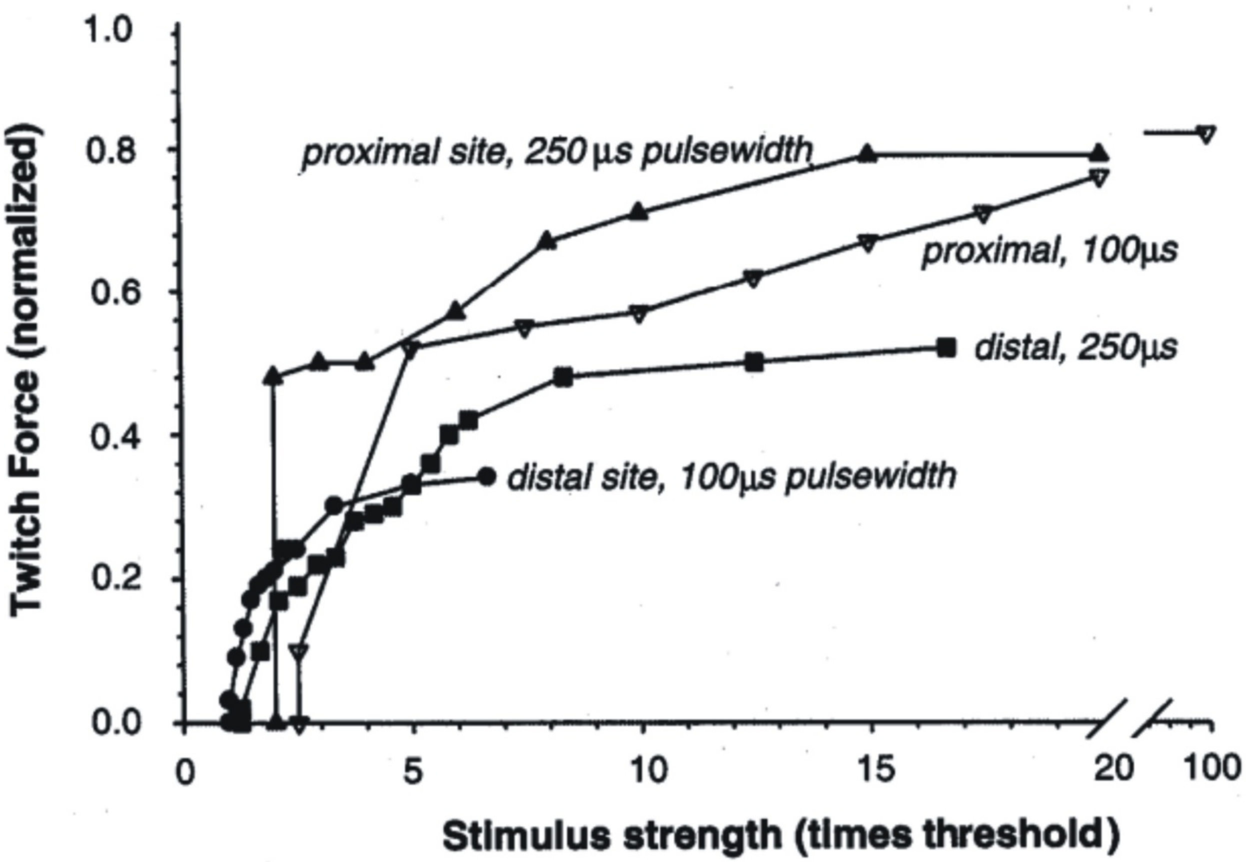


EFFECTS OF ELECTRICAL STIMULATION



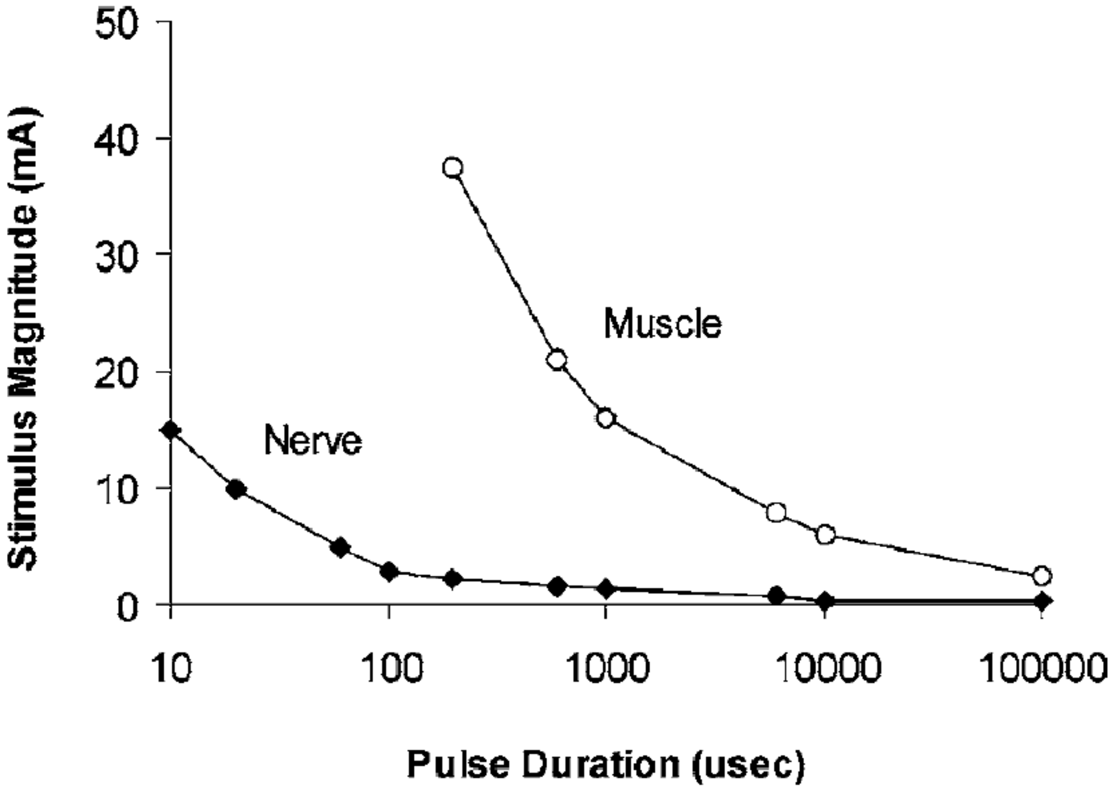
Current-force relation at nerve stimulation

EFFECTS OF ELECTRICAL STIMULATION



Current-force relation at muscle stimulation

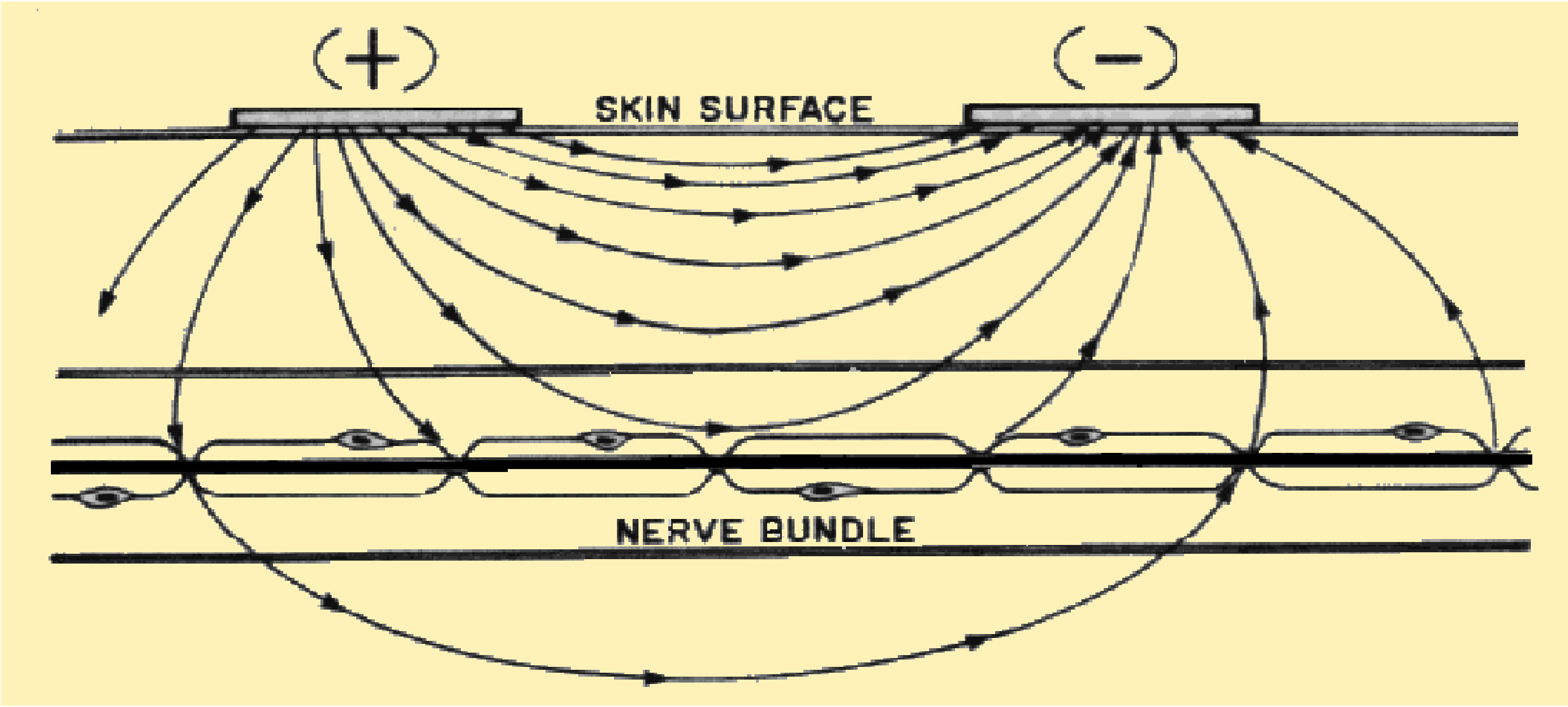
EFFECTS OF ELECTRICAL STIMULATION



http://www.ece.mcmaster.ca/~ibruce/courses/EE3BA3_presentation04.pdf

Charge production threshold for nerves and muscles: threshold is much lower in nerves than in muscles

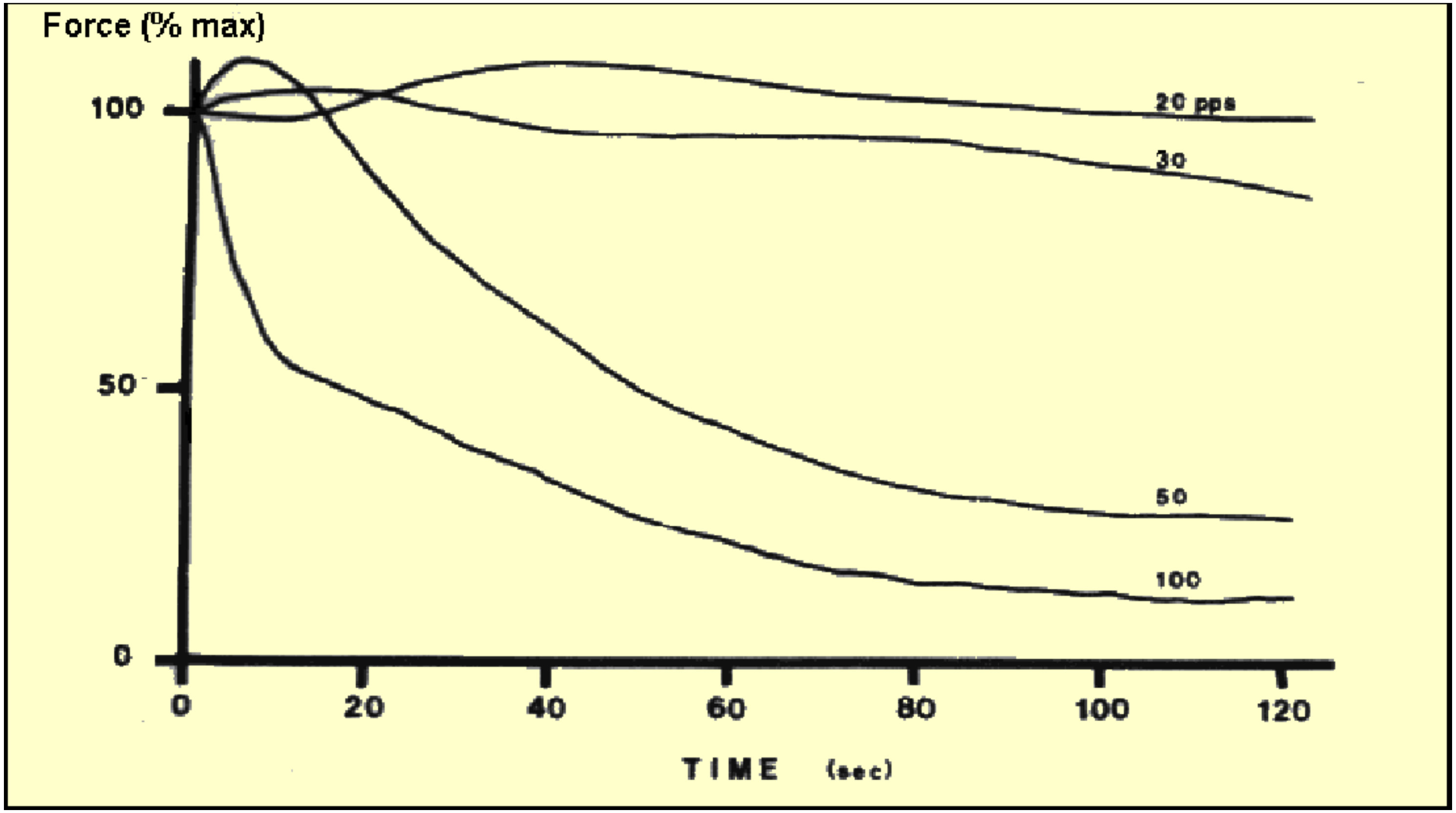
EFFECTS OF ELECTRICAL STIMULATION



Functional Electrical Stimulation: A Practical Clinical Guide (2nd Edition). Benton, Baker et al., 1981

Representation of current density at nerve stimulation

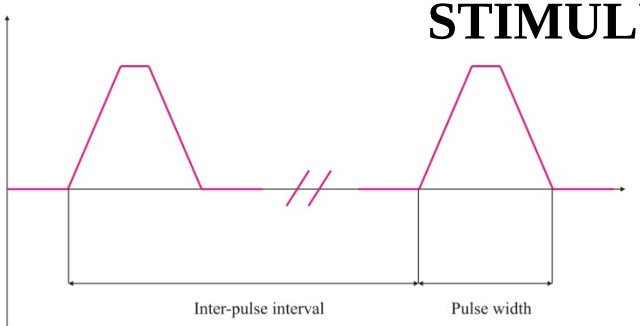
EFFECTS OF ELECTRICAL STIMULATION



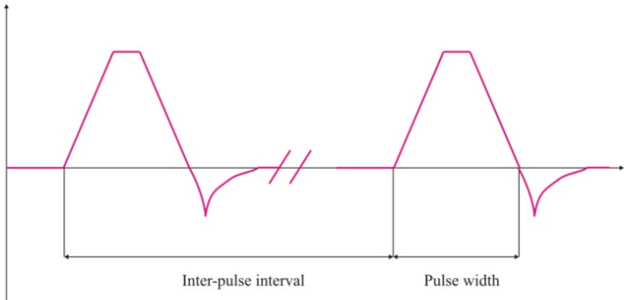
Functional Electrical Stimulation: A Practical Clinical Guide (2nd Edition). Benton, Baker et al., 1981

Effect of stimulus frequency on fatigue

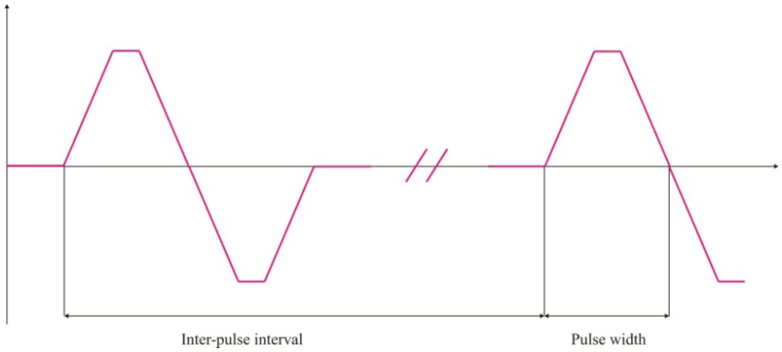
STIMULUS WAVEFORMS



Monophasic

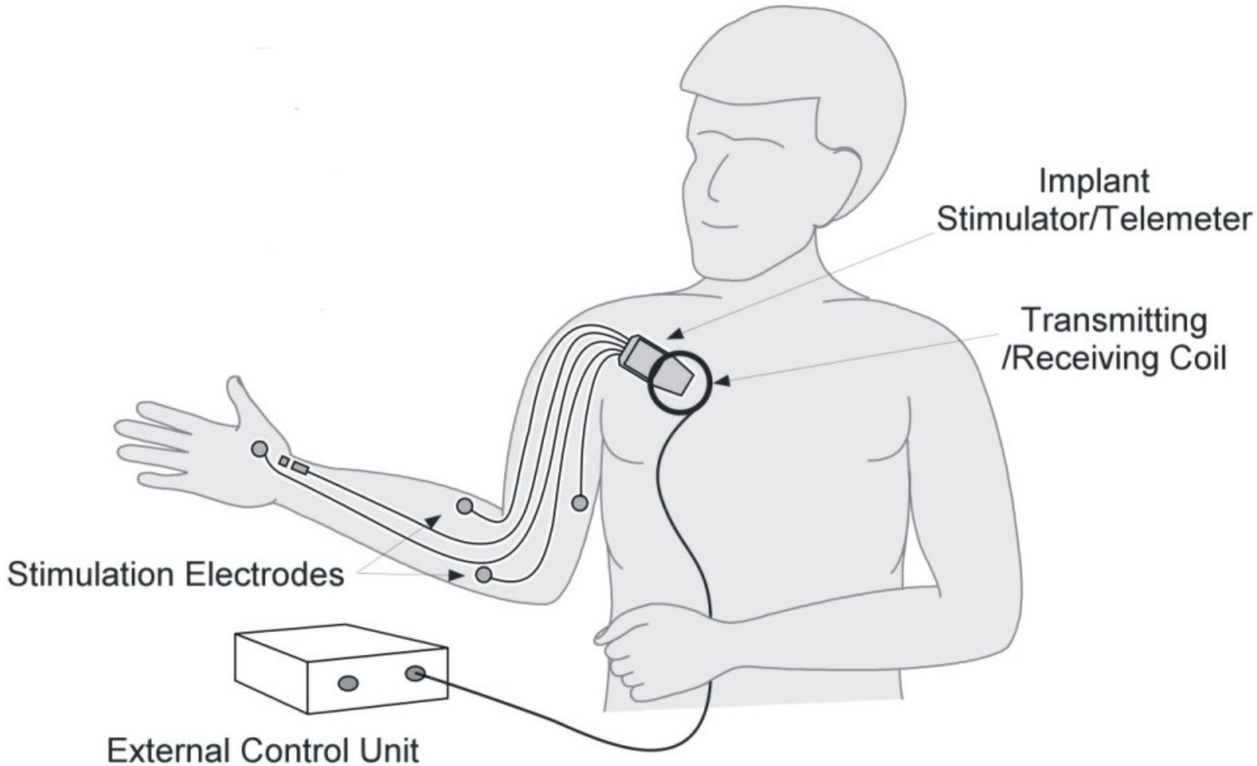


The monophasic waveforms tend to be asymmetric biphasic as the net charge built up in the body by the waveform discharges



Biphasic charge balanced

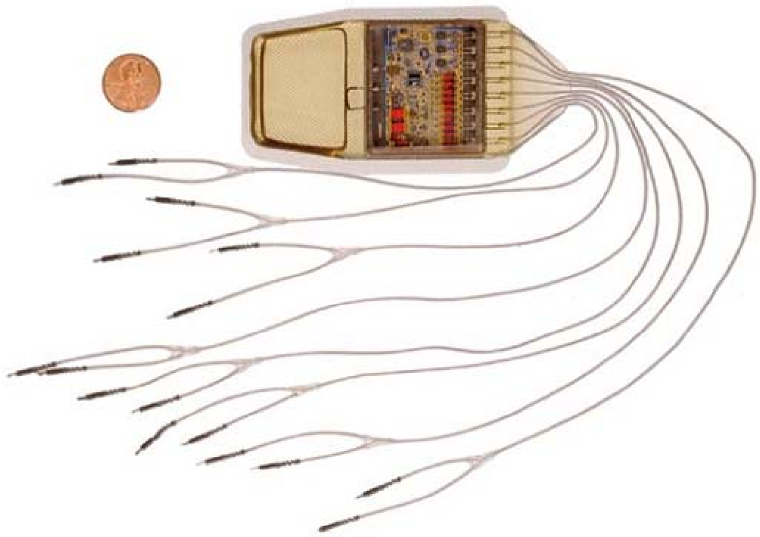
UPPER LIMB FES SYSTEMS



http://www.rehab.research.va.gov/jour/02/39/3/Bhadraf1.jpg

Schematic of a typical upper limb FES system

UPPER LIMB FES SYSTEMS



http://fescenter.org/images/stories/press/Report_to_the_Community_2010.pdf

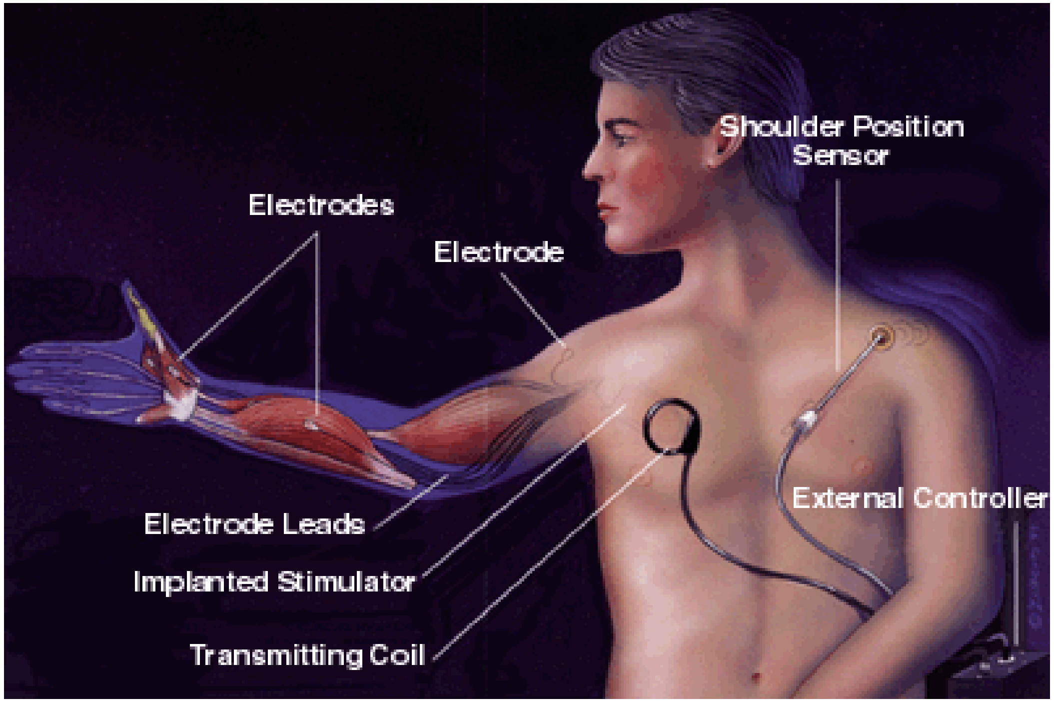
Different electrodes typically used in upper limb FES systems

Sixteen channel implantable stimulator developed for upper and lower limb FES systems

FREEHAND SYSTEM

- Developed at Case Western Reserve University, Cleveland, Ohio in 1986
- Given FDA approval for general use in 1997
- System overview:
  - Shoulder position sensor implanted into non-injured shoulder
  - External control unit: receives shoulder position information and computes stimulation pattern based on it.
  - Implanted stimulator: receives stimulation pattern from external controller via a transmitting coil and stimulates implanted electrodes via electrode leads
  - Electrodes: implanted into arm and wrist muscles to stimulate them according to the pattern received from the stimulator
- Programmable to six different movements, including palmar and lateral grasp

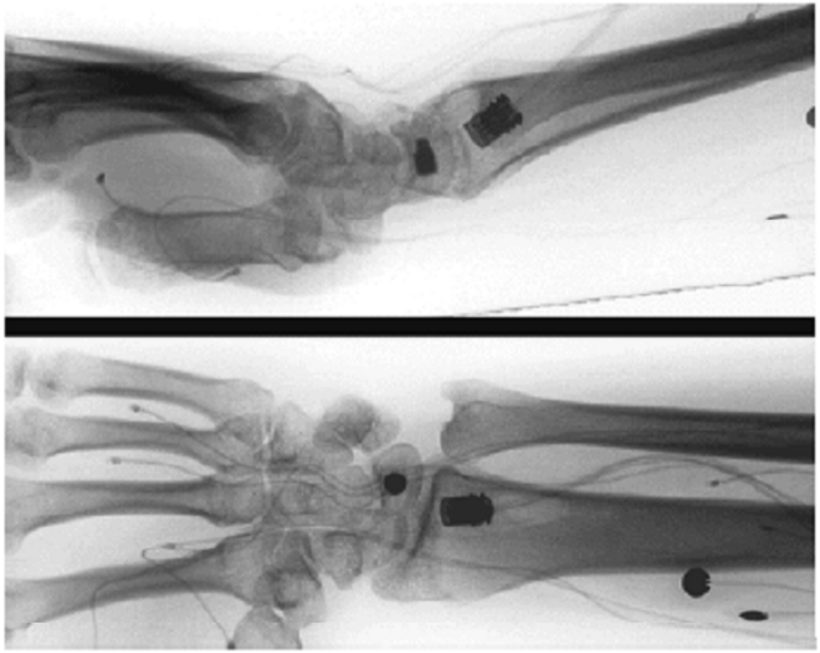
FREEHAND SYSTEM

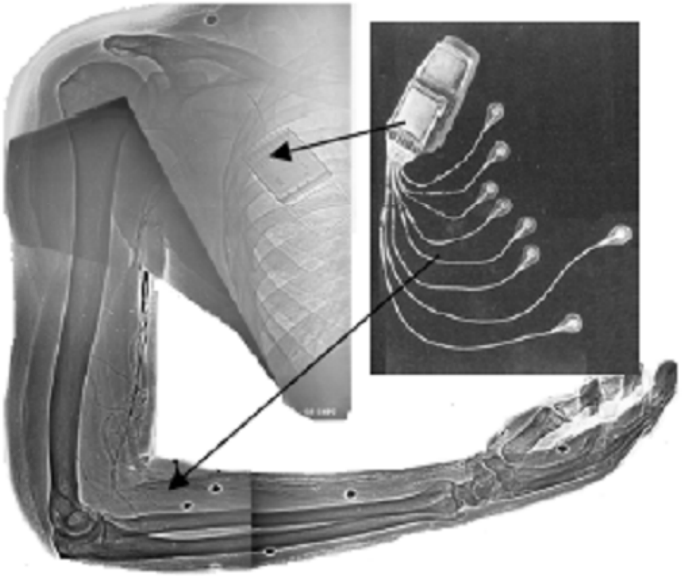


http://www.sci-recovery.org/sci-therapies.htm

Schematic of Freehand system components

FREEHAND SYSTEM





X-ray pictures showing implanted Freehand system components

FREEHAND SYSTEM IN USE

Patient applying make up with help of her implanted Freehand system

NESS H200 SYSTEM

- Developed by NESS Ltd., Israel in 2004
- Originally called Handmaster
- Non-invasive prosthesis: no implanting operation needed
- Two parts: orthosis and microprocessor
- Orthosis: external stimulating device applied on forearm and wrist
- Stimulates four different muscles in forearm wrist through the skin
- Microprocessor: computes stimulation patterns for different tasks

NESS H200 SYSTEM

http://medgadget.com/2006/04/ness_h200_syste.html

Orthosis Microprocessor

Patient using her NESS H200 system

http://www.ectron.co.uk/Neuro_Rehabilitation/

BIONIC GLOVE

- Developed at the University of Alberta in 1996
- Non-invasive device
- For patients with intact wrist moving capabilities
- Electrodes placed on skin over wrist
- Sensor records wrist movements, transmits the data to the microprocessor
- Microprocessor computes finger stimulation patterns based on wrist movement data
- Stimulator stimulates electrodes placed over wrist
- The whole system can be worn on a glove on wrist

BIONIC GLOVE

http://www.ualberta.ca/~aprochaz/bgtemp.html

Patient using his Bionic Glove

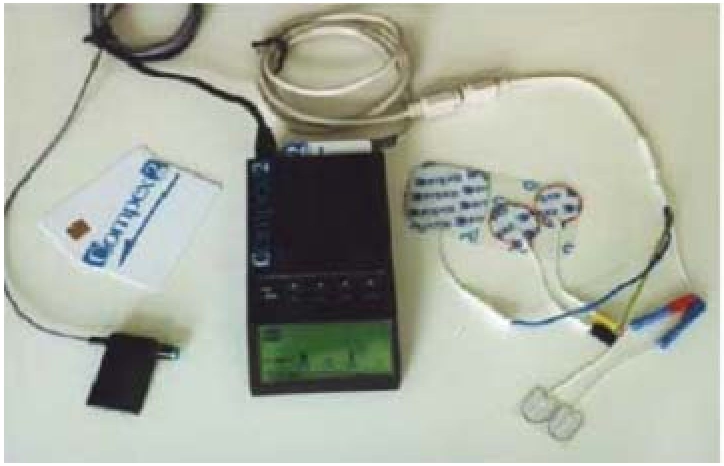
BELGRADE GRASPING SYSTEM

- Developed at the Belgrade University in 2001
- Not only wrist and forearm but also elbow stimulation
- Non-invasive, uses skin surface electrodes

Patient using Belgrade Grasping System (left) and electrode placement for grasping function (right)

ETHZ-PARACARE NEUROPROSTHESIS

- Developed at the Technical University of Zurich in 2000
- Restores hand grasping function
- Patient controls the external control unit by hand



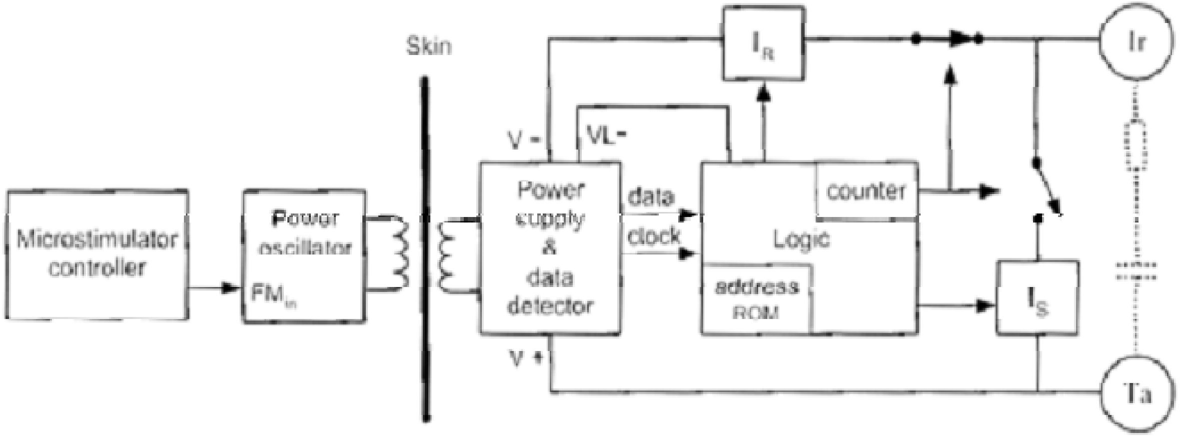
ETHZ-Paracare system components (left) and Patient using ETHZ-Paracare system for grasping (right)

BION MICROSTIMULATOR

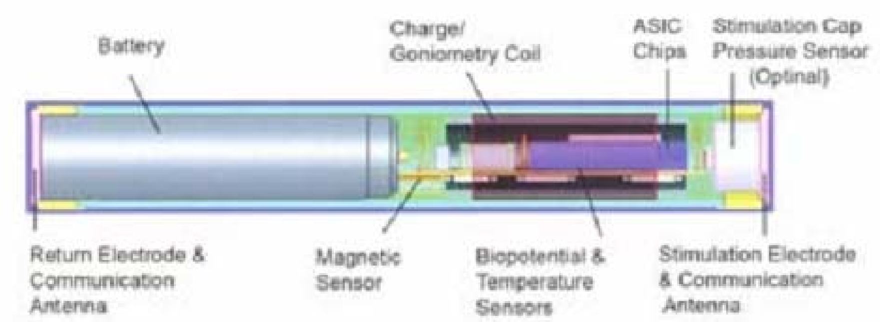
- Developed by Advanced Bionics Corporation in 2005
- Implantable, battery powered microstimulator
- Small enough to be able to be implanted into a muscle or near a nerve
- Recharging and communication through a magnetic transmission coil
- Several different uses: chronic pain, bladder function restoration, shoulder subluxation treatment

Demonstrating the size of a BION microstimulator

BION MICROSTIMULATOR



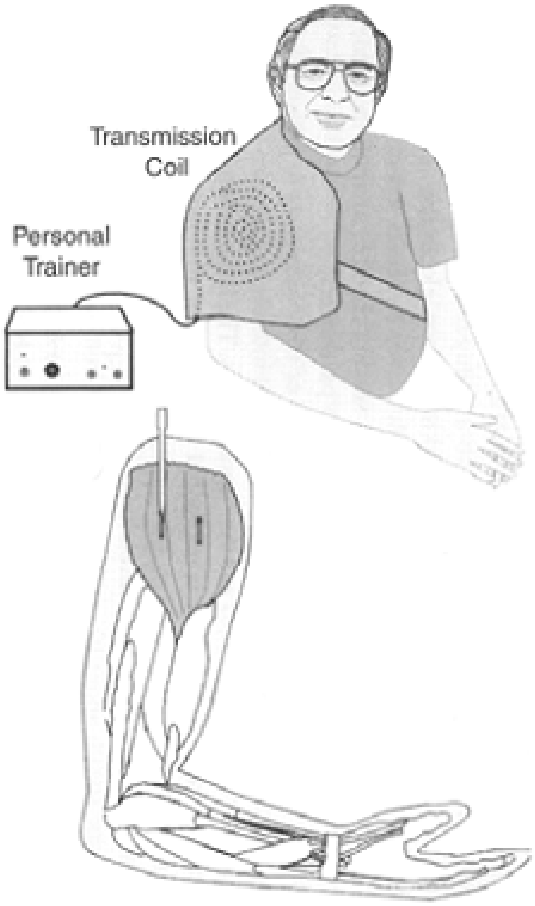
Block diagram of BION 1, the first version of BION stimulators



The latest version of BION stimulators

BION MICROSTIMULATOR FOR SHOULDER SUBLUXATION TREATMENT

- Shoulder subluxation: paralyzed shoulder joint (for example in stroke survivors) lets the humerus to leave the cotyle of shoulder which causes pain
- Stimulation of shoulder joint keeps humerus in the cotyle and reduces pain
- BION stimulator implanted into shoulder to provide stimulation
- 6 hours/day stimulation

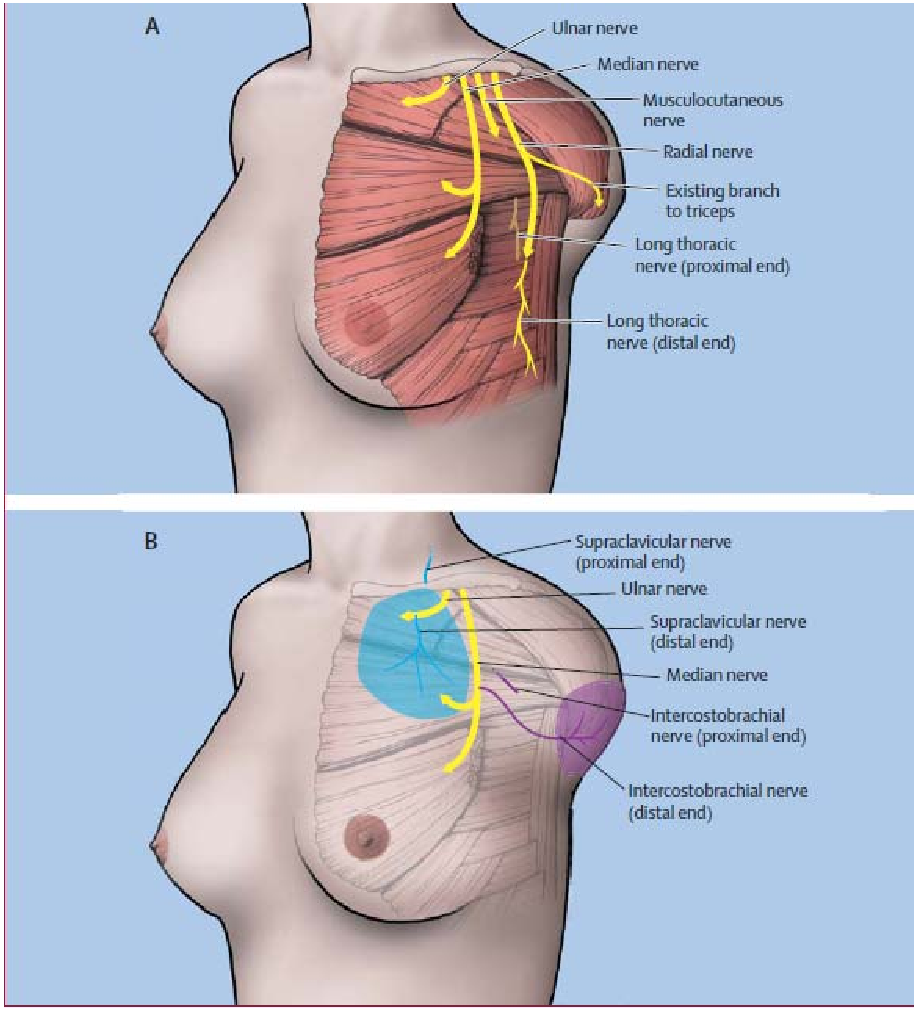


Shoulder subluxation treatment (top) and electrode position in shoulder (bottom)

BIONIC ARM

- Developed at the Rehabilitation Institute of Chicago in 2006
- Full arm prosthesis for upper limb amputees
- Prosthesis attached to the shoulder
- Loose ends of arm motor and sensory nerves re-innervated into chest using technique called targeted re-innervating
- Smarter control of prosthetic arm possible with regaining sense of touch: prosthetic arm moved with the movement of chest muscles and arm sensory nerves re-innervated into chest sensory nerves
- Two veterans already use the system

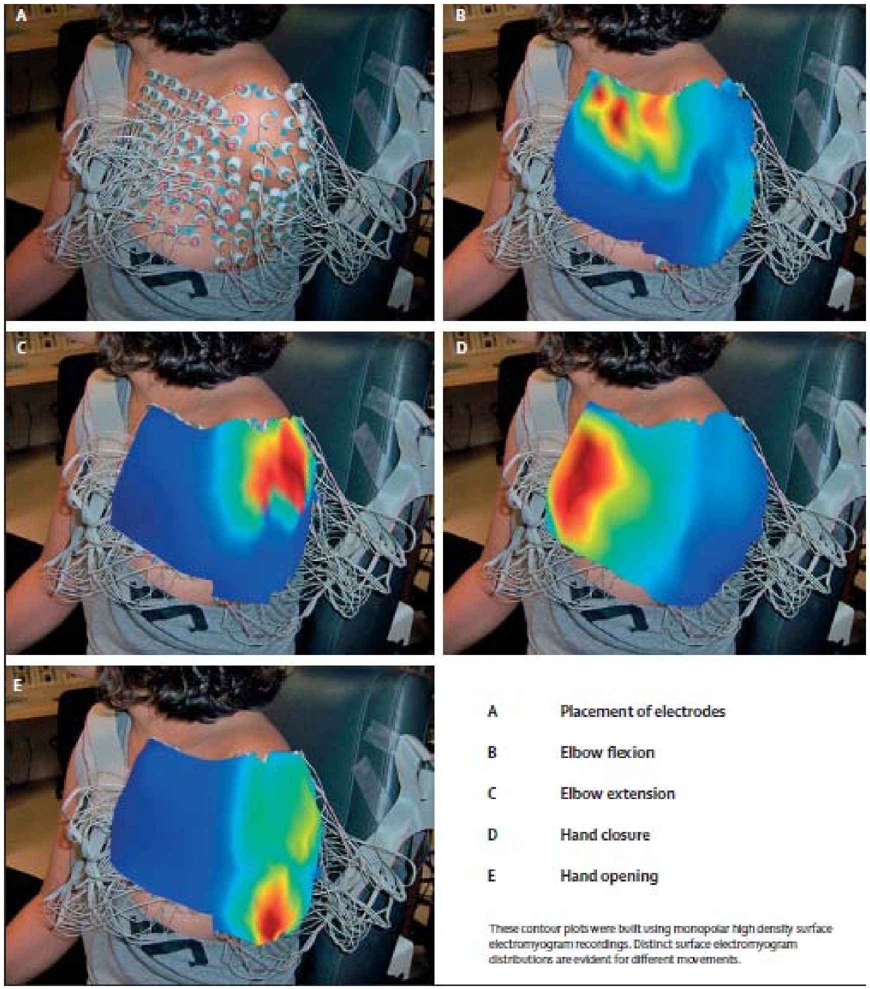
BIONIC ARM



Schematic of targeted motoric re-innervation (top) and targeted sensory re-innervation (bottom)

Kuiken, TA; Miller, LA ; Lipschutz, RD ; Lock, BA; Stubblefield, K; Marasco, PD; Zhou, P; Dumanian, GA; Targeted reinnervation for enhanced prosthetic arm function in a woman with a proximal amputation: a case study, LANCET, 369 (9559): 371-380 FEB 3 2007

BIONIC ARM



Maps of surface electromyogram amplitude for four different movements

Kuiken, TA; Miller, LA ; Lipschutz, RD ; Lock, BA; Stubblefield, K; Marasco, PD; Zhou, P; Dumanian, GA; Targeted reinnervation for enhanced prosthetic arm function in a woman with a proximal amputation: a case study, LANCET, 369 (9559): 371-380 FEB 3 2007

BIONIC ARM

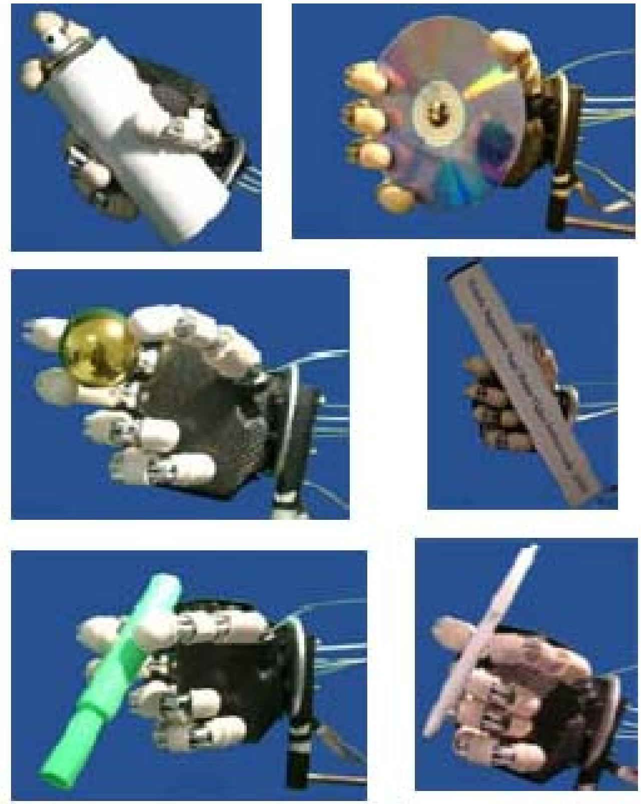
www.ric.org

Patients wearing their Bionic Arm prosthesis

CYBERHAND PROJECT

- European research project with institutions from Italy, Spain, Germany, Denmark
- Led by Scuola Superiore Sant'Anna, Pontedera, Italy
- Aims to develop a complex system implementing several functions:
- Efferent and afferent regeneration-type electrodes
- Implantable system for neural stimulation and recording
- Efferent and afferent telemetric links
- "Biologically-inspired" mechatronic hand
- Biomimetic sensors
- External unit for decoding patient's intentions and for prosthesis control
- System to deliver the cognitive feedback to the patient

CYBERHAND PROJECT



Prototype of CyberHand (left) and illustrations of implemented functions (right)

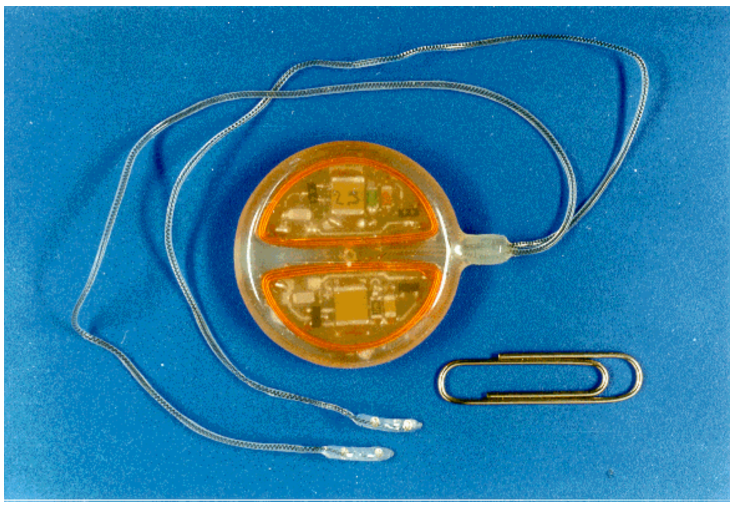
I-LIMB HAND

- Developed by Touch Bionics Inc. in 2008
- Uses myoelectric signals recorded from skin surface to control hand and fingers
- First upper limb prosthesis that has five individually powered fingers
- Implements four different grip patterns and two grasps
- Has different colour skin-like coverings

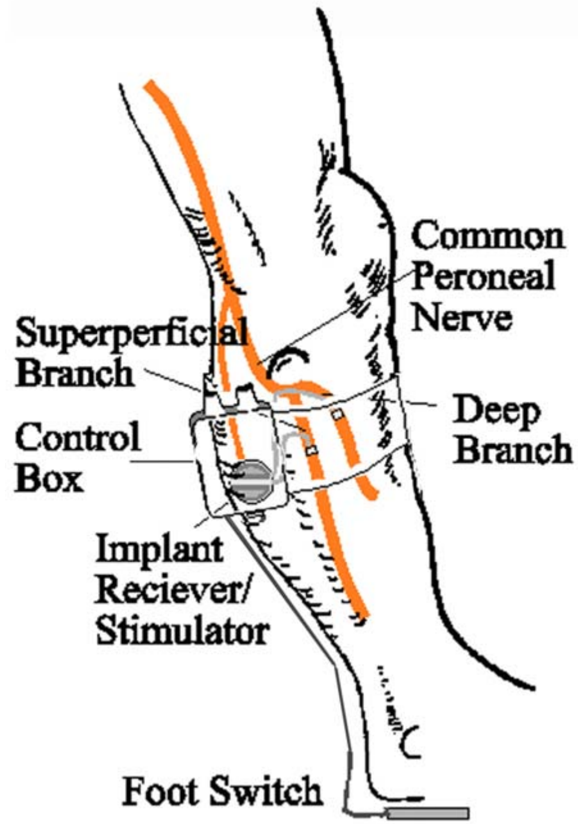
www.touchbionics.com

STIMUSTEP™
IMPLANTED DROPPED FOOT STIMULATOR

Strains the flexor muscles of the ankle when the foot is not on the floor.



Developed by the University of Twente and Roessingh Research. & Development in Holland in collaboration with the UK based company, Finetech-Medical Ltd.

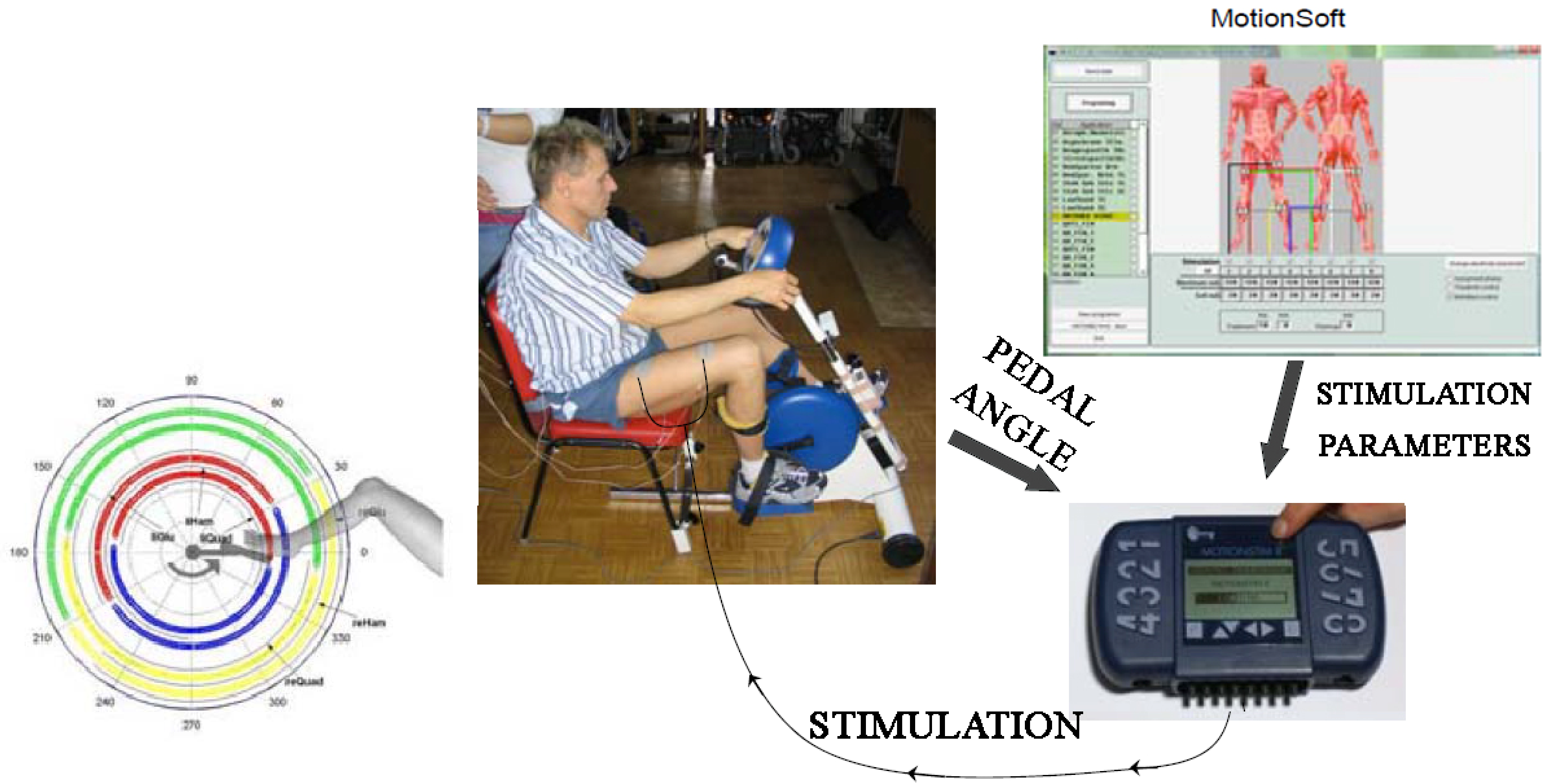


FUNCTIONAL ELECTRIC STIMULATION OF A PARAPLEG PATIENT

- 8 channel
- stimulation pattern making for every individual person
- changeable parameters:
  - Frequency: 1-200Hz (1Hz step)
  - Current: 0-130mA (1mA step)
  - Impulse width: 10us-1ms
  - Impulse type:
    - unipolar
    - bipolar
- Data gathering to SD card

PPKE ITK

FES CYCLING


MotionSoft
PEDAL ANGLE
STIMULATION PARAMETERS
STIMULATION

FES CYCLING

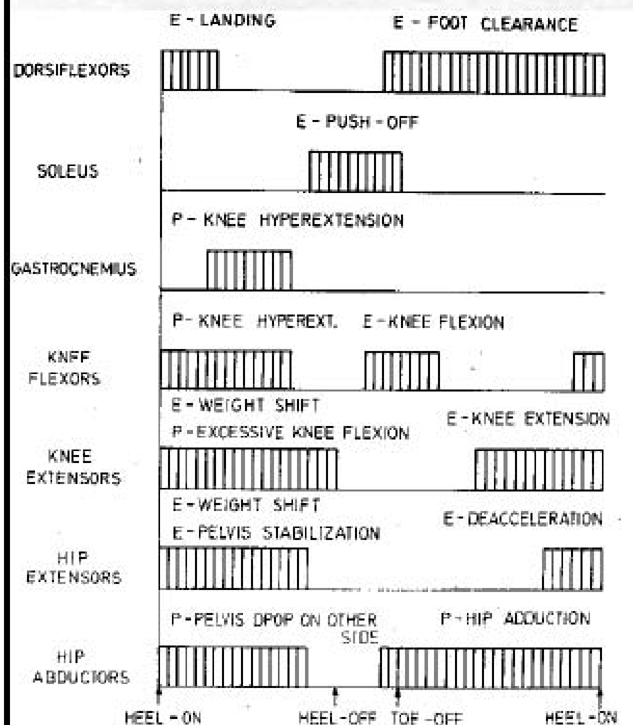
Muscle contraction is an electrochemical process that is stimulated by an electric current and propagated through nerve and muscle cells. When an electrical potential is applied between two electrodes placed on the surface of the body electric current passes from one electrode to the other through the tissue. If the tissues contain any muscles they will contract during the passage of the electricity and relax when it stops. By controlling the timing of the electrical impulses and the positioning of the electrodes it is possible to create various patterns of muscle contraction and relaxations that can enable a paralysed limb to perform a function.

Critical Events in Each Phase of Gait

Periods	Stance Period				Swing Period			
Tasks	Weight Acceptance		Single Limb Support		Swing Limb Advancement			
Phases	Initial Contact (0%)	Loading Response (0-10%)	Mid Stance (10-30%)	Terminal Stance (30-50%)	Pre Swing (50-60%)	Initial Swing (60-75%)	Mid Swing (75%-87%)	Terminal Swing (87-100%)
Temporal Events	Initial Contact	B: Initial Contact E: Opposite Foot-off	B: Opposite Foot-Off E: Heel-off (body leads foot)	B: Heel-of (body leads foot) E: Opposite inital contact	B: Opposie inital contact E: Foot-of	B: Foot-off E: Feet adjacent (knee extends)	B: Feet adjacent (knee extends) E: Tibia Vertical	B: Tibia vertical E: Initial contact
Critical Events	• Heel first initial contact	• Hip stability • Controlled knee flexion for shock absorption • Controlled ankle PF	• Controlled tibial advancement	• Controlled ankle DF with heel rise • Trailing l mb posture	• Passive knee flexion to 40° • Rapid ankle PF	• Max knee flexion (>60°)	• Max hip flexion (30°) • DF to neutral	• Knee extension to neutral

http://www.ece.mcmaster.ca/~ibruce/courses/EE3BA3_presentation04.pdf

Multichannel FES in hemiplegia



6-channel stimulator with graphical sequences, Trnkoczy et al, 1977

Optimal stimulation sequences for multichannel stimulation:
Stanič, Ačimović et al, 1974, 1978

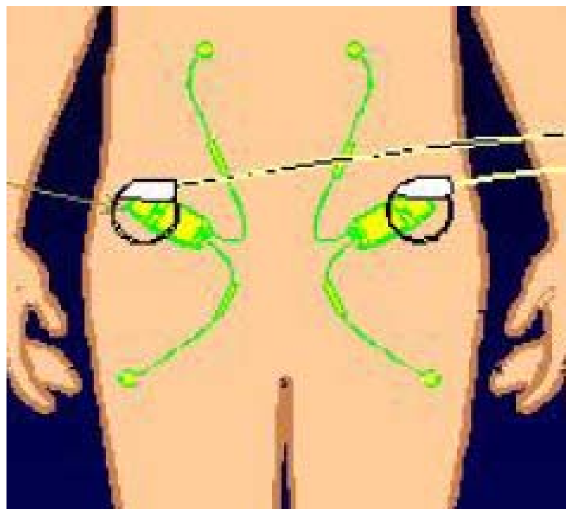
May, 2003 Paul Meadows – Advanced Bionics

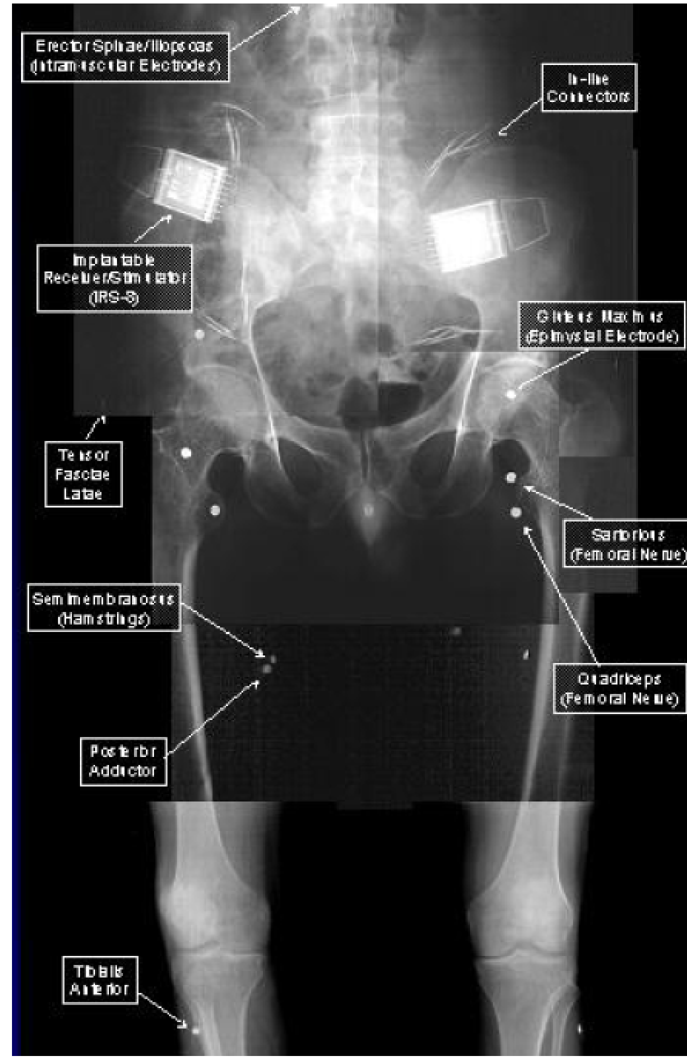
WALKING MOBILITY SYSTEM

Implantable Reciever Stimulator
External Control Unit
Clinical Interface

Target Muscles:

Vastus lateralis
Gluteus Maximus
Semimembranosus
Erector Spinae
Tibialis Anterior
Iliopsoas
Sartorius
TFL





Cleveland FES Center

Dual Implant Walking System

IMPLANTED PATIENTS

SWISS FEDERAL INSTITUTE OF TECHNOLOGY

Dept. of Information Technology and Electrical Engineering

FES Roller

http://control.ee.ethz.ch/~ncg/previous_projects/neuroprostheses.php


Erigo®
HOCOMA AG
www. hocoma.ch
Tilt Table with Integrated Robotic Stepping System

ERIGO

TILT TABLE WITH INTEGRATED ROBOTIC STEPPING SYSTEM

Movement therapy and loading of the legs are important elements in the rehabilitation of bed-ridden neurological patients. The development of a tilt table with an integrated stepping system provides physicians and therapists with the opportunity to do intensive movement therapy of legs combined with verticalization. Accordingly, the Erigo allows two approved forms of therapy to be accomplished at the same time. The Erigo therefore supports and facilitates the mobilization of bed-ridden patients.

Rehabilitation technique, to fortificate the muscles using the whole body.

LOKOMAT

BODY WEIGHT SUPPORTED TREADMILL TRAINING

The Lokolift is an electronically controlled body weight support system for treadmill training that allows a constant and precise body weight support. The user-friendly patient handling through the user interface allows the therapist to change the weight support of the patient without having to stop the training. Based on a closed loop control, the weight support is measured exactly, registered by the computer and sent to the drives for the adjustment of the weight support. The integrated drives provide a low-inertia movement and allow a physiological gait that supports a successful rehabilitation process.

FUTURE DIRECTIONS

LOWER EXTREMITY SYSTEMS

- Ambulation
- Closed loop control for balance and posture
- New fundamental aproaches to interfacing with the nervous system
- Incomplete spinal cord injury for ambulation
- Combination therapies

REQUIREMENTS OF A PRACTICAL FES SYSTEM
(electrical orthosis)

1. **Should be Simple to put on and put off (Don and Doff)**
   This is *vital* as it will to a large extent determine the amount of use and how much the patient will get out of their system. This will limit the number of connections and leads that are external to the body.

2. **Function must be Relevant to the User**
   Some functions seem to have 'obvious' relevance to anyone. But even a function like standing may be of very little use to paraplegic in adapted accommodation.

3. **System must Consistently Provide the Desired Function**
   The electrical orthosis must provide the desired function under a range of working conditions both external, e.g. location, and internal, e.g. electrode positioning.

4. **The System must include the User**

The condition of the user's muscles, bones, ligaments and cardiovascular performance are of vital importance in ensuring that the required function can be attained safely and repeatably.

5. **User must be Aware of the Limitations of the System**

It must be ensured that the user has realistic expectations. With open-loop systems the user should understand the problems that may occur, eg with fatigue, and realise how these will affect the performance of the system.

6. **User must Understand Committment Required to Maximise the Benefits**

Generally a long term commitment to a training program (>3 months for "sit to stand") is required.

7. **System should Ideally be Fail Safe**

At present this is not always possible, e.g. how does one make an electrical stimulation only standing system fail safe! With open-loop systems the user should possess the strength/control to cope in the event of a systems failure. The degree to which failure is dangerous depends on the system - but the possibility of failure needs to be carefully considered in programming the stimulator.

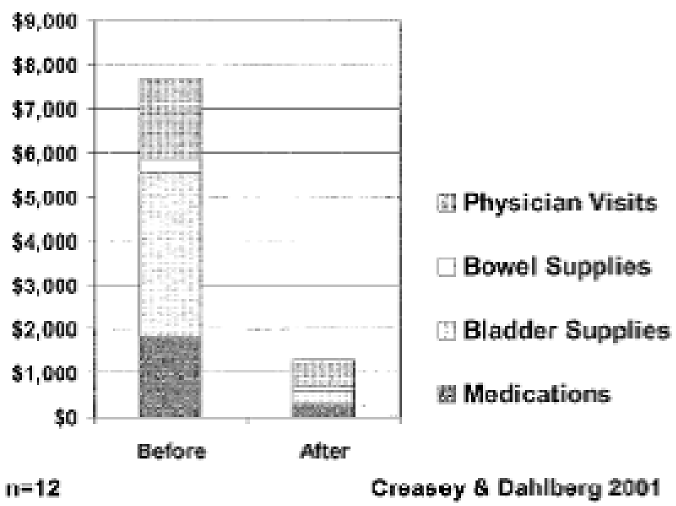
A practical electrical orthosis consists of two components. First, a reliable and adaptable system capable of responding to changing parameters. Second, a trained user with the necessary motivation.

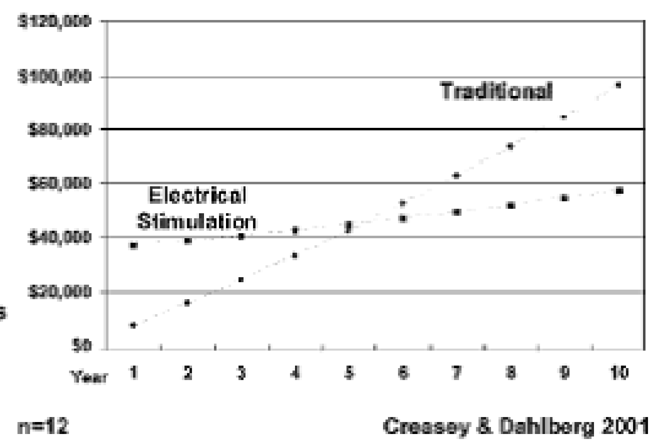
Both parts are of equal importance!

BOVEL CONTROL

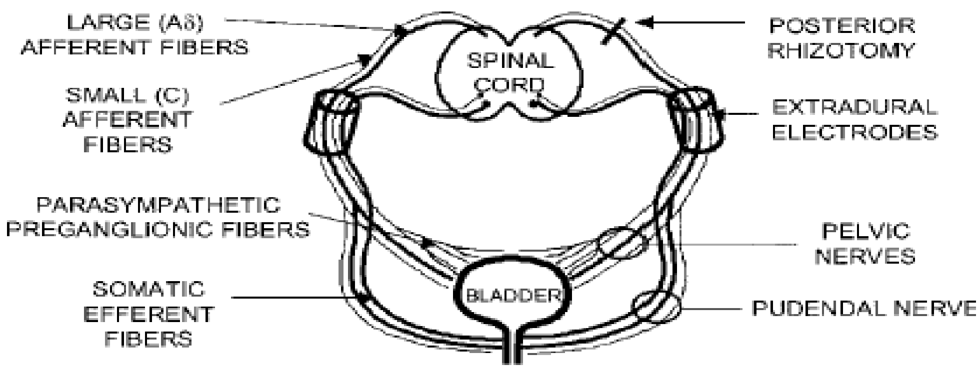
Annual and cumulative costs of bladder and bowel care after spinal cord injury are reduced after combined sacral dorsal root rhizotomy and implantation of a sacral anterior root stimulator for bladder emptying. Cumulative costs of bladder and bowel care after spinal cord injury: comparison of traditional and electrical stimulation treatment.

Jezernik et al., Neurological Research, 2002, 24: 413-430.





BLADDER INNERVATION



Systems	Spinal segment	Periferial descending	Stimulus effect
Parasympatic	S2 - S4	Nervus pelvicus	Bladder depleteing muscle contraction. Inner sphincter yielding (the bladder deplete).
Sympatic	Th11 - L2	Nervus hypogastricus	Bladder depleteing muscle yields. Urethra contraction. Inhibition of the parasimpatic ganglions (retention)
Motoric	S3 - S4	Nervus pudendalis	Urethra spinchter contraction.

- When the thoracic spinal cord is injured (crosswise lesion), first complete retention, and then automatical bladder develops: there is no involuntary bladder, but the bladder automatically eliminated, if it reaches a limit, but the excretion is not perfect.

- If the sacral spinal cord (S2-S4) is damaged, the wall of the bladder becomes atonical, therefore a widening of the bladder and urinary retention develops, with incontinence (autonomous bladder).

- If the sensory part of the sacral reflex arc is damaged, then the need of urination and the bladder reflex ceases.

- The bladder saturates and incontinence (ischuria paradoxa) develops.

- Reflex incontinence: complete spinal cord lesion, there is no sensory stimulus
- Pressure incontinence: Detrusor instability,
- Stress incontinence: pl. effect of cough onset of urination

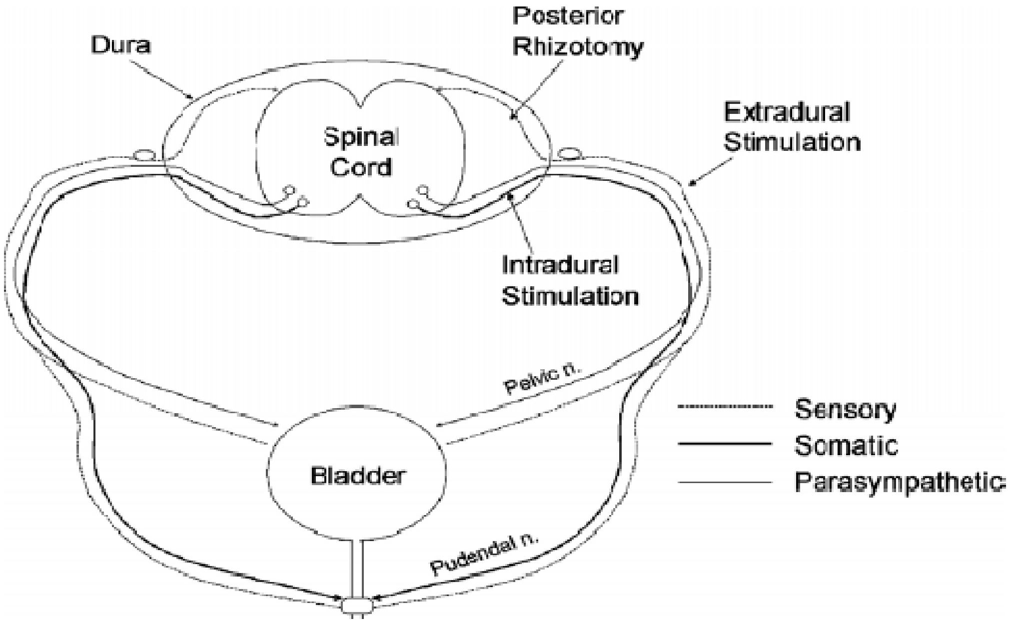
- **Sacral anterior root stimulation (SARS):** thick fibers to the bladder sphincter, thin preganglionar parasympathetic fibers to the bladder.

  Solution: repetitiv short stimulus series

- **Extradural stimulation:** mostly after posterior root cutoff
- **Neuromodulation:** (Medtronic Interstim)

REGULATE THE BLADDER OPERATION OF INTERVENTION

Bladder innervation, posterior rhizotomy site (transection of sacral dorsal roots to abolish bladder hyper-reflexia and detrusor–sphincter dyssynergia), and location of extradural electrodes for sacral anterior root stimulation to produce bladder contractions and bladder emptying.

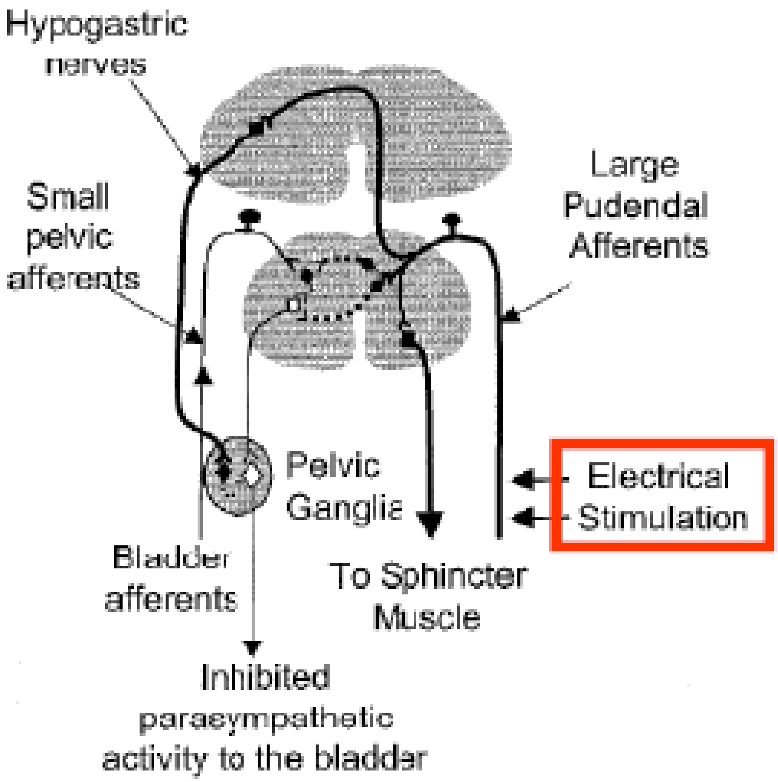


http://www.ece.mcmaster.ca/~ib

THE SPINAL REFLEX INFLUENCE WITH THE ELECTRICAL STIMULATION OF N. PUDENDALIS

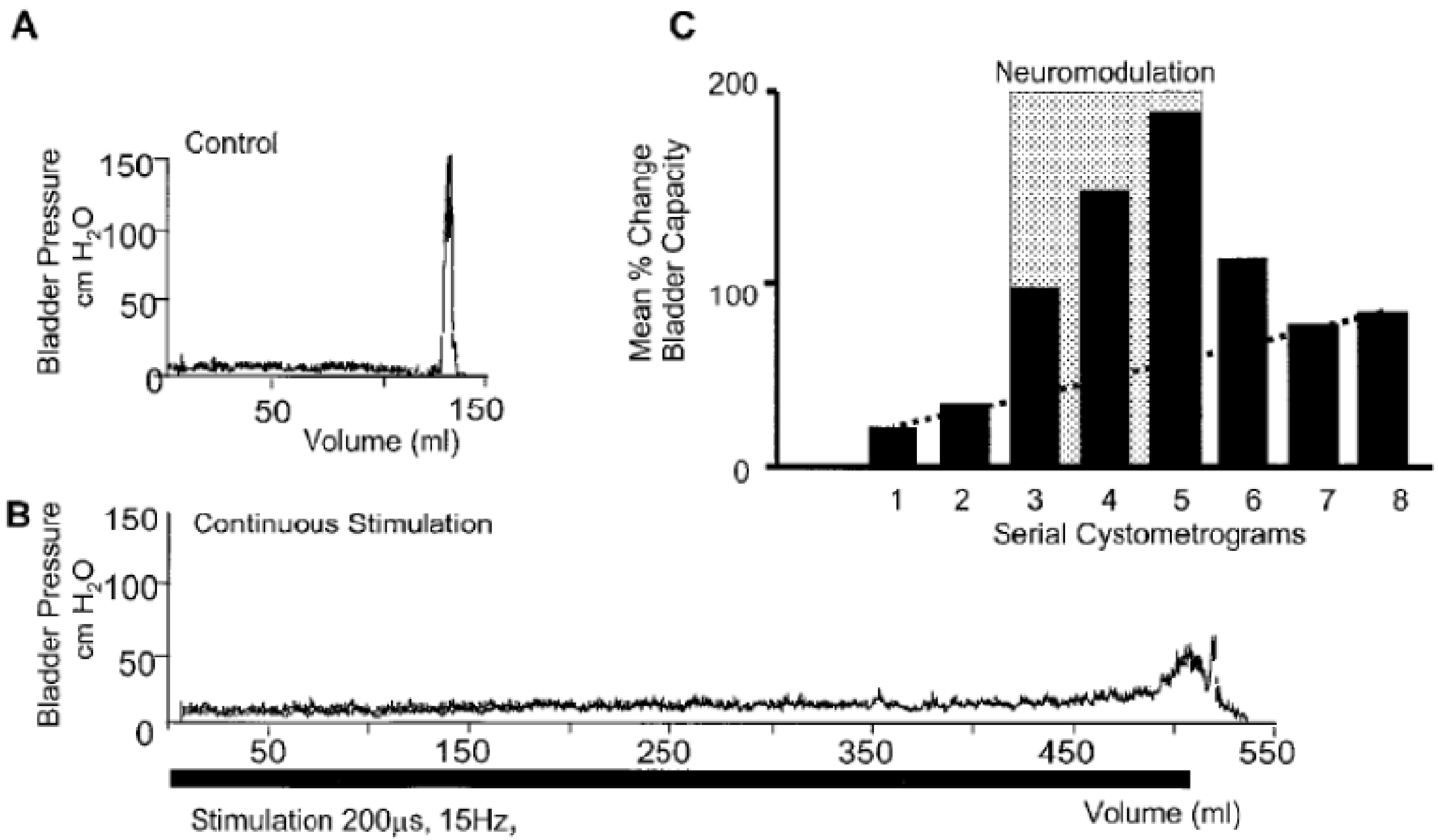
Spinal reflex pathways controlling the lower urinary tract.

Electrical stimulation of large pudendal afferents inhibits parasympathetic activity to the bladder. Such stimulation can be achieved by implanted electrodes (sacral afferent stimulation) or by transcutaneous electrical stimulation (anal and vaginal plug electrodes, dorsal penile or clitorial electrodes).



Jezernik et al., Neurological Research, 2002, 24: 413-430.

REDUCED BLADDER CAPACITY DEMONSTRATED IN A CONTROL CYSTOMETROGRAM (CMG) OF A SPINAL CORD INJURED PERSON

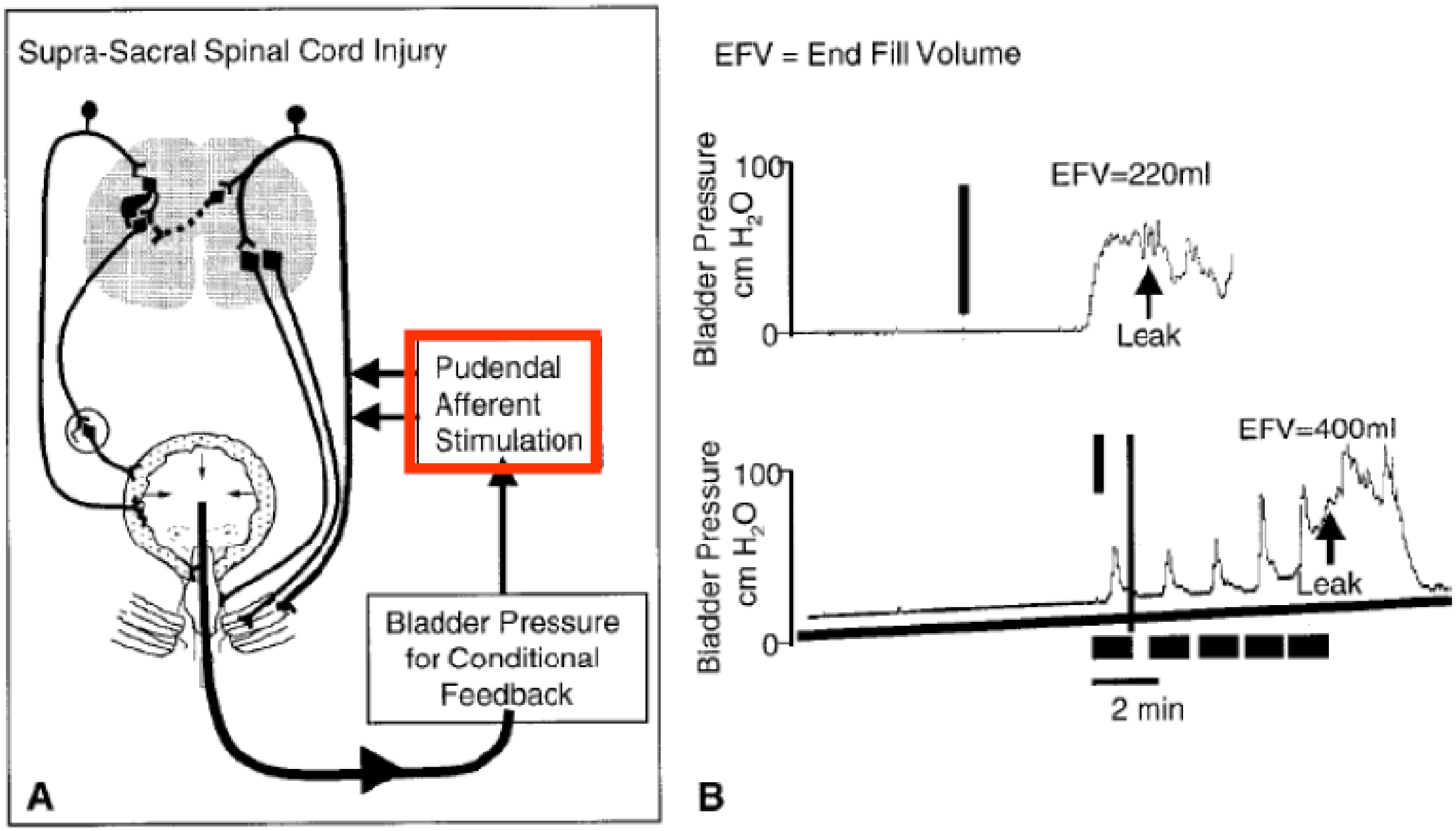


Jezernik et al., Neurological Research, 2002, 24: 413-430.

REDUCED BLADDER CAPACITY DEMONSTRATED IN A CONTROL CYSTOMETROGRAM (CMG) OF A SPINAL CORD INJURED PERSON

- **A:** Control,
- **B:** Increase in the bladder volume during a cystometry performed during a continuously applied electrical stimulation (15 Hz stimulation frequency, 200 μsec pulse width).
- **C:** Mean change in the bladder capacity obtained during a series of cystometries. Cystometrograms that were measured with neuromodulation switched on are indicated in the middle of the graph. The carry-over effects of neuromodulation can be observed.

SCHEMATICS SHOWING THE PRINCIPLE FOR CONDITIONAL NEUROMODULATION



Jezernik et al., Neurological Research, 2002, 24: 413-430.

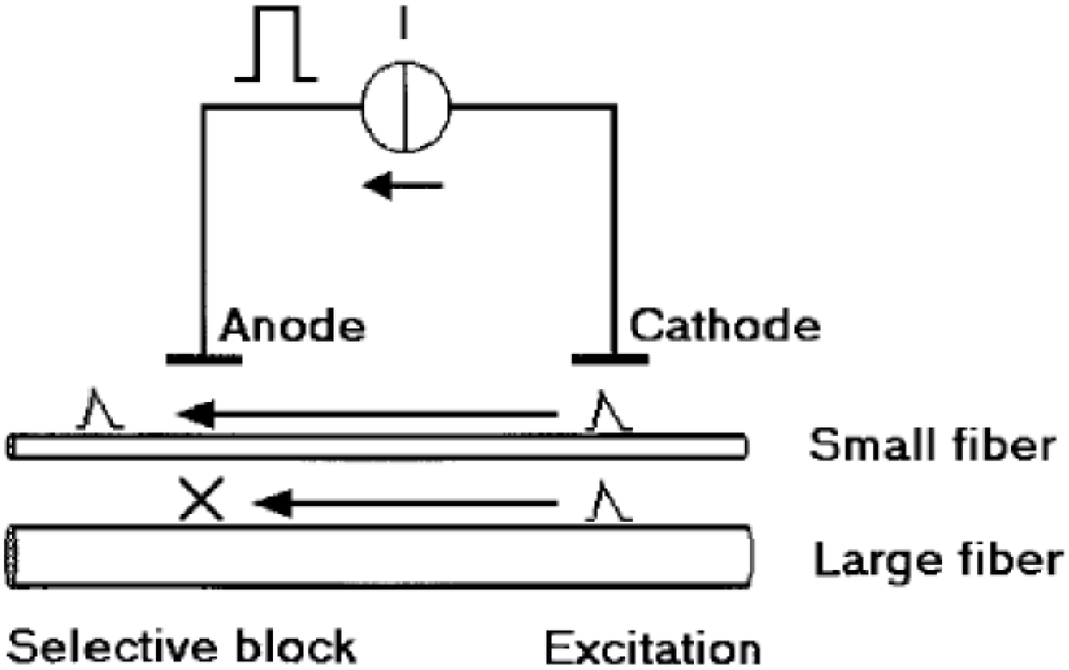
SCHEMATICS SHOWING THE PRINCIPLE FOR CONDITIONAL NEUROMODULATION

- **A:** Bladder pressure is sensed and the bladder pressure signal used to detect bladder contractions and to trigger pudendal afferent stimulation via dorsal penile electrodes only when needed, i.e. if there is no contraction there is no need for stimulation.

- **B:** Top panel shows a cystometrogram without neuromodulation, and the bottom panel shows a cystometrogram during a conditional neuromodulation (switched on/off based on the bladder pressure signal). Urine leakage occurred at a higher bladder volume when the conditional neuromodulation was applied.

PRINCIPLE OF SELECTIVE SMALL FIBER ACTIVATION

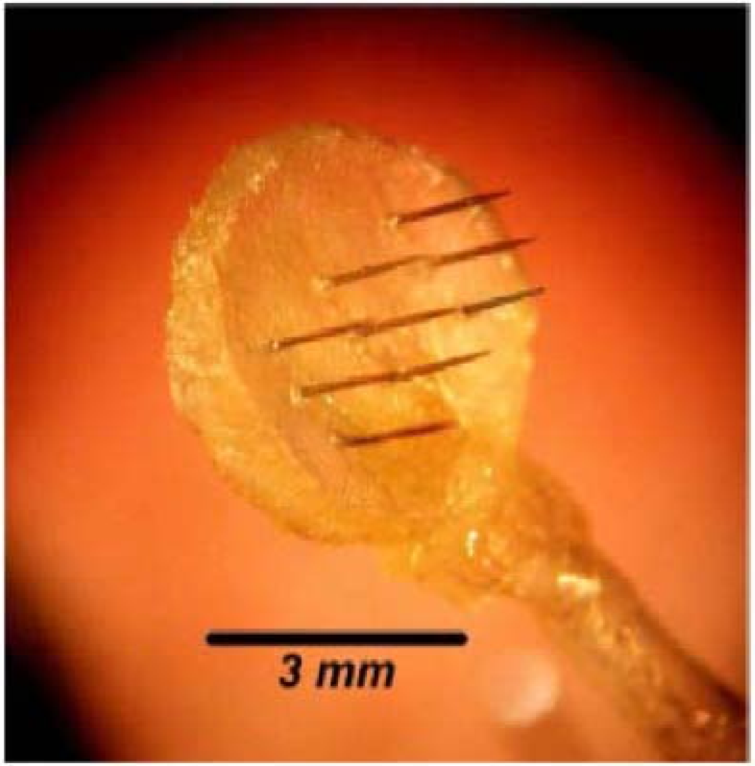
Near the cathode both small and large fibers are excited to produce action potentials (APs) which will propagate along the fibers. Near the anode the fiber membranes are hyperpolarized. If sufficiently hyperpolarized, an AP cannot pass the hyperpolarized zone, i.e. the fiber is blocked. Large fibers can be blocked at lower currents than required to block the smaller ones, which enables a selective fiber blockage.



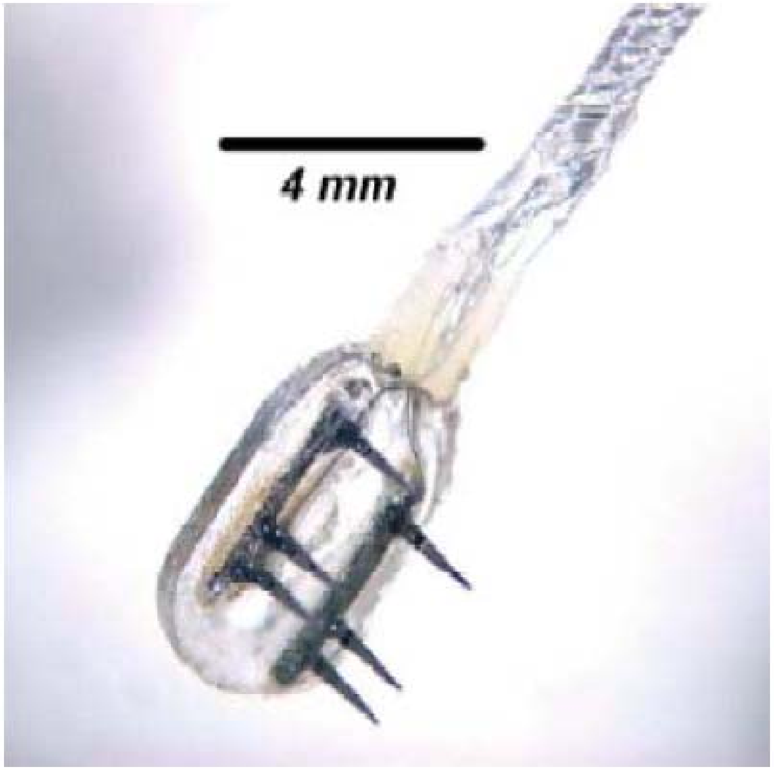
Jezernik et al., Neurological Research, 2002, 24: 413-430.

SPINAL CORD STIMULATION RESEARCH METHOD

MULTICONTACT ELECTRODE FOR SACRAL SPINAL CORD STIMULATION



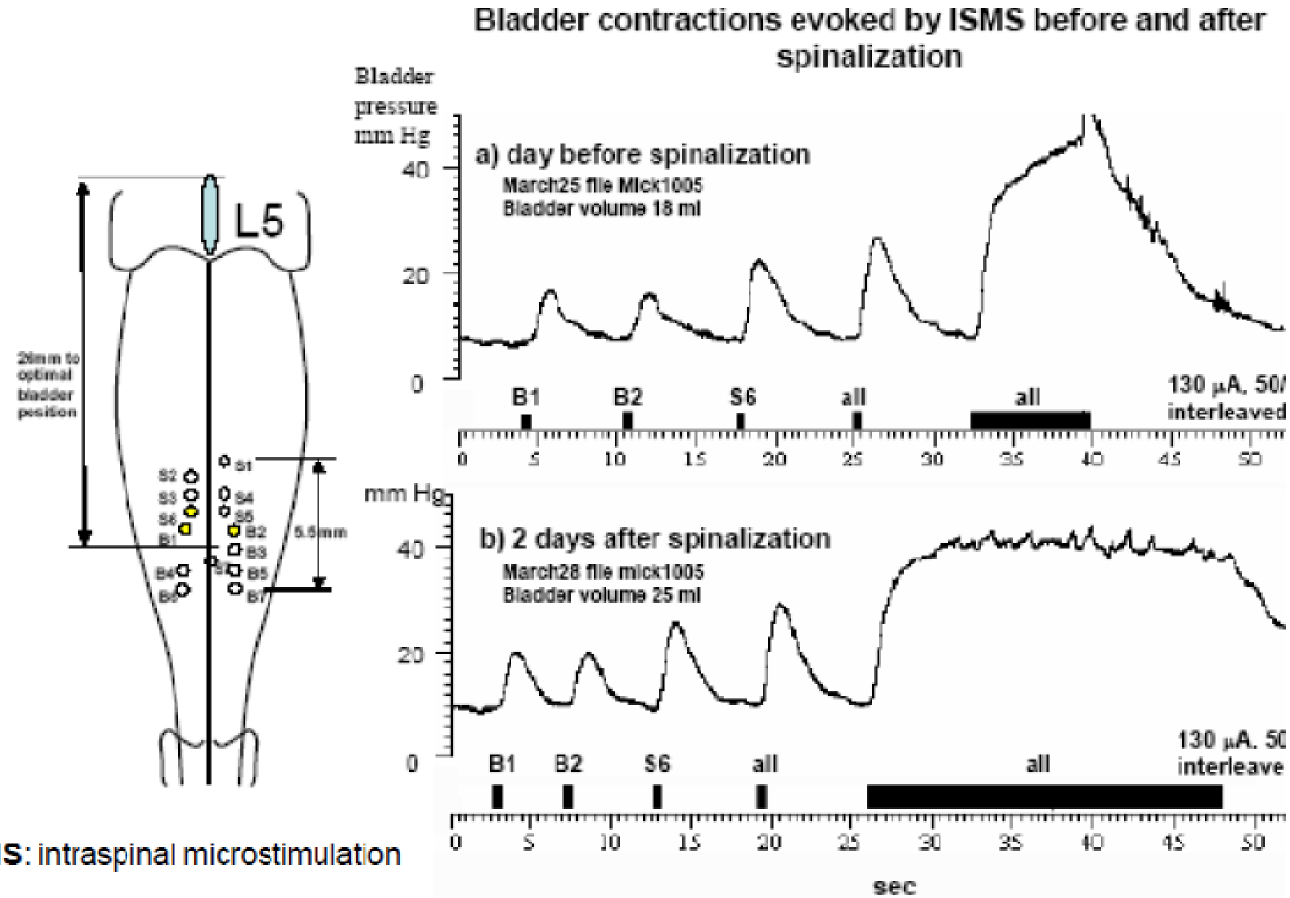
Array of discrete iridium microelectrodes



Array of multisite silicone probes

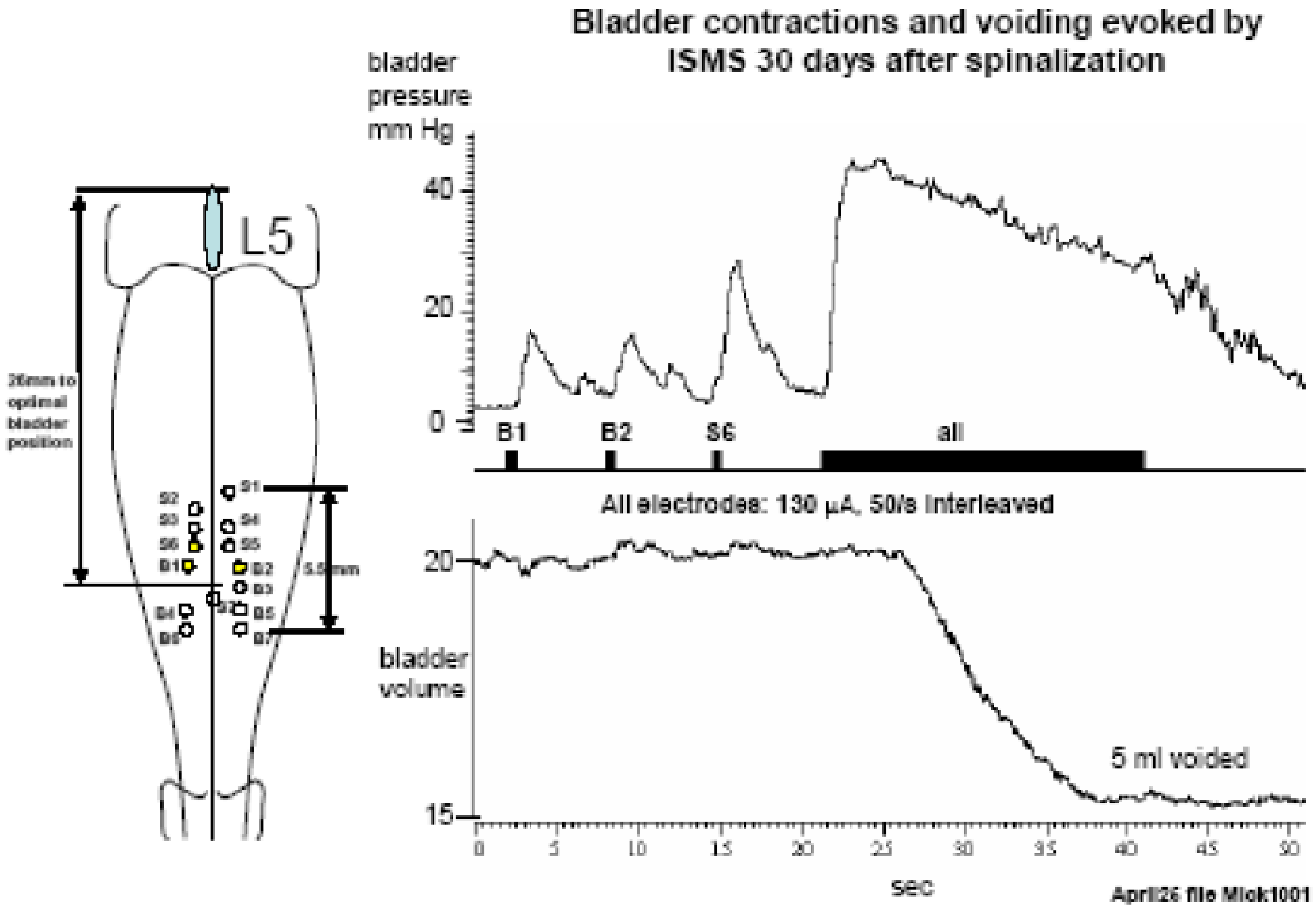
http://www.ninds.nih.gov/qpr/fes/N01-NS-1-2340QPR06.pdf

CAT BEFORE AND AFTER SPINAL CORD CUTOFF

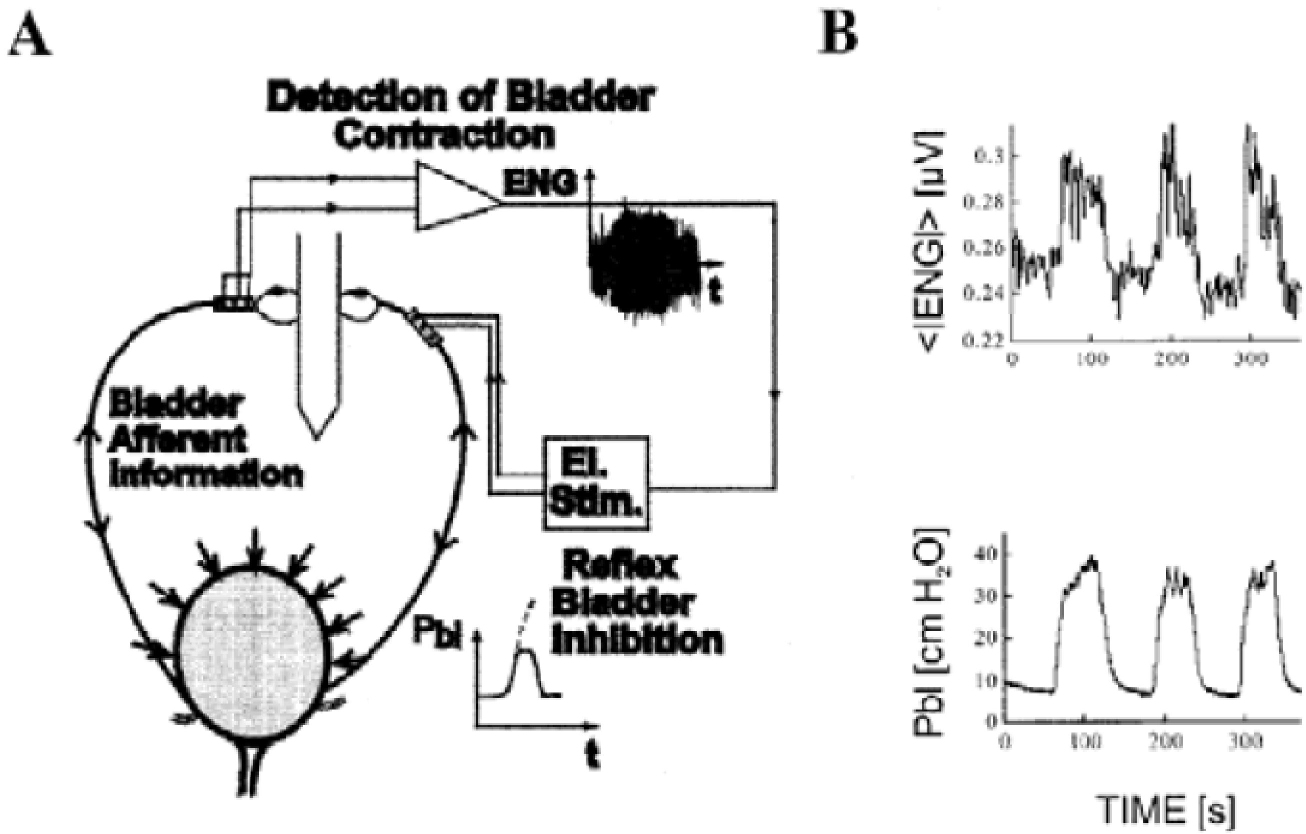


ISMS: intraspinal microstimulation

STIMULATION INDUCED URINATION IN ALERT CATS WITH SPINAL CORD CUTOFF



Neuroprosthesis for afferent nervous activity



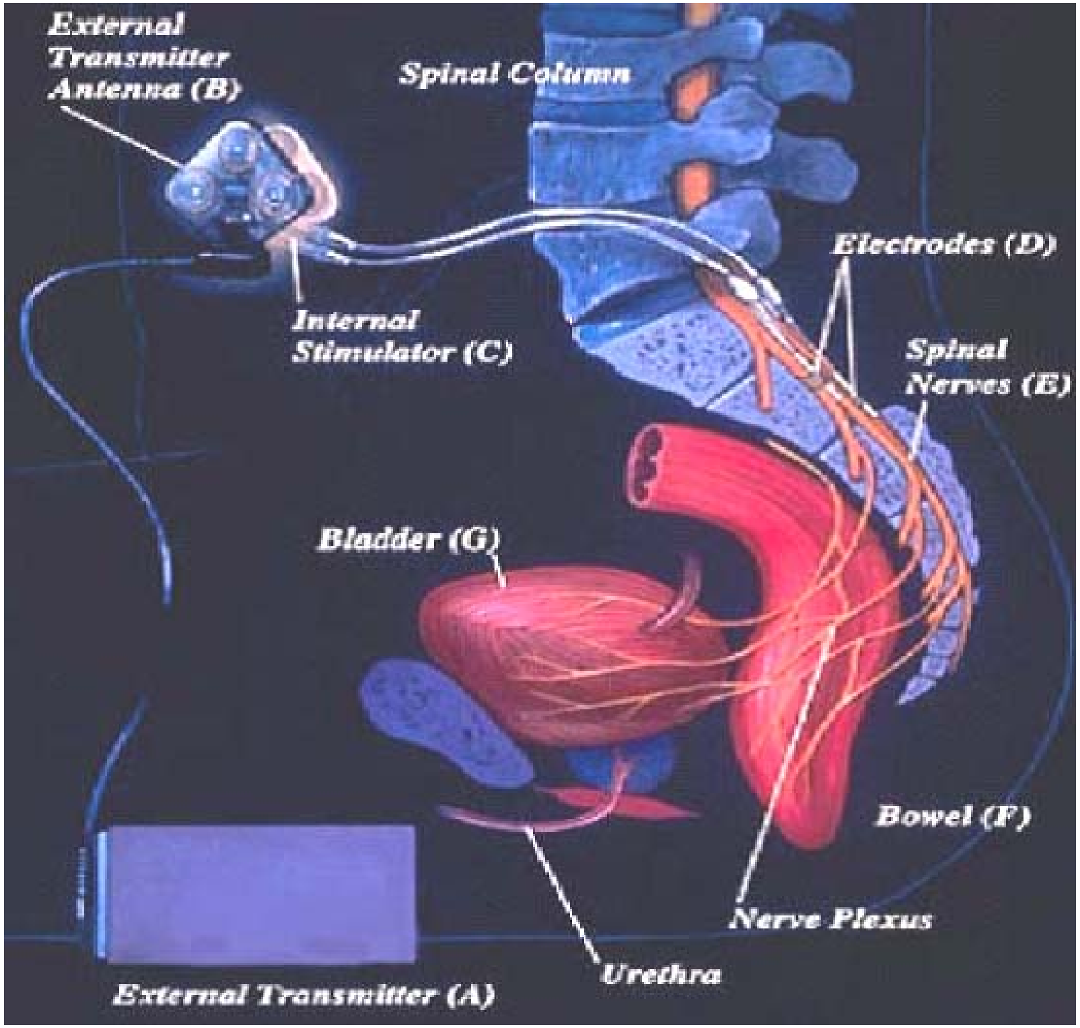
Jezernik et al., Neurological Research, 2002, 24: 413-430.

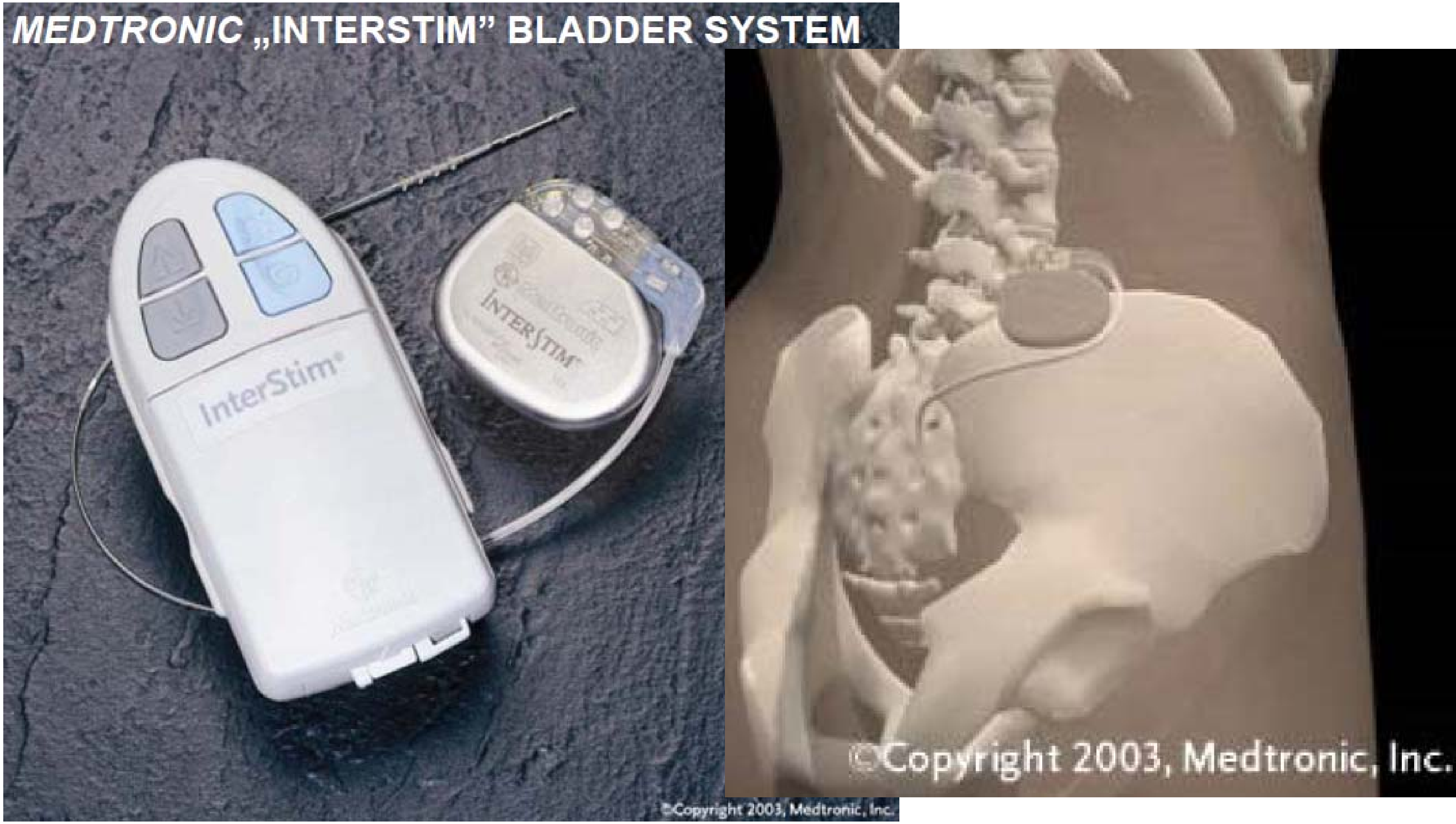
NEUROPROSTHESIS FOR AFFERENT NERVOUS ACTIVITY

- **A:** A neural prosthesis that would detect overactive bladder contractions by recording and processing of the bladder afferent nerve traffic, and that would after detection inhibit the bladder and prevent high bladder pressures. The latter could be achieved by conditional stimulation of the bladder inhibitory nerves.

- **B:** Actual bladder afferent nerve signal (top panel) recorded during three bladder contractions (corresponding bladder pressure is shown in the bottom panel). Bladder contractions can be detected from the increases in the ENG signal

- The Finetech Medical **VOCARE Bladder System** consists of the following subsystems:
- The **Implanted Components** include the Implantable Receiver-Stimulator and Extradural Electrodes.
- The **External Components** include the External Controller, External Transmitter, External Cable, Transmitter Tester, Battery Charger and Power Cord.
- The **Surgical Components** include the Surgical Stimulator, Intradural Surgical Probe, Extradural Surgical Probe, Electrode Test Cable, and Silicone Adhesive

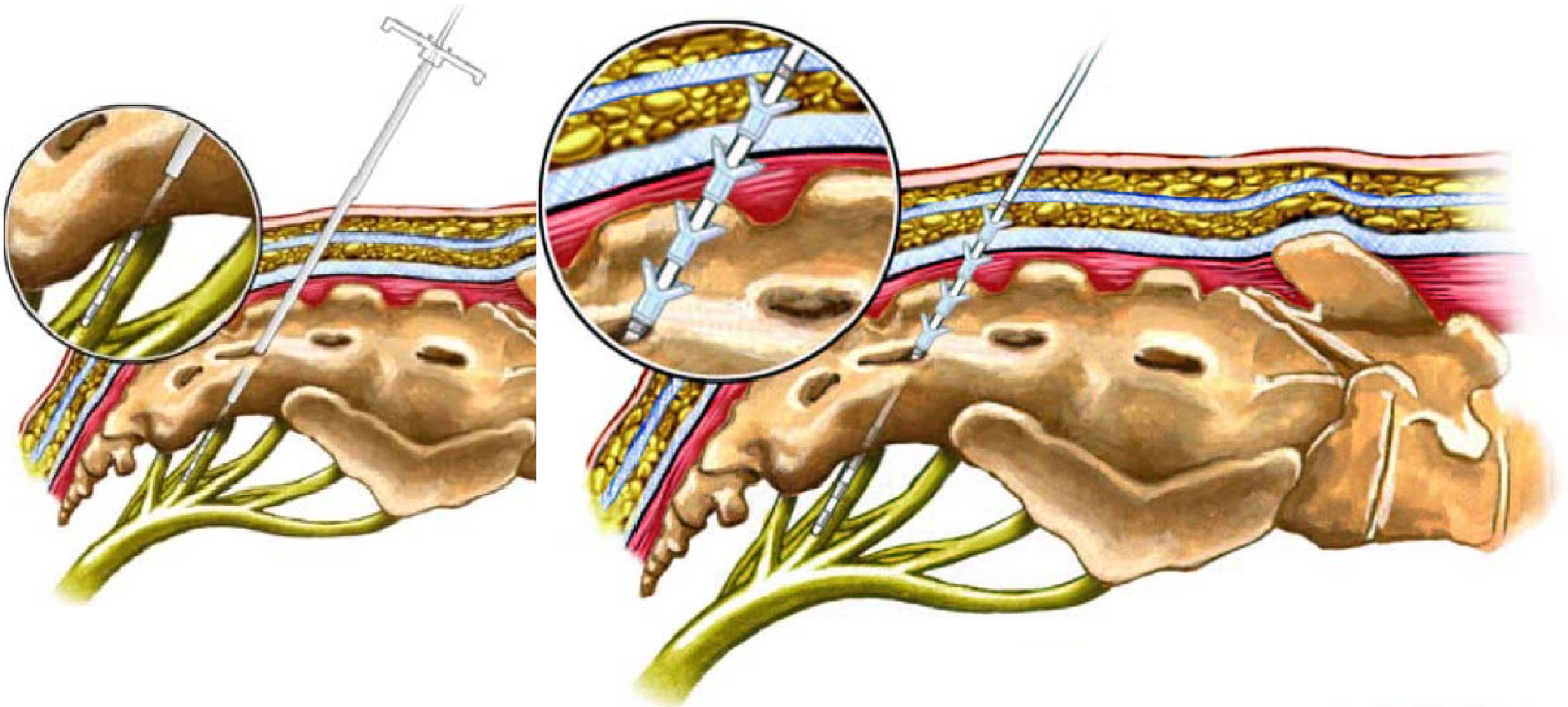



MEDTRONIC „INTERSTIM” BLADDER SYSTEM
InterStim®
INTERSTIM
©Copyright 2003, Medtronic, Inc.
©Copyright 2003, Medtronic, Inc.

The **INTERSTIM BLADDER SYSTEM** is a radiofrequency powered motor control neuroprosthesis, which consists of both implanted and external components.

The **VOCARE BLADDER SYSTEM** delivers low levels of electrical stimulation to a spinal cord injured patient's intact sacral spinal nerve roots in order to elicit functional contraction of the muscles innervated by them.

MEDTRONIC INTERSTIM SYSTEM



Procedure and location of the permanent wire electrode placement for the Medtronic Interstim system. The electrode is usually placed into the sacral foramina S3.

www. medtronic.com

REFERENCES AND FURTHER READING

- Benton L. A., Baker L. L., Bowman B. R., Waters R. L., Functional Electrical Stimulation: A Practical Clinical Guide (2nd Edition), Rancho Rehabilitation Engineering Program. Rancho Los Amigos Medical Centre, 1981.
- Chapin J. K., Moxon K. A. (eds.), Neural Prostheses for Restoration of Sensory and Motor Function, CRC Press, 2001.
- Zhou D., Greenbaum E. (eds.), Implantable Neural Prostheses 1 – Devices and Applications, Springer, 2009.
- http://www.ece.mcmaster.ca/~ibruce/courses/EE3BA3_presentation04.pdf
- http://www.ece.mcmaster.ca/~ibruce/courses/EE3BA3_2005/EE3BA3_presentation6.pdf
- http://www.ece.mcmaster.ca/~ibruce/courses/ECE795_2008/ECE795_lecture09.pdf
- http://www.ece.mcmaster.ca/~ibruce/courses/ECE795_2008/ECE795_lecture10.pdf

REVIEW QUESTIONS

- What is functional electrical stimulation (FES)?
- What are the most common origins of paralysis?
- For which stimulation is charge production threshold higher: nerve or muscle stimulation?
- What is the effect of stimulus frequency on fatigue?
- List and characterize three upper limb FES systems!
- List and characterize three lower limb FES systems!
- What is body weight supported treadmill training?
- What are the requirements of a practical FES system?
- How do FES systems for bladder function restoration work?