Clinical Application of the Threshold Equalizing Noise Test in Patients with Hearing Loss of Various Etiologies: A Preliminary Study

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Background and Objectives: We aimed to make a preliminary assessment of the prevalence of cochlear dead regions (DRs) and the factors affecting the results of the threshold-equalizing noise (TEN) test in patients with hearing loss of various etiologies. Subjects and Methods: Between May and July 2014, 109 patients (191 ears) with hearing loss who visited our outpatient clinic were prospectively enrolled. Pure tone audiometry and TEN (HL) test were performed for all the patients. DR at each frequency was indicated by masked thresholds of ≥10 dB above the TEN level and ≥10 dB above the absolute threshold. Results: DR was present in 15.7% (n=30) of the 191 ears. According to disease entity, 16.6% of patients with sensorineural hearing loss had a DR. However, DR was absent in patients with chronic otitis media. According to audiometric configurations, DR was most common in moderately severe, flat hearing loss. Significantly worse hearing thresholds for both mean hearing level and hearing threshold at each frequency were found in the presence of DR (p<0.001). Logistic regression analysis showed that only the mean hearing level (odds ratio: 1.053, 95% confidence interval: 1.021–1.085) affected the presence of DR. Conclusions: Although performance of the TEN test is limited by frequencies and hearing levels, it provides additional information regarding DRs and may therefore have the potential to be used as a prognostic tool for diverse diseases causing hearing loss.

KEY WORDS: Threshold equalizing noise test  Hearing loss  Cochlear dead regions.
eral hearing loss: in fact, some do not even expect to be prescribed hearing aids for unconditional use.

The aim of this study was to make a preliminary assessment of the prevalence of DRs and the factors influencing the results of the TEN (HL) test in patients with hearing loss of various etiologies, not confined to sensorineural hearing loss.

Subjects and Methods

Between May and July 2014, we prospectively enrolled 109 patients (191 ears) with hearing loss who visited the outpatient clinic at Eulji University Hospital and agreed to participate in this study. The Institutional Review Board of Eulji University Hospital approved this study.

The following patient information was recorded: age, gender, presence of diabetes or hypertension, presence of tinnitus, and/or dizziness. One of three audiologists with more than five years’ experience performed pure tone audiometry and the TEN (HL) test using the MADSEN astera (GN Otometrics, Copenhagen, Denmark) with TDH-39 headphones in the sound booth. Pure tone air and bone thresholds were obtained at 0.25, 0.5, 1.0, 2.0, 4.0, and 8.0 kHz, and the TEN (HL) test was performed at 0.5 Hz, 1 kHz, 2 kHz, and 4 kHz. The mean hearing level was calculated using the arithmetic mean of the pure tone thresholds at 0.5, 1, 2, and 4 kHz.

For frequencies at which the absolute hearing threshold was ≤60 dB HL, the TEN level was set to 70 dB HL [3]. If the hearing loss exceeded 70 dB HL, the TEN level was set to 10 dB above the audiometric threshold at each frequency, up to a maximum of 86 dB HL. If the patient could not tolerate the loudness of the TEN, or if the maximal TEN level was reached, the TEN level was set equal to the audiometric pattern did not fall into low tone or high tone hearing loss categories. Total hearing loss was determined when the average hearing loss exceeded 90 dB [7]. The mean hearing levels were classified into six groups following the International Organization for Standardization (ISO 1964): normal, −25 dB; mild hearing loss, 26–40 dB; moderate hearing loss, 41–55 dB; moderately severe hearing loss, 56–70 dB; severe hearing loss, 71–90 dB; and profound hearing loss, ≥91 dB.

For statistical analyses, binary logistic regression analysis was conducted to identify the factors influencing the TEN (HL) test results among the factors identified by univariate analysis. All statistical analyses were performed using SPSS software (ver. 18.0, SPSS Inc., Chicago, IL, USA) and R Commander Plug-in for the EZR Package (RcmdrPlugin.EZR), and a p-value of <0.05 was considered significant [8].

Results

The baseline characteristics of the 109 patients (191 ears) included in this study are listed in Table 1. A total of 24 pa-

Table 1. Patients’ characteristics

| Factors                        | Values          |
|--------------------------------|-----------------|
| Age (years old)                | 56.29 ± 14.725  |
| Sex (male/female)              | 58/51           |
| Diabetes                       | 6 (5.5)         |
| Hypertension                   | 28 (25.7)       |
| Accompanying tinnitus          | 55 (50.5)       |
| Accompanying dizziness         | 18 (16.5)       |
| Mean hearing level (dB)        | 42.58 ± 25.23   |
| Audiometric configurations     |                 |
| Low-frequency hearing loss     | 7 (3.7)         |
| High-frequency hearing loss    | 100 (52.4)      |
| Flat hearing loss              | 75 (39.3)       |
| Total hearing loss             | 9 (4.7)         |
| Initial diagnosis              |                 |
| Acoustic trauma                | 1 (0.9)         |
| Chronic otitis media           | 8 (7.3)         |
| Herpes zoster oticus           | 2 (1.8)         |
| Meniere’s disease              | 7 (6.4)         |
| Sensorineural hearing loss     | 77 (70.6)       |
| Sudden hearing loss            | 14 (12.8)       |

Data were shown as the mean ± SD for continuous variables and number (%) for categorical variables. SD: standard deviation.
Dead Regions in Hearing Loss of Various Etiologies

Data were shown as number. Patients (22.1%) had a DR at one or more frequencies. Of the 191 ears, DR was detected in 30 ears (15.7%). Moreover, 28 patients (34 ears) showed an inconclusive result because of limit in the highest signal level at each frequency. Of these, 7 patients (7 ears) had both DR and inconclusive DR according to frequency.

According to the mean hearing level (Table 2), DR was the most common in patients with moderately severe hearing loss (50.0%), followed by those with severe hearing loss (33.3%), and moderate hearing loss (13.6%). In contrast, inconclusive DR was the most common in patients with profound hearing loss (100.0%), followed by those with severe hearing loss (76.2%), and moderately severe hearing loss (17.9%).

The presence of DR according to the hearing level showed a significant difference ($p<0.001$) (Table 2). In addition, the hearing threshold at each frequency with a DR was significantly higher than that at frequencies without a DR ($p<0.05$) (Fig. 1).

With regard to audiometric configurations (Table 3), flat hearing loss was the most common in patients with both DR and inconclusive DR. High-frequency hearing loss was the second most common in patients with DR; however, total hearing loss was the second most frequent in patients with inconclusive DR.

With regard to frequencies (Table 4), DR was the most common at 4000 Hz (n=20), followed by 1000 Hz (n=13), 2000 Hz (n=11), and 500 Hz (n=7). The number of frequencies that showed a DR was one (n=19), two (n=4), three (n=4), and all four frequencies (n=3). The overall detection rate of DR below 60 dB was 0.9%.

With regard to the disease diagnosed in the patient (Table 5), 16.6% of patients with sensorineural hearing loss had a DR. Similarly, DR was present in 14.3% of patients diagnosed with

### Table 2. Results of the threshold equalizing noise test according to degree of hearing loss

| Degree of hearing loss* | Number of ears | Positive DR* | Inconclusive DR* |
|-------------------------|----------------|--------------|------------------|
| Normal hearing (≤ 25 dB)| 62             | 0 (0.0)      | 0 (0.0)          |
| Mild hearing loss (26–40 dB)| 49      | 5 (10.2)     | 2 (4.1)          |
| Moderate hearing loss (41–55 dB)| 22     | 3 (13.6)     | 2 (9.1)          |
| Moderately severe hearing loss (56–70 dB)| 28     | 14 (50.0)    | 5 (17.9)         |
| Severe hearing loss (71–90 dB)| 21      | 7 (33.3)     | 16 (76.2)        |
| Profound hearing loss (≥ 91 dB)| 9       | 1 (11.1)     | 9 (100.0)        |

Data were shown as number (%) for categorical variables. *degree of hearing loss was classified following the International Organization for Standardization (ISO 1964). †$p<0.001$. DR: cochlear dead region

### Table 3. Results of the threshold equalizing noise test according to audiometric configuration

| Audiometric configuration | Positive DR* | Inconclusive DR* |
|---------------------------|--------------|------------------|
| Low-frequency hearing loss| 0 (0.0)      | 0 (0.0)          |
| High-frequency hearing loss| 8 (26.7)    | 5 (14.7)         |
| Mild hearing loss         | 4/8          | 2/5              |
| Moderate hearing loss     | 1/8          | 2/5              |
| Moderately severe hearing loss| 2/8        | 0/5              |
| Severe hearing loss       | 1/8          | 1/5              |
| Flat hearing loss         | 21 (70.0)    | 20 (58.8)        |
| Mild hearing loss         | 1/21         | 0/20             |
| Moderate hearing loss     | 2/21         | 0/20             |
| Moderately severe hearing loss| 12/21       | 5/20             |
| Severe hearing loss       | 6/21         | 15/20            |
| Total hearing loss        | 1 (3.3)      | 9 (26.5)         |

Data were shown as number (%) for categorical variables and number of affected ears/total numbers of ears for adjusting hearing levels. †$p<0.05$. DR: cochlear dead region

Fig. 1. Hearing threshold at each frequency according to the presence of cochlear dead regions (DRs).

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sudden hearing loss. In contrast, DR was absent in cases of chronic otitis media and Meniere’s disease.

Finally, binary logistic regression analysis showed that the mean hearing level was the sole factor that influenced the presence of DR (Table 6).

### Discussion

In this study, we assessed the prevalence of DRs and the factors influencing the results of the TEN (HL) test in patients with hearing loss of various etiologies. The strength of this study is that, for the first time in Korea, the TEN (HL) test was performed for patients with not only sensorineural hearing loss for hearing aid fitting but also hearing loss of various etiologies. We found that 22.1% patients (15.7% of the total 191 ears) with hearing loss who visited the outpatient clinic during the study period had a DR. Compared to previous studies reporting the prevalence of DR (31–57.4% based on patients, 23–46% based on ears), the prevalence of DR appears low in our study [4-6]. We argue that the reason for this low prevalence is that we performed a TEN test in all patients with hearing loss, regardless of the severity.

Interestingly, the prevalence of DR varied according to the final diagnosis of the patient (Table 5). Although patients with chronic otitis media showed the second highest pure tone thresholds, the highest being associated with acoustic trauma, DR was not detected in any of these patients. To our knowledge, the TEN test had not been previously performed in any of these patients. The region of the inner ear with hair cells responsible for high frequency sounds may be vulnerable to chronic otitis media [9]. Based on the results of this preliminary study, we assumed that the possibility of inner ear damage in chronic otitis media may not be too high or may be limited to specific regions. However, this assumption should be verified by further studies.

In this study, we found that DR was the most prevalent in the moderately severe hearing loss group (50.0%) (Table 2). On the other hand, inconclusive DR was more commonly found, rather than DR, in patients with profound hearing loss (100.0%). Of the 191 ears, 17.8% (34 ears) showed inconclusive DR and those were quite common. Thus, we couldn’t ignore these inconclusive results and we analysed these independently, not included in assessing DR. Although hearing loss of more than 90 dB is associated with the presence of DR [10], additional psychophysical tuning curves are not feasible to confirm DR in clinical settings. Thus, inconclusive DR is generally determined in patients with severe-to-profound hearing loss.

### Table 4. Distribution of pure tone thresholds and cochlear dead regions

| dB | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
|----|--------|--------|--------|--------|
| 0  | 5      | 3      | 2      | 5      |
| 5  | 12     | 14     | 9      | 2      |
| 10 | 23     | 11     | 13     | 7      |
| 15 | 25     | 25     | 13     | 11     |
| 20 | 17     | 18     | 15     | 1      |
| 25 | 16     | 11     | 14     | 14     |
| 30 | 13     | 15     | 18     | 9      |
| 35 | 11     | 9      | 10     | 11     |
| 40 | 7      | 12     | 11     | 15     |
| 45 | 10     | 10     | 11     | 12     |
| 50 | 2      | 5      | 8      | 12     |
| 55 | 7      | 5      | 10     | 10     |
| 60 | 3      | 5      | 7      | 10     |
| 65 | 7      | 6      | 5      | 8      |
| 70 | 1      | 6      | 7      | 10     |
| 75 | 2      | 3      | 10     | 7      |
| 80 | 7      | 3      | 3      | 5      |
| 85 | 2      | 5      | 2      | 5      |

### Table 5. Difference in the presence of cochlear dead regions according to disease entity

| Disease               | Mean hearing level (dB) | Number of DRs/total ears |
|----------------------|-------------------------|--------------------------|
| Acoustic trauma      | 63.75                   | 1/1                      |
| Chronic otitis media | 63.38 ± 15.18           | 0/10                     |
| Herpes zoster oticus | 53.13 ± 22.10           | 1/2                      |
| Meniere’s disease    | 26.07 ± 16.48           | 0/7                      |
| Sensorineural hearing loss | 40.69 ± 24.88   | 26/157                  |
| Sudden hearing loss  | 54.20 ± 28.91           | 2/14                     |

### Table 6. Results of univariate and logistic regression analyses for detection of cochlear dead regions

| Variable              | p value for univariate analysis | p value for logistic regression | Odds ratio | 95% confidence interval |
|-----------------------|---------------------------------|---------------------------------|------------|-------------------------|
| Age                   | 0.433                           | –                               | –          | –                       |
| Sex                   | 0.215                           | –                               | –          | –                       |
| Diabetes              | 0.065                           | 0.090                           | 3.533      | 0.820–15.217             |
| Hypertension          | 0.779                           | –                               | –          | –                       |
| Tinnitus              | 0.412                           | –                               | –          | –                       |
| Dizziness             | 0.740                           | –                               | –          | –                       |
| Affected side         | 0.778                           | –                               | –          | –                       |
| Mean hearing level    | <0.001                          | 0.001                           | 1.053      | 1.021–1.085              |
| Audiogram pattern     | 0.004                           | 0.158                           | 2.278      | 0.726–7.143              |

The mean hearing level was calculated using the arithmetic mean of the pure tone thresholds at 0.5, 1, 2, and 4 kHz.
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It is necessary to confirm the stability of the TEN (HL) test. Second, additional evaluation of the TEN test in a larger sample is necessary. Pepler, et al. [5] reported that the slope may only increase the prevalence of DR among 70 ears; however, they found that the presence of DR may vary according to the frequency. In addition, an isolated DR, limited to one frequency, was the most common according to the number of affected frequencies, which is similar to the findings of Hornsby and Dundas [12], although the clinical significance of this finding remains unknown.

Patients with flat hearing loss, especially with moderately severe hearing loss adjusted according to the hearing level, showed the highest prevalence of DR, which is in contrast to the results of a previous study that reported a close relationship between steep-sloping hearing loss and the presence of DR [11]. This difference may be attributed to the ambiguity of the audiometric criteria used [7] and worse hearing thresholds in patients with flat type hearing loss. Likewise, Pepler, et al. [5] reported that the slope may only increase the prevalence of DR according to increasing hearing impairment. Accordingly, in our study, logistic regression analysis revealed that the audiometric pattern was not associated with the presence of DR.

DR was the most frequently detected at 4000 Hz, which is consistent with the findings of a previous study [5]. This may suggest that the presence of DR may vary according to the frequency. In addition, an isolated DR, limited to one frequency, was the most common according to the number of affected frequencies, which is similar to the findings of Hornsby and Dundas [12], although the clinical significance of this finding remains unknown. For hearing aids fitting, application of TEN (HL) test at 2 kHz or below is recommended on the basis that amplification should be provided for frequencies up to 1.7 times the edge frequency of DR and the TEN test results at 3 kHz or above may not influence the audibility [5,6]. On the contrary, few studies report the significance of TEN test results in the management of hearing loss, unless hearing aid fitting is the goal. We believe that the TEN (HL) test may play a role in predicting the prognosis of inner ear diseases such as sudden hearing loss, which high frequency hearing loss is regarded as one of prognostic factors. Diseases such as sudden hearing loss, in which high frequency regions in new referrals and existing adult hearing aid users. Ear Hear 2004;25:478-87.
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Although performance of the TEN test is limited by frequencies and hearing levels, it provides additional information regarding DRs and may therefore be potentially used as a prognostic tool for diverse diseases causing hearing loss.

Acknowledgments

This research was supported by EMBRI Grants 2013 EMBRI-D00005 from Eulji University.

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