Basics of Electrical Stimulation

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Learning Objectives

- After this course learners will be able to describe the proper placement for a cochlear implant electrode array.
- After this course learners will be able to define key terms and features of electrical stimulation.
- After this course learners will be able to identify potential limitations, side effects, and patient factors that can affect outcomes with a cochlear implant.

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What do we need to know to understand how electrical stimulation is different than acoustic stimulation?

- What do we stimulate?
- How do we stimulate?
- What are the limitations?
- What are the potential side effects?
- How does patient history impact our expectations at the most basic level?

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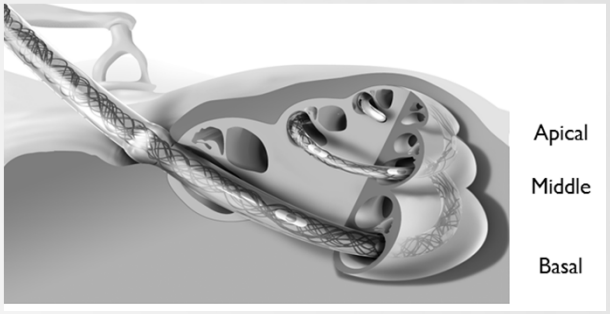
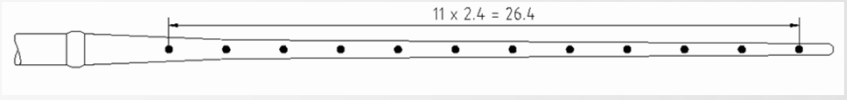
What we stimulate





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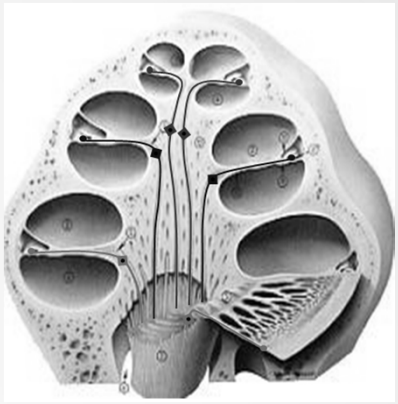
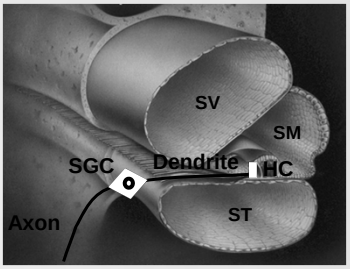
The cochlea
Axons in the modiolus



Low freq.
Mid freq.
High freq.



Low frequency axons are located in the middle of the modiolus and are surrounded by high frequency structures

Cross section modiolus:

5

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Electrode placed properly

No pressure on inner or outer wall

Intact:

- Basilar membrane
- Spiral lamina
- Spiral ligament
- Modiolus

Note: Insertions in cadaver temporal bones typically do not reach the apex

Courtesy of T. Balkany, MD
Univ. of Miami, USA

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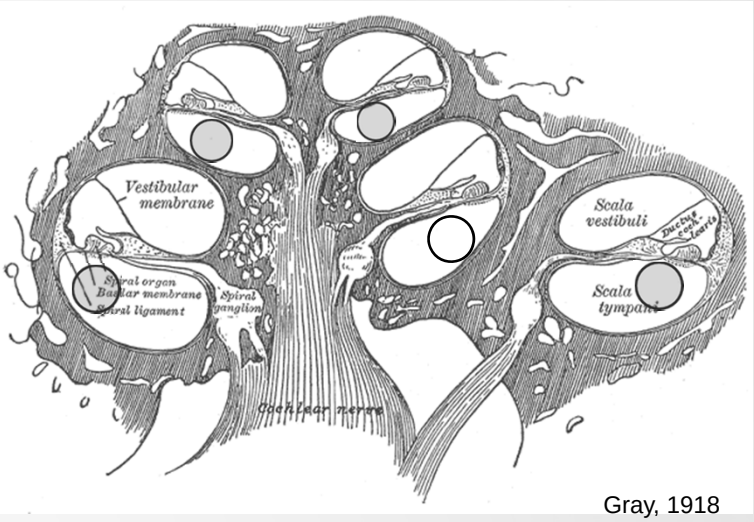
What we stimulate



Gray, 1918

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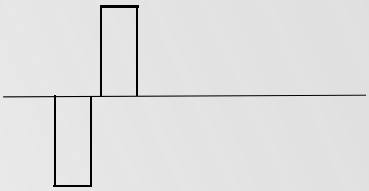
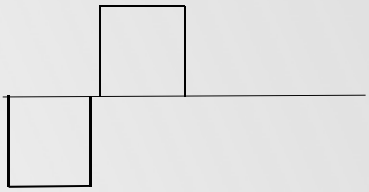
How we stimulate:

- We stimulate using a biphasic charge balanced square wave electrical pulse
  - Biphasic
  - Charge-balanced

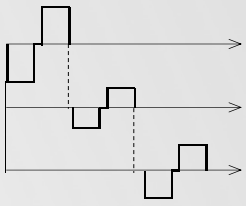


- The pulse can vary in amplitude or duration
  - Impacts loudness variation
  - Number of nearby nerve fibers stimulated

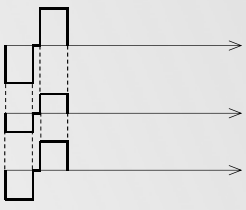


Stimulation modes

- Sequential stimulation



- Parallel stimulation
  - If channel interaction is not intended, some form of channel interaction compensation is necessary
  - *FS4-P coding strategy uses parallel stimulation with Channel Interaction Compensation (patented)



*Fine structure coding is not indicated for prelingual children in the USA

Key terms

- MCL: Most Comfortable Loudness
  - The loudest level on each channel that the patient can comfortably tolerate. Should be set equal to the loudness of 100 dB SPL sound.
- THR: Threshold
  - The level *just below first audibility* on each channel
- Dynamic range:
  - Input Dynamic Range (IDR) = the processing "window" of the coding strategy in the processor
  - "Regular" dynamic range = the loudness range a patient gets on a channel, difference between MCL and THR

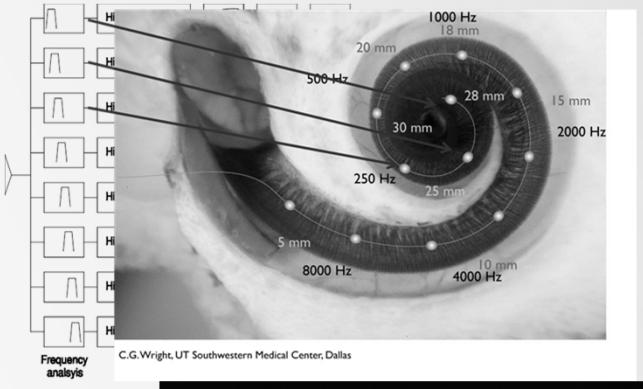
Key Terms

- Stimulation rate: the rate at which pulses are delivered to each channel.
  - Higher rates are generally preferred = better resolution…up to a point.
  - Maximum rate of the current MED-EL implants is 50794 pps (pulses per second), although most patients end up with rates somewhere around 20-30,000 pps.
  - Stimulation rate is dependent upon how much current is needed to reach MCL
    - As you increase "loudness", the system decides whether that increase is best achieved by increasing **amplitude** vs **pulse duration** to meet your request
    - Increases in pulse duration slow the rate slightly
    - Software's rate decisions are based on maintaining the fastest rate but also maximizing power efficiency

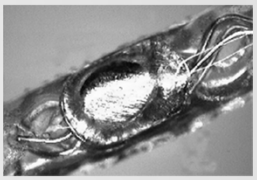
Key terms

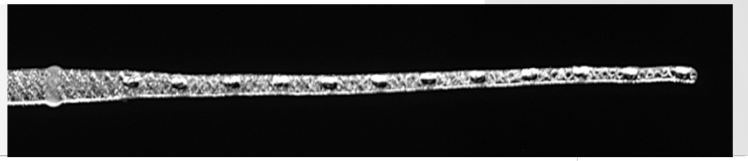
- Channel vs contact vs electrode
  - These terms get used interchangeably A LOT so it can be confusing at first.
- Contact = the actual metal contact on the electrode array
- Electrode = can refer to the entire array, or to the contact, or to a pair of contacts that function as one channel

Terminology of the electrode array



Contacts vs Electrodes vs Channels

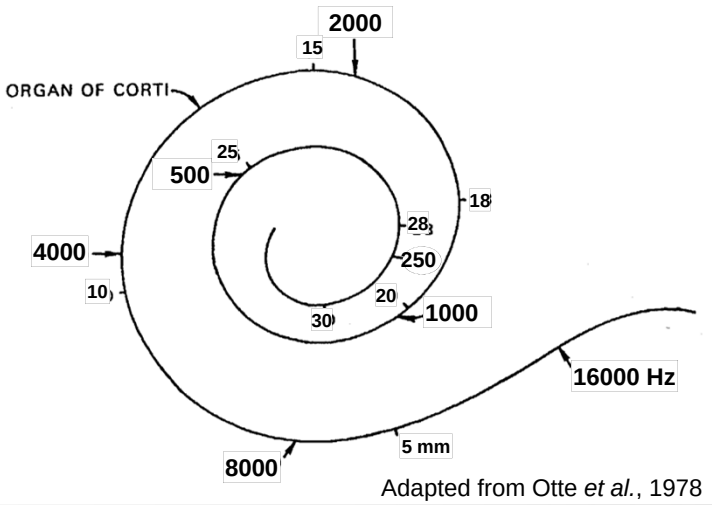




Key Terms

- Channel – the number of discrete areas that will be stimulated along the array with pitch-specific information. MED-EL electrodes offer up to 12 channels of stimulation.
  - That doesn't mean the patient only hears 12 pitches… MED-EL processors can deliver up to 250 distinct spectral shapes.
  - However, the number of pitches each patient actually can discriminate is patient-dependent.
- MAP – a slang term rather than an acronym. The program on the processor that is individualized for each person

Tonotopic Arrangement of Cochlea



Adapted from Otte *et al.*, 1978

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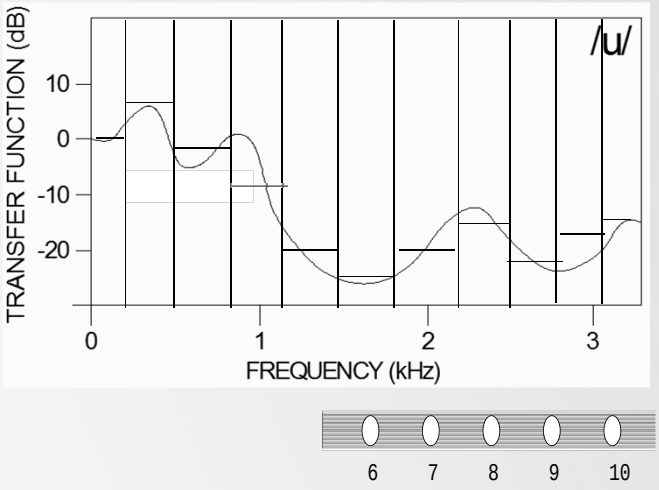
Spectral shape (aka Envelope)



– FineHearing

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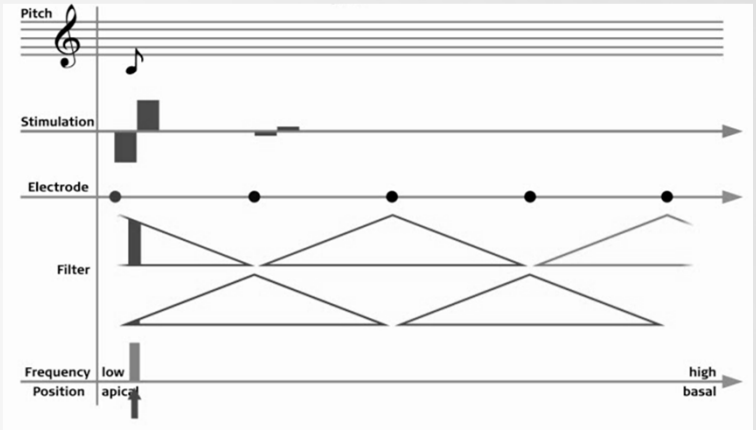
FineHearing technology: Place coding

- Shifts in frequency create changes in amplitudes
  - 250 spectral bands



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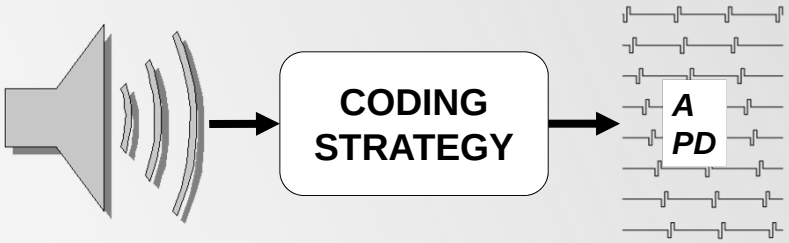
What the heck is a coding strategy???



A coding strategy is a set of rules by means of which the stimulation parameters are derived from the sound signal.

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History of coding strategies

Feature extraction	Peak Picking	All Envelope	Fine Structure
F0/F2 (C)	SPEAK (C)	CIS (M)	FSP (M)
F0/F1/F2 (C)	ACE (C)	CIS+ (M)	FS4-p (M)
MPEAK (C)	MP3000 (C)	HDCIS (M)	FS4 (M)
	N-of-M (M)	HiRes (A)	
		HiRes120 (A)	

1980s **1990s** **2000s**

M - MED-EL, C - Cochlear, A - Advanced Bionics

Variations on the theme: Coding strategies

- Stimulate all channels that are activated in the map
  - CIS strategies (CIS, CIS+, HDCIS, even High Res/High Res 120 is a CIS type strategy)
  - “Continuous Interleaved Stimulation”
  - Includes a method of managing channel interactions
    - Interleaved stimulation: only one pulse at a time (staggered order in MED-EL systems)
    - Pulses delivered in pairs on adjacent channels intended to evoke one intermediate pitch
- Stimulate only a subset of channels activated
  - Stimulate only the n channels with the highest energy
  - N-of-M strategies (n-of-m, ACE, SPEAK)

Coding Strategies

Fine Structure coding strategies are unique to MED-EL

- The pulses delivered to the lowest frequency channels are timed to closely follow the zero crossings of the original waveform
  - Exploits the natural ability of the auditory system to analyze phase information
  - Increases musical pitch quality, improves speech understanding in quiet and noise, improves tonal language perception, speculated to improve localization for bilateral users via better representation of ITD
- In FS4-P, we stimulate two channels in parallel if there were two channels with zero crossings in that frame
  - When two channels are stimulated, Channel Interaction Compensation (CIC) is enabled to ensure that an intermediate pitch percept is NOT delivered inadvertently.

*FS coding strategies are not FDA approved for prelingual children in the US

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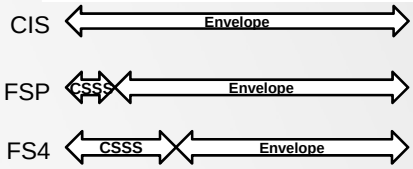
The Portfolio of Fine Hearing Coding Strategies

CIS/HDCIS/FSP/FS4 – All implants
FS4-p – Pulsar, Sonata, CONCERT,
SYNCRONY



- CIS: No FS
- FSP: FS up to 350 Hz
- FS4: FS up to 1 kHz

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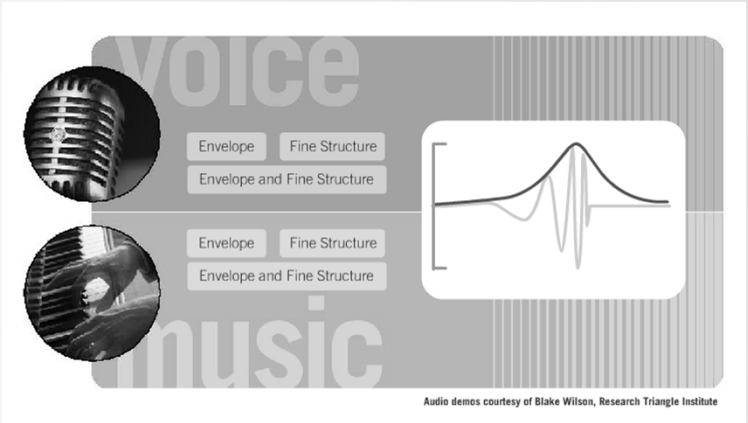
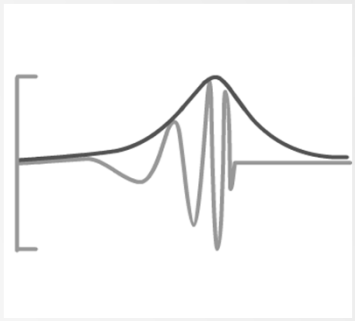
What Does Fine Structure Contribute to the Picture?



Auditory Nerve Fiber Responses to Sounds of Different Pitches



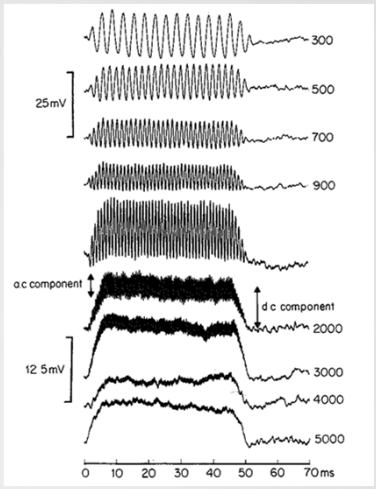
Envelope

Fine Structure

Palmer & Russel (1986)

Low

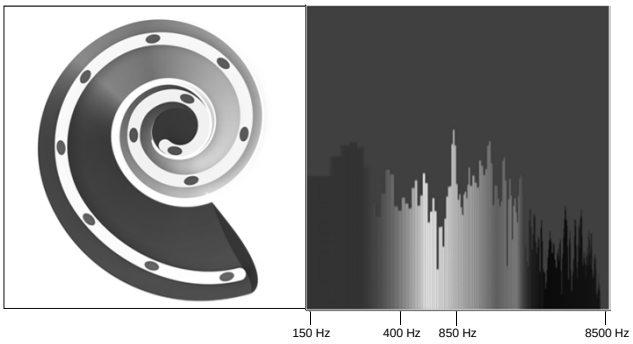
High



Triformance: MED-EL combines the "what" and the "how"

- Stimulate the entire cochlea from base to apex
  - Longer atraumatic electrode arrays with widely spaced channels
- Stimulate using temporal (time) coding in the lows and envelope coding in the highs, following the natural firing pattern of the auditory system
- 250 distinct spectral shapes (pitch coding) delivered along the array

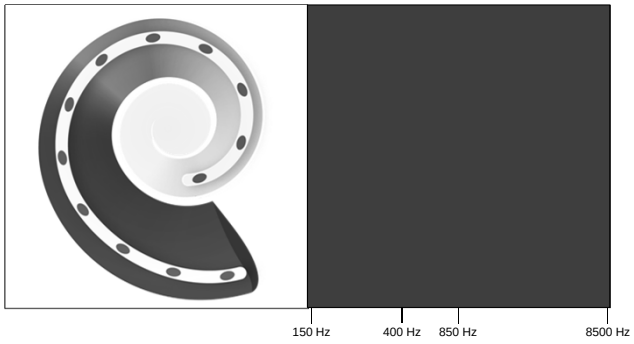
Triformance:
How does it sound?



Triformance:
How does it sound without Triformance?

Limited Sound Spectrum

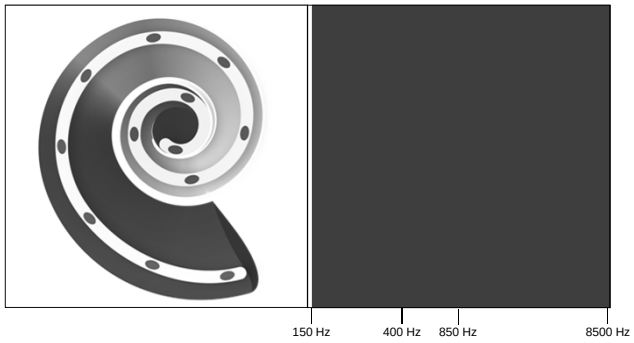
- Limited Cochlear Coverage
- Partially Preserved Structures
- Unnatural Sound Coding



Triformance:
How does it sound with Triformance?

Limited Sound Spectrum
- Limited Cochlear Coverage
- Partially Preserved Structures
- Unnatural Sound Coding

Full Sound Spectrum:
Triformance
- CCC Complete Cochlear Coverage
- SP Preserved Cochlear Structures
- FH Natural Sound Coding



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Nerve survival

- Depending on the number of surviving (stimulable) neural elements near an electrode contact:
  - Low MCLs, resulting in wide dynamic ranges and high rates of stimulation
  - High MCLs resulting in wide pulse durations and lower rates of stimulation
  - No response at some areas in the cochlea resulting in channels needing to be deactivated
  - Good pitch perception along the array vs poor pitch differentiation at some or along all of the array
  - Good vs poor ability to estimate loudness
  - Good vs poor ability to be consistent in estimating loudness or identifying pitch

Nerve survival (continued)

- Depending on the number of surviving (stimulable) neural elements near an electrode contact:
  - Pitch-like (“bell-like”, “tone-like”) vs ‘odd’ or ‘different’ percept compared to other areas of the cochlea
  - Some patients (particularly those with prior history of meningitis and possible ossification) may have issues with:
    - Never reaching MCL no matter how high you go
    - No response at some or even all of the cochlea
    - Very good ranging to extremely poor speech understanding
  - High current requirements may cause inadvertent stimulation of the facial nerve
    - Solution: reduce amplitude by increasing pulse duration on the offending channels, or deactivate channels

“Programming dilemma”

- Patient’s charge requirements are high enough that rate is significantly reduced
- Sometimes there is a trade-off between
  - Turning off some channels to increase rate
  - Lowering MCLs in order to increase rate
  - Turning off some channels because of poor percept
  - Turning off channels that are ‘outliers’: significantly higher current requirements or very different dynamic ranges compared to the other channels
  - Making the best of a reduced number of available channels
  - Accepting an atypical map in favor of wearability

Channel number

- Speech understanding in quiet reaches maximum at somewhere around 6-8 channels
- Speech understanding in noise requires somewhere around 10 channels
- Music appreciation? 100’s of channels?

>> turning off a channel that isn’t contributing to the experience does not compromise the patient, up to a point

- More channels provide some redundancy but when many channels become too closely spaced together, channel interaction begins to ‘muddy’ the differences between individual channels >> reduced performance

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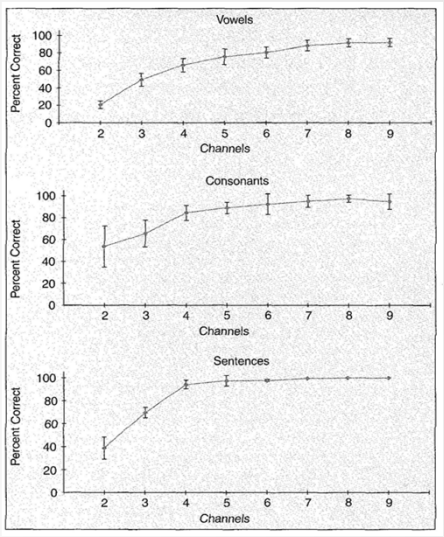
Is there an optimal number of channels?



	Orig
2	
4	
6	
8	
10	

Dorman, Loizou & Rainey, 1997.

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Some potential side effects

- Initial experience, esp for long-term deaf individuals with little “good” hearing aid experience may include:
  - Tactile sensations: These usually will eventually become sounds, assuming the electrode is in the cochlea
  - Poor differentiation of pitch between neighboring channels
  - Poor or possibly no open set speech understanding: Auditory therapy helps speed progress, but progress is slow compared to patients with shorter lengths of deafness
  - Inability to tolerate much loudness growth, esp in the high frequencies
  - Narrow dynamic ranges (diff btwn THR and MCL)
  - Poor tolerance to everyday environmental sounds that they may not have heard in a long time, if ever.
  - No sound percept
- These experiences typically resolve over time but patients need encouragement and highlighting of their progress

Some potential side effects

- Reduction in tinnitus
- Increase in tinnitus
- Taste disturbances, metallic taste
- Facial nerve stimulation: usually resolved by reducing pulse amplitude by increasing pulse duration or deactivating offending channels
- Inability to identify environmental sounds, especially initially
- Poor speech understanding, esp initially
- Adaptation to pulse trains of consistent loudness (rare)

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Patient factors

- Meningitis may prompt ossification, increased propensity for ADHD-like behavior, central auditory problems, inability to reach MCL, no sound sensation in some or all of the cochlea
- LVA may increase propensity for map fluctuations
- Seasonal allergies/hay-fever can sometime initiate temporary map fluctuations
- Long lengths of deafness generally increase the risk of slower progress or poor overall performance
  - "Good" hearing aid use seems to mitigate this to some degree
- Areas of 'no response' on pre op audio may indicate areas of poorer nerve survival or more fluctuation in levels initially

Expectations as they relate to success

- Prepare candidates (and yourself) for possible outcomes based on hearing history
- If possible, start with an ideal candidate for your first patient:
  - For adults:
    - Short length of deafness
    - Consistent hearing aid use
    - Good communication skills
    - Motivated to succeed
    - Able to come to the clinic easily
    - Measurable pre-op residual hearing is helpful
  - In addition, for kids:
    - Young age
    - Strong family support
    - Able to provide a COR/VRA/conditioned response or sit quietly for ESRT
    - Family is working with an auditory therapist who understands development of spoken language in deaf children

Take advantage of available support

- Visit on-demand training modules provided by the company
- Arrange for your Clinical Account Manager to be present for your first stimulation
  - They can also help
    - Hone your MED-EL counseling skills in the pre-op phase
    - Explain the ordering process
    - Establish realistic expectations
    - Connect you/candidates with other users
    - Develop your confidence with the programming software
    - Set up the hardware (DIB, software, demo kits)
- Above all, be excited! You are beginning a very fulfilling journey >>>

  what you provide in new beginnings for a patient's ability to "hear life" will come back to you many-fold in satisfaction that you made a real difference