Electrodes for Stimulation and Sensing

Lecture 5: EE 546 Winter 2020

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FES System Components

DECISION TO MOVE

COMMAND INTERFACE

SENSORS

MOVEMENT

PARALYZED MUSCLES

CONTROL SYSTEM

ELECTRONIC STIMULATOR

ELECTRODES
Electrodes for Stimulation

- Stimulator has some number of output “channels” of stimulation
- A single channel might branch into several stimulating or alternatively only one channel to each stimulating electrode
- Above applies for muscle, cortical, deep brain stimulation and other stimulation
Basic Idea-Muscle Stimulation

- Generate electrical charge pulses that, in some sense, mimic natural stimulation
- **Stimulator** is a constant-current or constant-voltage generator
- Tissue is an ionic conductor, impedance 10-100 ohms
- Electrodes are capacitive conductors, impedance from 500-5k ohms (induce phase shift 10-30 degrees)
Stimulating Electrodes

- Where are the anodes and cathodes? — 2 approaches
- Monopolar:
  - Common anode for many different cathode electrodes (cathodes located near stimulation sites of interest)
- Bipolar
  - Separate cathode and anode for each “channel” of stimulation (both located near site of interest)
Often stimulate one channel (and one electrode) at a time

Why?
- So no confusion about where the anode is and where the cathode is
- So that currents don’t sum to greater amount than desired at some location in tissue
Current Regulation vs Voltage Regulation

Fig. 4.25: Current regulated stimulation (A), and voltage regulated stimulation (B). The top panels are the output of the stimulator, the bottom the current and voltage applied to the tissue.
Constant-current is generally preferred

- When stimulator has low output impedance (constant-voltage operation), then electrical charge delivered to target depends on impedance of interface between tissue and electrodes.
- When stimulator is current regulated (i.e., has high output impedance), can ignore this impedance issue.
Stimulus Waveform Design

- Issues:
  - Efficacy of stimulation
  - Avoid pain (in some cases)
  - Avoid tissue damage
  - Avoid electrode degradation (corrosion)
Stimulus Waveform Design

- Efficacy of stimulation
  - Rectangular pulse (need fast rise time)

- For implanted electrodes, avoid tissue damage and electrode degradation (corrosion)
  - Related to pH change at electrode-tissue interface
  - At cathode, pH may increase due to OH⁻ production; at anode, will become more acidic
Monophasic vs Biphasic

- Monophasic is unidirectional waveform
- Biphasic is bidirectional
- **Biphasic** is usually preferred
  - Less pain when used with surface stimulation (electrodes on surface of skin)
  - Less pH change with biphasic (although reactions not completely reversed)
Monophasic constant current

T is pulse duration, IPI is “interpulse interval”

Idealized shape
Biphasic constant current

Idealized shape
Biphasic charge-balanced constant current

Idealized shape
Biphasic compensated constant current

Idealized shape
Electrical Safety Issues with Implanted Electrodes

- Area of stimulating surfaces
- Current density and rate of change of current density at the interface
Stimulation Modulation Methods

- Pulse width (pulse duration) or pulse amplitude modulation
  - These effect Recruitment—“How many” muscle fibers are stimulated

- Temporal Summation (modulation of IPI, which is approximately pulse frequency)
Types of Electrodes

- Surface Electrodes
- Subcutaneous electrodes
  - Intramuscular electrodes
  - Epimysial electrodes
  - Nerve Electrodes
- Spinal Stimulation
Surface Electrodes

- Consist of conductor, adhesive and interfacial layer (material in between electrode and skin)
- Often use saline or gels for interfacial layer
- Design Needs:
  - low impedance
  - even distribution of current
  - flexibility, reliable skin contact,
  - ease of application and removal
  - adequate duration of use
Surface Electrodes

- Surface Electrodes do not allow good selectivity of stimulation
- Impedance generally 1k – 5k ohms
- Surface electrodes require larger currents (30mA or more for 100-300 microsecond pulses)
- Surface electrodes cause pain if pulses are short
Subcutaneous Electrodes

- Better selectivity and more repeatable excitation
- More permanent positioning
- Less pain (electrodes further away from pain receptors)
- Lower current needed (power management consideration)
- Require invasive procedure to implant, and possible problems from failures
Intramuscular Electrodes

- Can place by injecting through hypodermic needle ("percutaneous intramuscular electrodes")
- Often implanted in procedure that includes stimulation with probe to find good sites
  Helical coil of multi-stranded wire
- Can run wires under skin, from injection site to stimulus location
Intramuscular Electrodes

- Teflon coated, except at simulation tip
- 316L stainless steel or other corrosion resistant materials
- Some versions coiled around central core of polypropylene or similar material, for strength
- Some versions include “barbs” to anchor electrode during implantation
Intramuscular Electrodes

- Excellent selectivity of muscles
- Requires about 10% of stimulation of surface electrodes
- Typical impedance 300 ohms (if tissue and surface anode included, then perhaps 1.5k ohms)
- High failure rate—over 20% per year
  - Breakage, corrosion, but mostly altered physiological response—perhaps from movement
- Need to maintain skin interface
Epimysial Electrodes

- Electrode on disc of reinforced polymer, placed surgically on surface of muscle near motor point
- Similar response properties to intramuscular electrodes
Nerve Electrodes

- Produce precise response
- Require lower power
- Potential to damage nerve
- Different strategies for placement
  - Adjacent to nerve, encircling it, or intraneural
Nerve Electrodes

Fig. 4.35: A) Huntington type helix nerve electrode; B) circular cuff electrode with a longitudinal slit; C) flat cuff electrode for selective stimulation.
Nerve Electrodes

- Different designs of cuff electrodes, different number of contacts, different methods to adjust size
- Intraneural Electrodes penetrate the epineurium
  - Require very low stimulation levels
  - MEMS and microwire approaches
  - Potential intraspinal use
Interesting ways to use nerve electrodes in stimulation

- Unidirectional Propagation
- Selective Activation
- Blocking Action Potentials

See great description and animations at [http://www.cwru.edu/groups/ANCL/ANCL.htm](http://www.cwru.edu/groups/ANCL/ANCL.htm) courtesy of Prof. J. Thomas Mortimer
Stimulators

- External units
- Implant multichannel stimulators
- Single channel stimulators (e.g., BION microstimulators)
- Magnetic
- [optical]
CWRU-Cleveland FES Center
Implanted Stimulator
(16 channel version)
BION™ Implants for Neuromuscular Stimulation
Electrodes for Sensing

- Use of EEG, cuff electrodes, types of intraneural electrodes and cortical electrodes for signal measurement and recording
- Can also use for stimulation—but must be careful to avoid stimulation artifacts
- If use surface electrodes for recording, get many many added signals
Electrodes for Sensing

- Hard signal processing problems
  - Separating signals of interest
  - Filtering, deconvolution or otherwise interpreting coded signals
- Use of wavelets, singular value decomposition methods, support vector machines, empirical mode decomposition, artificial neural nets, adaptive logic networks to interpret
Electrodes for Sensing

- Example: using electrodes to detect signals corresponding to triggering reflex responses—used for foot-drop correction systems by Sinkjaer group (Aalborg) and Hoffer (Simon Fraser)

- Example: using evoked EMG (generated by muscles in response to stimulation) to estimate and track fatigue (Chizeck and Erfanian)
Electrodes for Sensing

- EEG to non-invasively detect intended motion, as BCI
- ECoG (acute use)
- Various cortical electrodes and cortical electrode arrays (limited use in humans)
- EMG (muscle activity) detection
- Deep Brain Stimulator electrodes can be used to acquire signals