Outline

I. Learner Outcomes
II. Overview: Basic Principles
III. Tinnitus Monitoring
IV. Ototoxicity Monitoring in Adults
V. Objective Monitoring
VI. Ototoxicity Monitoring in Children
VII. Establishing Program
IV. Monitoring Hearing in Adults

Kelly M. Reavis, M.S., CCC-A
"Now just relax and we'll begin your hearing test."
Test Characteristics

- Sensitivity & Specificity
  - (high hit rate & low false positive rate)

- Reliability (test-retest)

- Time efficiency
Sensitivity & Specificity

**Sensitivity (hit rate)**
- Percentage of times ears with hearing change identified as having hearing change by the experimental measure
- 100% - sensitivity = false negative or miss rate

**Specificity (correct rejection rate)**
- Percentage of times ears with no hearing change are correctly labeled as no change by the experimental measure
- 100% - specificity = false positive or false alarm rate
<table>
<thead>
<tr>
<th>GOLD STANDARD</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CHANGE</td>
<td>Hits</td>
<td>False Alarms</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>NO CHANGE</td>
<td>Misses</td>
<td>Correct Rejection</td>
</tr>
<tr>
<td></td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

**Sensitivity & Specificity**

- **Hits** (Sensitivity)
- **False Alarms**
- **Misses**
- **Correct Rejection** (Specificity)
Reliability & Time Efficiency

● Reliability (test-retest)
  - Determine size change (e.g., in pure-tone threshold or OAE amplitude) likely to be real and not random variability
  - Significantly different change with 0.05 level of confidence provides 95% probability that change is real

● Time Efficiency (clinically practical)
Monitoring Principles

- **High- to low- frequency progression**
- **High-frequency testing is reliable** (Fausti et al., 1998; Frank, 1990; Frank & Driesbach, 1991; Gordon et al., under review)
- **Studies have shown the efficacy of high-frequency monitoring** (Dreschler et al., 1989; Fausti et al. 1984; Jacobson et al., 1969; Ress et al., 1999; Tange et al., 1985; Van der Hulst et al., 1988; Fausti et al., 1993; Fausti et al., 1994)
- **Studies have shown testing in 1/6-octave intervals provides earlier detection** (Fausti et al., 2003; Vaughan et al., 2003)
- **Individualized protocols targeting the highest frequencies** a person can hear
Keep in Mind

- There are no normative high-frequency sensitivity (i.e., threshold) standards due to lack of standardization in
  - calibration,
  - instrumentation,
  - and methodological procedures

There is also a high degree of inter-subject threshold variability in high frequency sensitivity

- Threshold variability increases with age (in elderly) and with higher test frequencies

However, the key to serial monitoring is intrasubject reliability.

High-frequency test-retest threshold variability is within a clinically acceptable range ($\pm 10 \text{ dB}$).

As a result, monitoring near individual’s high-frequency hearing limit is effective.
ASHA Change Criteria

- > 20 dB change at 1 test frequency
- > 10 dB change at 2 adjacent test frequencies
- Loss of response at 3 consecutive test frequencies where responses were previously obtained

*Change confirmed by retest*
ASHA Change Criteria

- Normal variability in pure-tone thresholds occurs at random frequencies.

- Threshold shifts at adjacent test frequencies indicate more systematic change (Atherly, 1963; Dobie, 1983)
  - Notion of examining threshold shift across frequencies

- Threshold shifts on repeated tests are also a stronger indication of a true threshold change (Royster & Royster, 1982)
1/6\textsuperscript{th} Octave Testing
Provides Earlier Detection
### 1/2 Octave vs. 1/6 Octave

#### 1/2 Octave Protocol

<table>
<thead>
<tr>
<th>Test Frequency (kHz)</th>
<th>Change From Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 8</td>
<td>0</td>
</tr>
<tr>
<td>11.2</td>
<td>+10</td>
</tr>
<tr>
<td>16</td>
<td>5</td>
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</tbody>
</table>

#### 1/6 Octave Protocol

<table>
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<tr>
<td>&lt; 8</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>11.2</td>
<td>+10</td>
</tr>
<tr>
<td>12.5</td>
<td>+10</td>
</tr>
<tr>
<td>14</td>
<td>+10</td>
</tr>
<tr>
<td>16</td>
<td>5</td>
</tr>
</tbody>
</table>
## 1/2 Octave vs. 1/6 Octave

### 1/2 Octave Protocol

<table>
<thead>
<tr>
<th>Test Frequency (kHz)</th>
<th>Change From Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1.5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>+10</td>
</tr>
</tbody>
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### 1/6 Octave Protocol

<table>
<thead>
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<th>Test Frequency (kHz)</th>
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<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>6.35</td>
<td>+10</td>
</tr>
<tr>
<td>7.13</td>
<td>+15</td>
</tr>
<tr>
<td>8.00</td>
<td>+10</td>
</tr>
</tbody>
</table>
Compared to testing in 1/6\textsuperscript{th}-octave steps above and below 8 kHz, testing conventional frequencies alone resulted in initial ototoxic hearing change missed or detected later in 76/210 ears.

<table>
<thead>
<tr>
<th></th>
<th>AMG (N=25 ears)</th>
<th>Cisplatin or Carboplatin (N=185 ears)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of Ears Missed or</td>
<td>28%</td>
<td>37%</td>
</tr>
<tr>
<td>Detected Later</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Number of Frequencies between 2 – 20 kHz in 1/6 Octave steps?

......25 Test Frequencies x 2 ears =

50 Test Frequencies

OUCH!
Individualized Sensitive Range for Ototoxicity (SRO)
Highest Audible Frequency

- Frequency (kHz) vs Threshold (dB SPL)
- Highest audible frequency is marked at 14 kHz
Highest Audible Frequency
Initial Ototoxicity Detection

Frequency Reference to 100 dB SPL Threshold

Ear Showing Change (#)

AMG N=134
CDDP N=188

R-13, R-12, R-11, R-10, R-9, R-8, R-7, R-6, R-5, R-4, R-3, R-2, R-1, R, R+1, R+2

SRO
SRO Principle

- Thresholds > 100 dB SPL remain unchanged
- Most initial changes seen within one octave below the highest audible frequency
- Range for each individual is unique and specific to their hearing configuration

*A sensitive range for ototoxicity (SRO) is the uppermost frequency with a threshold ≤100 dB SPL and 6 lower consecutive frequencies in 1/6th octave steps*
Case Example using SRO

Threshold (dB SPL)

-10  0  10  20  30  40  50  60  70  80  90  100  110  120

21-Jan, Baseline & Retest
11-Feb, Monitor
18-Feb, Monitor Retest
20-Feb, Monitor Retest
### Sensitivity: SRO 1/6th Octave

<table>
<thead>
<tr>
<th></th>
<th>Total (Ears)</th>
<th>Hit</th>
<th>Miss</th>
<th>Initial Change on SRO</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMG</td>
<td>54</td>
<td>46</td>
<td>8</td>
<td>85%</td>
</tr>
<tr>
<td>Cisplatin</td>
<td>226</td>
<td>207</td>
<td>19</td>
<td>92%</td>
</tr>
<tr>
<td>Carboplatin</td>
<td>59</td>
<td>50</td>
<td>9</td>
<td>85%</td>
</tr>
<tr>
<td>Total</td>
<td>339</td>
<td>303</td>
<td>36</td>
<td>89%</td>
</tr>
</tbody>
</table>

Example SRO Above 8 kHz

SRO Test Frequencies:
8, 9, 10, 11.2, 12.5, 14, 16 kHz
Example SRO Below 8 kHz

SRO Test Frequencies:
6.35, 7.13, 8, 9, 10, 11.2, 12.5 kHz
Example SRO Below 8 kHz

SRO Test Frequencies:
4.49, 5.04, 5.66, 6.35, 7.13, 8, 9 kHz
Case Example of Ototoxic Threshold Shifts: SRO < 8 kHz
**S** = *Sensitive*, detects ototoxicity 90% of the time

**R** = *Range*, 1 octave in 1/6 octave steps (7 frequencies) at the upper limits of hearing

**O** = *Ototoxicity*, early detection is key
Ototoxicity Identification Device

A portable, handheld audiometer-like device that will enable time-efficient, reliable and sensitive early detection of ototoxicity.
### Specificity: Booth vs. Ward

#### False Positive rate, using ASHA Criteria

<table>
<thead>
<tr>
<th>Earphone Type</th>
<th>Booth</th>
<th>Ward</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Koss Pro/4X</strong></td>
<td>&gt; 20 dB at 1 Frequency</td>
<td>&gt; 10 dB at 2 Consecutive Frequencies</td>
</tr>
<tr>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>ER-4B</strong></td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Sennheiser HDA 200</strong></td>
<td>0%</td>
<td>2%</td>
</tr>
</tbody>
</table>


Technical Considerations

- **Audiometer**
  - High frequencies and 1/6\textsuperscript{th} octave capability
  - Capable of high output with low noise floor
  - Portable

- **Earphone Selection**
  - High frequency capability
  - High output capability
  - Insert ER-3A and Circumaural TDH-39/49 WILL NOT work for high frequency measurement

- **Calibration**
Technical Considerations

- Earphone placement
- Stimulus Tone:
  - Pulsed
  - Increase duration of tone presentation
- Ambient Noise:
  - Single-walled vs. Double-walled sound booth
  - Hospital ward testing
    - Make noise measurements
    - “Do Not Enter - Test in Progress” sign
- Listening check:
  - High frequencies, High Output
CONSISTENT EARPHONE PLACEMENT IS KEY
Conclusions

- Evidence-based protocol
  - High frequencies are reliable
  - Sensitive Range for Ototoxicity (SRO) exists
- Time-efficient protocol
  - ~90% initial detection rate using SRO
- Portability
  - Only 7 frequencies in SRO
  - OtoID
  - Earphones can be used on ward