How to use and interpret the TEN(HL) test
for diagnosis of Dead Regions in the cochlea

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Healthy Organ of Corti

Healthy Outer Hair Cells (OHCs)

1. Normal absolute threshold
2. Sharp tuning on the basilar membrane – good frequency selectivity
3. Nonlinear input-output functions

Loss of OHCs
Consequences of OHC loss
1. Elevated absolute threshold
2. Broad tuning on the basilar membrane - reduced frequency selectivity
3. Difficulties in understanding speech specially in background noise
4. Linear input-output functions
5. Loudness recruitment

Healthy Inner Hair Cells (IHCs)
Act as transducers to transform basilar membrane vibration into action potentials in the neurones of the auditory nerve

Loss of IHCs

Consequences of IHC loss
1. Reduced efficiency of transduction leads to elevated absolute thresholds
2. “Noisy” transmission of information in the auditory nerve
3. No transduction of basilar membrane vibration
A Dead Region is a region of the cochlea where there are no functioning Inner Hair Cells and/or neurones (Moore, 2000)


Anatomically the extent of a Dead Region is defined in terms of “place” or distance along the basilar membrane.

Off-frequency listening
Basilar-membrane vibration in a Dead Region is not detected by the neurones innervating that region but via off-frequency listening.

Off-frequency listening detecting a tone via a place with characteristic frequency different from the frequency of the tone
Johnson-Davies & Patterson, 1979
Detection of tones falling within a Dead Region


The true hearing loss in a Dead Region is effectively infinite.

Dead Region and Audiogram

It is not possible to determine from the pure tone audiogram alone whether or not a patient has a Dead Region.
Dead Region and Audiogram

The data of Vinay and Moore (2006) indicate that, for each test frequency, 59% or more of ears had a Dead Region when the absolute threshold was above 70 dB HL. Therefore:

A Dead Region may be present when the absolute threshold is 70 dB HL or greater.

Dead Region is very likely to be present, if

The absolute threshold is \textbf{70 dB HL} or greater


59\% DEAD REGION prevalence

Identification of a Dead Region

1. Threshold-Equalizing Noise (TEN) test:
   - TEN(SPL) \cite{Moore2000}
   - TEN(HL) \cite{Moore2004}

2. Psychophysical tuning curve (PTC)
   - “Classical” method \cite{Kluk2005}
   - “Fast” method \cite{Sec2005}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{dead_region_chart}
\caption{Chart showing critical frequency levels for dead regions.}
\end{figure}

\begin{itemize}
\item Dead Region is very likely to be present, if
\item The absolute threshold is \textbf{70 dB HL} or greater
\item 59\% DEAD REGION prevalence
\end{itemize}
Diagnosis of Dead Region is crucial:

1. For counselling about the likely benefit from hearing aids
2. To help in the choice of hearing aid type or in deciding whether a person is a candidate for a cochlear implant
3. To help in fitting hearing aids appropriately

The TEN(HL) test for diagnosis of dead regions in the cochlea

- Simple and fast enough for clinical application
- Based on the detection of pure tone in the presence of a special noise

Threshold Equalizing Noise (TEN)

The noise is designed to produce almost equal masked thresholds in dB HL over the range 0.5 to 4 kHz, for normally hearing listeners and for listeners with hearing impairment but without dead regions.

EQUIPMENT:
- Two-channel audiometer with Telephonics TDH39, TDH49 or TDH50 earphones
- CD player
- TEN(HL) CD

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STEP BY STEP – setting up:

1. Feed the left output from the CD player to the left (or A) line-level input on the audiometer, and the right output from the CD player to the right (or B) input.


2. Select the left (or A) input channel 1 on the audiometer, and the right (or B) input for channel 2 on the audiometer.


3. Play track 1, set the audiometer so that both line inputs are played continuously (press the interrupt buttons), and adjust both VU meters to read 0 dB. Turn off the two inputs (press the interrupt buttons).

4. Mix the two channels, and direct the mixed channels to the desired ear (left or right).

To test Left ear:

To test Right ear:

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STEP BY STEP - testing:

5. Measure the absolute threshold (traditional Pure Tone Audiogram) for each ear at each frequency, using tracks 2-8 of the CD. Use a 2-dB final step size.

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STEP BY STEP - testing:

6. Set the desired noise level using the channel 1 control. The level in dB HL/ERB\textsubscript{N} corresponds to the dial reading on the audiometer.

![Graph showing frequency vs. level]

B.C.J. Moore, B.R. Glasberg and M.A. Stone, New version of the TEN test with calibrations in dB HL

STEP BY STEP - testing:

7. Measure the masked threshold for each ear at each frequency, using tracks 2-8 of the CD, while playing the noise continuously. Use a 2-dB final step size.

Desired noise level?

TEN(HL) level that (if possible) is 10 dB above the absolute threshold at the test frequency, or in the frequency region of interest (where a DR is suspected).

For example, if the absolute threshold = 70 dB HL, use a TEN(HL) level of 80 dB HL/ERB\textsubscript{N}.

B.C.J. Moore, B.R. Glasberg and M.A. Stone, New version of the TEN test with calibrations in dB HL
Reading on the audiometer

The pure tone level is controlled via channel 2.
The level in dB HL corresponds to the dial reading on the audiometer.

TEN(HL) Right
50

Pure Tone Right
52

Noise level = 50 dB HL/ERBN Masked Threshold = 52 dB HL

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STEP BY STEP - testing:
8. Repeat steps 4-6 for the other ear, if desired.
9. A Dead Region for a particular frequency is indicated by a masked threshold that is at least 10 dB above the absolute threshold and 10 dB above the TEN(HL) level per ERBN

Rationale behind the TEN(HL) test

Normal Hearing
In quiet In 60 dB/ERBN TEN

High-frequency Dead Region above 1.1 kHz
In quiet In 70 dB/ERBN TEN

TEN(HL) test – criteria for Dead Region

- Masked threshold 10 dB or more above the TEN level/ERB\(_N\)
  
  and

- Masked threshold 10 dB or more above the Absolute Threshold


TEN(HL) test - Normal Hearing

**NORMAL HEARING**

Masked thresholds = equal to = the nominal TEN(HL) level/ERB\(_N\)

ERB\(_N\) = equivalent rectangular bandwidth of the auditory filter at moderate sound levels for young listeners without any hearing loss

TEN(HL) test

**Hearing Loss without Dead Region**

- Masked thresholds less than 10 dB above the TEN level/ERB\(_N\)
  
  **NO DEAD REGION**

- 85 dBHL/ERB\(_N\)
- 95 dBHL/ERB\(_N\)

No Dead Region

TEN(HL) test

**Hearing Loss with Dead Region**

- Masked thresholds 10 dB or more above the TEN level/ERB\(_N\)
  
  **DEAD REGION**

- Masked thresholds 10 dB or more above the Absolute Threshold
  
  **High-Frequency Dead Region above 1.5 kHz**

- 85 dBHL/ERB\(_N\)
- 95 dBHL/ERB\(_N\)
**TEN(HL) test**

*Hearing Loss with Dead Region*

**DEAD REGION**

- Masked thresholds 10 dB or more above the TEN level/ERB

**and**

- Masked thresholds 10 dB or more above the Absolute Threshold

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**Presence of a Dead Region can influence perception of:**

1. **Loudness** → Rapid growth of loudness “super-recruitment” (McDermott et al. 1998)

2. **Pitch** → No clear pitch sensation (Huss and Moore, 2005)

3. **Speech** → For people with a Dead Region there may be little or no benefit to speech discrimination from amplifying frequencies well inside a DR (Baer, Moore and Kluk, 2002)

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**How to set up Aurical audiometer**

- **Select:**
  - speech
  - setup
  - options & 2 channels

- **To calibrate:**
  - Setup
  - Input sensitivity CD/T1

- **Save your setup:**
  - Setup
  - save as User Test

- **Select User Test**

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**Aurical → Johannes Lantz**
How to set up Siemens Unity audiometer

setup
- signal channels
  - CD1 in channel 1
  - CD2 in channel 2

To calibrate:
- Setup
  - Input sensitivity
    CD/T1

Settings
- task preferences
  IPSI

Choose test tone from CD player

Courtesy of Sinead Toal and Jonathan Profitt

Obtaining the **TEN(HL) CD**

http://hearing.psychol.cam.ac.uk/dead/TENCD.html

The preferred method of payment is by cheque or money order in pounds sterling or US dollars. The cost is UK £15 or US $25 including shipping. The cheque/money order should be made payable to B.C.J. Moore and sent to:

**Prof. Brian C.J. Moore**
Department of Experimental Psychology
University of Cambridge
Downing Street
Cambridge CB2 3EB, England

Be sure to include the mailing address where the CD should be sent.