Electrical Stimulation of the Cochlea to Reduce Tinnitus

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Overview

1. Mechanisms of influencing tinnitus
2. Review of select studies
3. Summary of what is known
4. Next Steps
1. Mechanisms of influencing tinnitus

Mechanisms of tinnitus

- Differences across subjects is large
- Must be ‘perceived’ in the auditory temporal lobe
- Can have source any place in auditory system
- Can be influenced by cochlea activity
Evidence of central involvement
(Tyler, 1981)

• Heard in 1 ear,
  – 8th nerve cut, no change in perception
  – mask ipsilaterally, tinnitus can be heard in the other ear
  – can be masked at low levels in contralateral ear

Tinnitus in the temporal lobe

– 1. Increased spontaneous activity
  • fed by increase, decrease, or edge
  • (e.g. Davis, 1948; Kiang et al., 1970)
– 2. Cross-fiber correlation
  • (Eggermont, 1984; Moeller, 1984)
  • normal or increased spontaneous activity
– 3. More fibers with similar best frequency following hearing loss
  • (Salvi et al., 1996)
– 4. Periodic spontaneous activity
Mechanisms of influencing tinnitus from the cochlea

- Must change spontaneous activity of nerve fibers
  - Increase activity
  - Decrease activity
  - De-synchronize activity across nerve fibers
  - Interfere with periodic activity

2. Review of studies

- Cochlear implant studies
- Kuk et al. (1989)
- Hazell et al. (1989)
- McKerrow et al. (1991)
- Dauman and Tyler (1993)
- Rubinstein et al. (2004)
Cochlear implant studies

Effectiveness- Cochlear implant speech processors

- Tyler and Kelsay (1990)
  - 34/42 better
  - 1/42 worse
- Gibson (1992)
  - 25/42 better
  - 4/42 worse
- Souliere et al. (1992)
  - 20/26 better
- Demajundar et al., (1999)
  - 62/80 better
Cochlear implant use: effect on contralateral ear

• Demajundar et al., (1999)
  – 14/70 patients reported tinnitus abolished

Cochlear implant use: post stimulus relief

• Souliere et al. (1992)
  – 14/28 patients
  – 4 greater than 2 hours
• Kim et al., (1995)
  – Present in 12/13 patients
Kuk et al., (1989)

- Eardrum stimulation
- ball electrode placed forehead ground

Subjects

- constant, non-fluctuating tinnitus
- 1 unilateral, 9 bilateral
- high-frequency hearing losses, 1 within normal limits
Stimuli

- square, sine, triangular waveforms
- 62-8000 Hz

Treatment

- maximum tinnitus reduction at lowest current was determined for different waveforms and frequencies
- optimum stimulus presented for 10 minutes
- ratings and noise masking measured in contralateral ear
Results

• 5 non-responders
  – no tinnitus reduction
• 5 responders
  – tinnitus reduced
Conclusions

• tinnitus reduction without stimulus audibility in 3/5
• unilateral in 3/4 bilateral patients
• Optimum stimuli varied among patients
• 10-minute Treatment Phase
• post-stimulation reduction lasted from 40 s to 4 hours

Hazell et al. (1989)

• 6/6 totally deaf patients
  – round window implant
  – sinusoids
Hazell et al. (1989)

- 5/8 hearing patients
  - platinum ball electrode round window
  - Only effective for stimuli < 400 Hz
Dauman, Tyler & Aran (1993)

- 2 cochlear implant patients
- Evaluated frequency of pulse trains and electrode position
- Stimulated randomly between threshold and Uncomfortable Loudness Level,
- 3 replications
- Individual rate and electrode preferences
Summary

- Intracochlear low frequency pulses 80-250 Hz can reduce tinnitus, some better than others
- Stimulus always heard
- Electrode position and inter-electrode distance matters
- 5 min stimulation resulted in 15 min of post-stimulus suppression
McKerrow et al. (1991)

- 6 patients with University of San Francisco cochlear implant
- ‘control’ - 2-6 MHz carrier, inaudible
- Experimental condition – noise at comfortable level

Condition 1. Inaudible 2-6 MHz Stimulation

- 30 minute
- 3/6 patients - suppression of tinnitus
  - 1 lasted 10-15 minutes then habituated
  - 1 bilateral effect
  - 1 increase in tinnitus for 5 min, following by brief decrease after 10 m of stimulation
Condition 2. Noise at comfortable level

- 30 minutes noise
- 5/6 rapid decrease to inaudible tinnitus
  - 4/5 bilateral
  - 1 tinnitus continued to decrease over 30 minute trial
• Post stimulation
  – 2/6 Gradual or 3/6 rapid return
  – 1/6 tinnitus continued to decrease for another 30 minutes

Rubinstein et al., 2003, 2004
• ‘conditioner’ stimulus
• High rate (3-5 kHz) pulses can produce spontaneous-like activity
  – Poisson Spike Timing
  – Across-fiber independence

CI subject AG, 4800 pps on one electrode
2 stimulus levels
Results

- CI subjects (N = 2)
  complete suppression: 1
  no suppression: 1

- Transtympanic subjects (N = 7)
  suppression without percept: 3
  suppression with percept: 3
  no suppression or percept: 1

- Several minutes of stimulation
  - Tinnitus initially unaffected
  - Reduction after several minutes
  - Tinnitus can start to emerge again
  - Can ‘re-suppress’ tinnitus with change (level, rate) of stimulation
Single sided incapacitating tinnitus and sensorineural deafness treated with cochlear implantation

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Significant improvement up to 24 months (p<0.001)
3. Summary of what is known

• Effectiveness of stimulation
  – Tinnitus can be reduced in some proportion of patients

• Optimal stimulus parameters
  – May be different for different subjects

• Ear of stimulation
  – Usually monaural effect,
  – binaural effect in some patients

Unpublished

• Laboratory trials
• Electric pulse trains
  – Electrodes – basal, mid, apical
  – Durations – 2, 8, 20 minutes
  – Levels – sub, at threshold, MCL
  – Wave files mixed with signal from speech processor
Effect of Location of Stimulated Electrode on the Perceived Loudness of Tinnitus

Electrode Locations: Base (#16), Middle (#8) and Apex (#1)
Stimulus Level: Most comfortable
Rate of Stimulation: 3569 pps
Duration of Stimulation: 2 minutes

Normalized Ratings of Perceived Loudness (0= inaudible; 100= loudest)

Perceived loudness of stimulus (basal electrode)
Perceived loudness of stimulus (middle electrode)
Perceived loudness of stimulus (apical electrode)
Perceived loudness of tinnitus (basal electrode)
Perceived loudness of tinnitus (middle electrode)
Perceived loudness of tinnitus (apical electrode)

During Stimulation
Post-stimulation
Effect of Location of Stimulated Electrode on the Perceived Loudness of Tinnitus (DR)

Electrode Locations: Base (#1), Middle (#3) and Apex (#6)
Stimulus Level: Most comfortable
Rate of Stimulation: 2400 pps
Duration of Stimulation: 2 minutes
Nucleus Hybrid Device (Rt ear)

Normalized Ratings of Perceived Loudness (0=inaudible; 100=loudest)

- Perceived loudness of stimulus (basal electrode)
- Perceived loudness of stimulus (middle electrode)
- Perceived loudness of stimulus (apical electrode)
- Perceived loudness of tinnitus (basal electrode)
- Perceived loudness of tinnitus (middle electrode)
- Perceived loudness of tinnitus (apical electrode)

Effect of Stimulus Level on the Perceived Loudness of Tinnitus (DR)

Electrode Location: Mid (#3)
Rate of Stimulation: 2400 pps
Duration of Stimulation: 2 minutes
Nucleus Hybrid Device (Rt ear)

Normalized Ratings of Perceived Loudness (0=inaudible; 100=loudest)

- Perceived loudness of stimulus (sub threshold)
- Perceived loudness of stimulus (just noticeable)
- Perceived loudness of stimulus (most comfortable)
- Perceived loudness of tinnitus (sub threshold)
- Perceived loudness of tinnitus (just noticeable)
- Perceived loudness of tinnitus (most comfortable)
- Perceived loudness of tinnitus (no signal)
Effect of Duration of Stimulation on the Perceived Loudness of Tinnitus (DR)

Electrode Location: Mid (#3)
Stimulus Level: Most comfortable
Rate of Stimulation: 2400 pps
Duration of Stimulation: 2*, 8 & 20 minutes
Nucleus Hybrid Device (Rt ear)

*Data for 2 minutes have been replicated from that obtained for effect of duration.
There wasn’t enough time to obtain data for 2 and 4 minutes of duration.

Summary – lab studies

- Optimal stimulus parameters are different for different subjects
- Perception of tinnitus suppression signal can decrease over time
- Effectiveness of signal to suppress tinnitus can, over time
  - Become less effective
  - Become more effective
    - Effectiveness during continuous stimulation can be prolonged/improved by changing (e.g. modulating) stimulus
- Post-stimulation effects
  - In some, tinnitus reduced minutes to hours after stimulus turned off
Preliminary field trials

- 3 patients
  1. CI plus contralateral Hearing Aid
  2. CI patient
  3. CI patient

Method field trial 1

- 1 patient
  - HA and contralateral CI
- Odd electrodes – Speech
- Even electrodes tinnitus suppression signal (2 different one alternated daily)
Method – field trial 2

- Wave files mixed with signal from speech processor
- Speech and tinnitus suppression signal on together
- Preliminary laboratory trial selecting likely beneficial tinnitus suppression signals
- Alternate daily tinnitus suppression signal
- Loudness, Annoyance, Acceptability Ratings
Managing the Tinnitus Patient

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Loudness Of Tinnitus (Subject #3)

Acceptability Of Listening To This Background Sound (Subject #3)
3. Summary of what is known

• Effectiveness of stimulation
  – Tinnitus can be reduced in some proportion of patients

• Optimal stimulus parameters
  – May be different for different subjects

• Ear of stimulation
  – Usually monaural effect,
  – Binaural effect in some patients

• Audibility of stimulation
  – Can suppress stimulus without percept
  – Possible advantage of conditioner

• Adaptation of continuous stimulation
  – Effectiveness can decrease over time with same stimulation

• Post-stimulation effects
  – In some, tinnitus reduced minutes to hours after stimulus turned off

• Tinnitus can re-emerge after being suppressed with continuous stimulation, and can be re-suppressed with stimulus change in level or periodicity
Next Steps

• Studies are needed to determine what changes in the stimulus are needed to maintain reduction during continuous stimulation