Electrostimulation: Outline

- Introduction
  - Basic principle (Depolarization, hyper polarization, etc.)
  - Stimulation types (Magnetic and electrical)
  - Main stimulation parameters (Current, voltage, etc.)
  - Characteristics (Muscular fatigue, accommodation)
- Technologies and architectures
  - Stimulator, electrodes, system flexibility, reliability, security, etc.
- Main applications
  - Pacemaker, Cochlear implants, DBS
  - Respiration, Vestibular prosthetics, etc.
  - Urinary bladder dysfunctions
  - Visual implant

Electrostimulation: Urinary bladder dysfunctions

- Introduction
  - Peripheral neural stimulators
- Neurostimulation vs neuromodulation
- Methods of neurostimulation
  - Detrusor muscle, Sacral roots
- Neural Interruption Techniques
  - Rhizotomy, ...
- Electrical blocking techniques
  - Anodic blockade
  - High Frequency Blockade
- Polystim neurostimulation system
  - Selective sacral stimulation
  - Experiments and History
Electrical neural stimulation: Facts

- Myelinated nerves respond to electrical stimulation more readily than non-myelinated fiber and larger fibers more readily than smaller ones.
- Smooth muscles differ from skeletal muscles. Excitation and contraction may spread from fiber to fiber in smooth muscle. The response to electrical stimulation is slower and thus, a sustained contraction can be maintained by lower stimulating frequencies.
- Autonomic nerves supplying smooth muscles are of smaller diameter than the somatic nerves and are therefore less readily stimulated than the larger myelinated fibers supplying skeletal muscles.
- If an applied stimulus is increased very slowly, the nerve threshold also increases due to accommodation and stimulation may not occur.
- Fatigue occurs in the muscle contractile mechanism and probably at the neuromuscular junction, but not in the nerve fibers.

Neurostimulation of the urinary bladder: Background

- Pelvic nerve stimulation studies performed in cats and dogs. Ingersoll, 1955.
- Sacral anterior roots stimulator (now known as Finetech-Brindley), was first tested in animal studies in 1969 and implanted first in humans in 1978.
Methods of neurostimulation of the urinary tract

Direct detrusor stimulation
- The advantages were: simplicity of the electrode placement procedure, high specificity of the target organ, and direct application in lower motor neuron lesions.
- However, the effects were not durable due to electrode displacement, production of fibrosis, erosion into the bladder, pain associated with stimulation, and the need for current densities above the physiological levels.

Spinal cord stimulation
- Spinal cord stimulation of the sacral segment was attempted in order to achieve bladder evacuation.
- The current density used was less than in direct detrusor stimulation. Jonas, 1975.
- Recently, microstimulation of the parasympathetic nucleus within the spinal cord has been shown to be feasible for the induction of selective bladder contraction without activation of the sphincteric muscle.

Pelvic nerve stimulation
- Pelvic nerves do not tolerate stimulation for long periods. Pudendal nerves are activated and therefore, outflow resistance is augmented, pain may result from hypogastric nerves and the bladder nerves may be permanently damaged.
- Failure of clinical application may be attributable to detrusor-sphincter dyssynergia (DSD) which was so high that bilateral pudendal neurectomy was proposed to overcome the outlet resistance.

Sacral nerve root stimulation
- Sacral roots (S3 in humans) have been identified as the most appropriate structures to induce bladder contractions.
- Stimulation of the ventral roots yielded responses similar to those achieved by stimulation of the entire roots.
- Advantages of this technique are stable fixation of the electrodes within the spinal canal and limit spread of current.
- DSD remains the major problem of sacral root stimulation.
Sacral nerve root stimulation (Continued)

- The ventral sacral roots are composed of both large somatic (A-α) fibers which innervate the pelvic floor and external urethral sphincter through the pudendal nerves and small preganglionic parasympathetic (A-δ) fibers which innervate the detrusor smooth muscle via the pelvic nerves.
- Large nerve fibers have lower stimulation threshold compared to small ones. Activation of small fibers, which requires higher current, results in simultaneous excitation of the large fibers with subsequent sphincteric contraction.

Improving the stimulation selectivity

- Dorsal Rhizotomy: consists of severing afferent sacral nerve roots that are involved in pathological reflex arc in suprasacral spinal cord lesions;
- Anodal Block: consists of interrupting action potentials propagation by hyperpolarization of the nerve membrane using an anode electrode;
- High-frequency block: may stop the propagation of nerve action potentials, may maintain the motor end-plate (neuromuscular junction) in a refractory status, and/or may fatigue the target muscle.

Methods of neurostimulation of the urinary tract

Neural Interruption Techniques: Dorsal Rhizotomy

Dorsal rhizotomy - consists of interrupting afferent sacral neurones that form a reflex arc in suprasacral SCI. There is Intradural or extradural dorsal rhizotomies. Rhizotomy is combined with implantation of a sacral anterior root stimulator.

Advantages

- Abolition of detrusor hyperreflexia, resulting in increased bladder capacity and compliance, reduced reflex incontinence, and protection of the upper urinary tracts from ureteric reflux and hydronephrosis.
- Reduction of sphincter dyssynergia, improving flow, and prevents autonomic dysreflexia arising from distension or contraction of the bladder or bowel.

Disadvantages

- Abolition of reflex erection, reflex ejaculation, reflex defecation, and sacral sensation, if present.

Neural Interruption Techniques: Pudendal neurotomy

Pudendal neurotomy - selective sectioning of somatic fibers results in low pressure voiding with negligible urethral resistance. However, the surgical approaches requires extensive operative exposure to trace the root into the pelvis, which makes these techniques undesirable.

Sacral rootlet deafferentation - Intradural dissection and stimulation of different rootlets of Sacral root nerves.

- Selective stimulation of these rootlets on an acute basis resulted in bladder contraction with a relatively less sphincteric activity.
- However, no rootlets gave a pure response and the long-term results have not been reported yet.
**Electrical blocking techniques: Anodal block**

Anodal block does not allow action potentials to pass an hyperpolarized zone created by electrode anodal blocking. Also, selective blockade of the large fibers is possible since large diameter fibers need a smaller stimulus for blocking than do small diameter fibers.

**Advantages**
- Selective small-fiber activation can be obtained by a combination of excitation of both large and small diameter fibers and by blockage, distal to the excitation point, of the propagation of the induced action potentials in the larger fibers.

**Disadvantages**
- This technique requires pulse duration of 700 µs, which is 6-12 times longer than normally used for nerve stimulation. This means that there is enough time for irreversible electro-chemical reactions to occur on the electrode contacts.

**Electrical blocking techniques: HF blockade**

HF blockade is used to maintain the nerve fibers in a refractory status preventing the muscle from contracting.
- Blocking frequency is > 600 Hz through using rectangular pulse waveforms. LF and HF currents at the same time are used to stimulate small nerve fibers without activation of the large diameter ones.
- Combining two frequencies (~30Hz and ~600Hz) such that the higher frequency blocks the urethral sphincter activity and reduces dyssynergia during micturition.

**Neuromodulation** by electrical stimulation allow to control the stress of the urinary incontinence. It is based on somatic afferent inhibition of sensory processes.
- This mechanisms depend on a physiological process in which the influence of activity in one neural pathway modulates the preexisting activity in another through synaptic interaction.
- Stimulation sites included anal, intravaginal, intravesical and transcutaneous at several locations on the body surface.

**Sacral Nerve Stimulator: “Interstim”**

- The Interstim Stimulation System (Medtronic Inc.) received FDA approval for use in urge incontinence in the USA in 1997.
- It consists of a neurostimulator and a lead with quadrupolar electrodes designed to be implanted at the S3 foramen to neuromodulate bladder sensory afferents.
- Adverse events included pain at the implant site (14.2%), new pain (10%), suspected lead migration (9.1%), infection (7%), pain at the lead site (5.5%) and transient electric shock (5.6%).
- Patients with this device should not undergo magnetic resonance imaging as it may change neurostimulator settings, damage the device, or injure the patient.
Polystim neurostimulation system

- Controller
  - TENS
  - Dual or more functions
- Implant
  - Miniaturizing
  - Accuracy, flexibility, etc.

The neurostimulator offers two stimulation modes:

Selective for voluntary voiding:
- Bi-frequency, high amplitude stimulation.
- Runs on a time limited basis.
- Uses inductive energy and stops as soon as the controller is removed.

Continuous for detrusor overactivity suppression:
- Low frequency, low amplitude pulse train.
- Runs on a continuous time basis.
- Needs a long life embedded battery.

Polystim neurostimulation system: Experiments

Permanent
Selective

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