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DERLEME

Koklear Ölü Bölge Tespitinde Threshold-Equalizing Noise (TEN) Testinin Kullanımı

Muhammed PINAR[1], Özge KALE PEŞAN[2], Işılay ÖZ[3]

ÖZ

Koklear ölü bölgeler, iç tüy hücreleri ve/veya spiral ganglion nöronların işlevsiz olduğu, bu nedenle akustik sinyalin merkezi sinir sistemine iletilmediği bölgeler olarak tanımlanır. Bu bölgelerdeki frekanslara ait akustik sinyaller, yeterli şiddette olduğunda komşu sağlıklı bölgeler tarafından algılanabilmekte, bu durum frekans çözünürlüğünü ve nöral kodlamayı olumsuz etkilemektedir. İleri derecede sensörinöral işitme kaybı, keskin frekans düşüşleri ve konuşmayı ayırt etme güçlüğü gibi belirtiler koklear ölü bölge varlığına işaret etmektedir. Son yıllarda, koklear ölü bölgelerin tespit edilmesinde Threshold-Equalizing Noise (TEN) testi kullanılmaya başlanılmıştır. Bu derleme çalışmasında 2020-2025 yılları arasında PubMed, Web of Science ve Scopus elektronik veri tabanlarında yayımlanan çalışmalar," threshold-equalizing noise" anahtar kelimesi kullanılarak incelenmiştir. Bu doğrultuda derleme çalışmamızda, TEN testinin koklear ölü bölge değerlendirilmesindeki rolü ortaya konmuştur. Literatürde TEN testinin eşiğinin şiddet ve frekanstan bağımsız olduğu, ani sensörinöral işitme kaybının prognozunun belirlenmesinde kullanılabileceği, tinnituslu bireylerin koklear ölü bölge belirlenmesinde kullanılmasının gerektiği ancak bu testin yetersiz kalabileceği, TEN testinin iç tüy hücresi disfonksiyonunu göstermesine rağmen dış tüy hücresi disfonksiyonunu da yansıtabileceği, şiddetli akut solunum yolu sendromu koronavirüs 2'nin erken döneminde koklear ölü bölge belirlemede yetersiz kaldığı ve testin uygulanmadığı bireyler için akustik değişim kompleksi ile normların oluşturulması gerektiği bildirilmiştir. Ayrıca TEN testinin yapay zekâ ile bütünleştirilerek öngörü gücünün artırılabileceği de bildirilmiştir. TEN testinin koklear ölü bölgeyi saptamada kullanımına ilişkin sınırlı sayıda çalışma bulunması nedeniyle, klinik kullanımının genişletilmesi için daha fazla araştırma yapılması önerilmektedir.

Anahtar Kelimeler: Gürültü; İşitme eşiği; Koklear

Use of Threshold-Equalizing Noise (TEN) Test in Detecting Cochlear Dead Region

Muhammed PINAR[1], Özge KALE PEŞAN[2], Işılay ÖZ[3]

ABSTRACT

Cochlear dead regions (DR) are defined as areas where inner hair cells and/or spiral ganglion neurons are nonfunctional, resulting in the failure of acoustic signals to be transmitted to the central nervous system. Acoustic signals corresponding to the frequencies within these regions, when presented at sufficiently high intensities, may be detected by adjacent healthy regions; however, this phenomenon negatively affects frequency resolution and neural encoding. Clinical indicators such as profound sensorineural hearing loss, steeply sloping audiometric configurations, and difficulties in speech discrimination suggest the presence of cochlear dead regions. In recent years, the Threshold-Equalizing Noise (TEN) test has been increasingly utilized for the detection of cochlear dead regions. In this review, studies published between 2020 and 2025 in the electronic databases PubMed, Web of Science, and Scopus were analyzed using the keyword "threshold-equalizing noise." Accordingly, our review highlights the role of the TEN test in the assessment of cochlear dead regions. The literature reports that the TEN test threshold is independent of both stimulus intensity and frequency; it may be used to determine the prognosis of sudden sensorineural hearing loss; it should be employed in the identification of cochlear DR in individuals with tinnitus, although it may be insufficient in some cases; TEN test reflects not only inner hair cell dysfunction but also outer hair cell dysfunction; it has limitations in detecting cochlear dead regions during the early stages of severe acute respiratory syndrome coronavirus 2 infection; and that acoustic change complexes should be used to establish normative data in populations where the test has not been applied. It has also been reported that the predictive power of the TEN test can be enhanced by integrating it with artificial intelligence. Due to limited studies on the TEN test for identifying cochlear DR, further research is recommended to expand its clinical use.

Keywords: Auditory threshold; Cochlear; Noise

[1]Department of Audiology, Institute of Health Sciences of Başkent University, Ankara, Turkey.
[2]Department of Audiology, Health Sciences Faculty of Başkent University, Ankara, Turkey.
[3] Department of Otolaryngology, Medical Faculty of Başkent University, Ankara, Turkey.
Sorumlu Yazar: Muhammed PINAR
E-posta adresi: ody.muhammedpinar@gmail.com **ORCID No:** 0000-0002-0899-5298
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INTRODUCTION

Cochlear dead regions (DR) are defined as areas where inner hair cells and/or their associated spiral ganglion neurons are non-functional (1). In these regions, the acoustic signal generated by the basilar membrane cannot be transmitted to the central nervous system. However, when the acoustic signal corresponding to the frequency of the dead region is presented at sufficient intensity, it may spread basally or apically along the basilar membrane. This spread can be detected in adjacent regions where functional inner hair cells and spiral ganglion neurons are located. Such spread particularly during the processing of acoustic signals at or near the dead region frequency may lead to degraded frequency resolution and ambiguities in neural coding (2). The presence of severe or profound sensorineural hearing loss, threshold values of ≥70 dB HL at the corresponding frequencies, steeply sloping audiometric configurations, poor speech discrimination scores, or patient reports of distorted or "buzzing" sounds may provide clues regarding the existence of cochlear dead regions (3).

Psychophysical tuning curves (PTCs) and masking techniques such as the Threshold-Equalizing Noise (TEN) test have been employed for the identification of cochlear dead regions (4,5,6). The TEN test enables the assessment of how an individual perceives sounds based on the use of off-frequency information. During the procedure, a specially designed spectrally shaped masking noise is presented ipsilaterally together with pure tones in order to produce spectrally altered masked thresholds, and the masked thresholds of the individual are measured. Two main versions of the TEN test exist: the sound pressure level (SPL)-calibrated version, which allows measurements at frequencies between 250 Hz and 8 kHz, and the hearing level (HL)-calibrated version, which is applied within the 500 Hz–4 kHz range (7,8). The HL-calibrated TEN test, owing to the reduced discomfort of spectrally narrowed masking noise at high intensity levels, is particularly suitable for detecting possible cochlear dead regions in individuals with severe hearing loss (9).

Prior to the application of the TEN test, air-conduction hearing thresholds must be determined. In clinical practice, the TEN test is typically conducted at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz using a 2 dB step-size threshold search method.

The stimuli are presented ipsilaterally (both pure tone and TEN noise delivered to the same ear). For the suspected dead region ear, when the threshold at the test frequency is <60 dB HL, TEN noise is presented at 70 dB HL; when the threshold is ≥70 dB HL, TEN noise is presented at 10 dB sensation level (SL); and when the threshold is ≥90 dB HL, TEN noise is presented at threshold level. A cochlear dead region at a given frequency can be confirmed when the masked threshold in TEN noise exceeds the unmasked threshold by ≥10 dB, and the masked threshold is ≥10 dB above the TEN noise level (3,10).

Identification of cochlear dead regions is critical for accurate assessment of hearing loss and optimization of individualized hearing aid fittings. Amplification at frequencies corresponding to dead regions may degrade rather than improve hearing quality. Therefore, determining the presence and location of dead regions may help restrict amplification at those frequencies, facilitate more effective frequency-specific adjustments, and enhance speech discrimination ability (11). Furthermore, identification of cochlear dead regions plays a critical role in cochlear implant (CI) candidacy selection and electrode placement planning. In particular, for patients receiving electric–acoustic stimulation (bimodal or hybrid CI), amplification at dead region frequencies should be restricted or avoided, as patients may derive minimal or no benefit. Cochlear dead regions identified by the TEN test provide valuable information for guiding electrode insertion depth and frequency mapping strategies (12). The aim of this study is to investigate the use of the Threshold-Equalizing Noise (TEN) test in the evaluation of cochlear dead regions and to raise awareness on this topic.

METHOD

Research strategy

Published studies on Threshold-Equalizing Noise (TEN) were reviewed through a comprehensive literature search. Electronic databases including PubMed, Web of Science, and Scopus were searched for studies published between 2020 and 2025 using the keyword “threshold-equalizing noise.”

Research questions

The following research questions were defined: ‘’ Has the Threshold-Equalizing Noise (TEN) test

been used in the evaluation of cochlear dead regions in the literature?'' and '' What findings have been reported regarding the use of the TEN test in the evaluation of cochlear dead regions?''

Study selection

The PRISMA flow diagram used for study selection is shown in Figure 1 (13). Twenty records were screened according to the PRISMA flow diagram. Ten articles were deemed suitable for this study and were reviewed. Nine of the articles were excluded because they did not include the TEN test used in audiology, and one article was excluded because it did not share the study findings. Data from the ten included studies were used in this study.

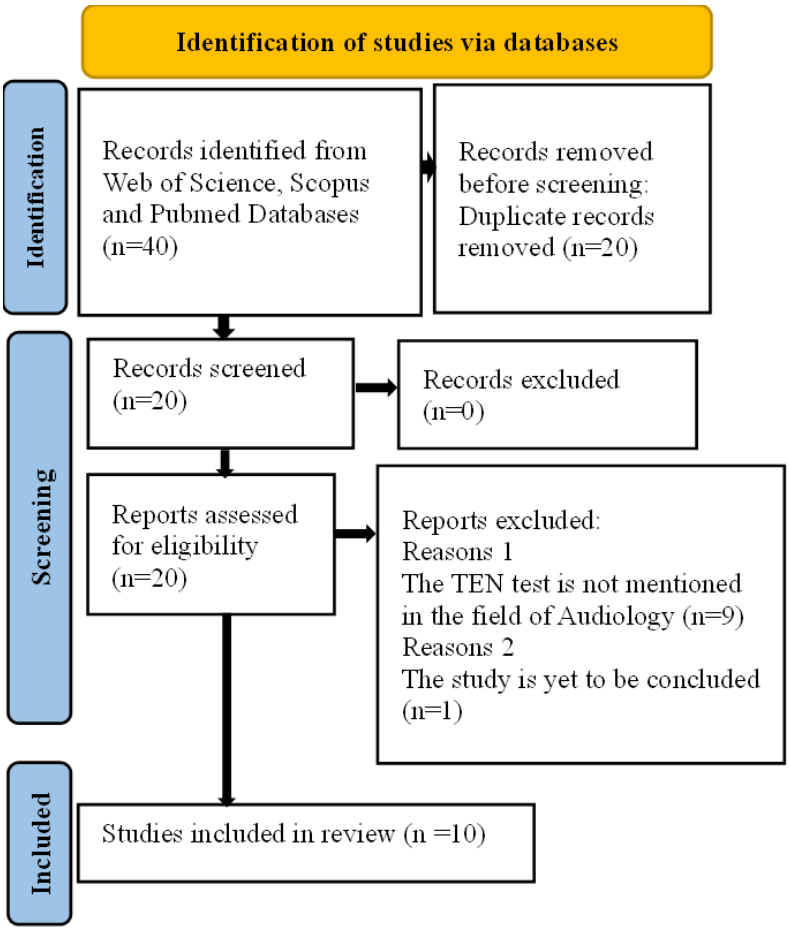

Figure 1. PRISMA Flow Diagram

RESULTS

Literature findings on the use of the threshold-equalizing noise (TEN) test in detecting cochlear dead regions

Vinay et al. (14) investigated the effects of age, stimulus frequency, and different TEN(HL) intensity levels on TEN test thresholds at 0.5, 1, 1.5, 2, 3, and 4 kHz with TEN levels of 30, 50, and 70 dB. They reported no differences between young and older normal-hearing adults, regardless of TEN level or test frequency. However, in older adults, thresholds were reported to be elevated, particularly at higher frequencies and higher TEN levels (14).

Choi et al. (15), in a prospective study on patients with sudden sensorineural hearing loss (SSNHL), evaluated the prevalence and clinical impact of cochlear dead regions. Systemic and/or intratympanic steroids were administered within the first month of symptom onset, and TEN(HL) testing was performed before and after treatment. Based on TEN test results, overall prevalence of dead regions was 20.8%, with frequency-specific prevalence at 6.7%. Although baseline pure-tone thresholds did not differ significantly between groups, word recognition scores and treatment-related hearing gains were poorer in the dead region group. The authors suggested that the TEN test may be useful in evaluating SSNHL prognosis (15).

Çınar et al. (16) assessed the early effects of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection on cochlear hair cells. Despite elevated high-frequency thresholds, no cochlear dead regions were detected using TEN testing. However, significant threshold shifts were observed at high frequencies, suggesting early functional changes in the basal cochlea during SARS-CoV-2 infection, detectable only with specialized measures (16).

Stone et al. (17) examined associations between TEN(HL) thresholds, age, hearing thresholds, and noise exposure. Increases in TEN thresholds were strongly related to absolute hearing thresholds, even within clinically “normal” ranges, but not to noise exposure. The authors concluded that the TEN test may reflect general cochlear dysfunction linked to outer hair cell impairment rather than inner hair cell loss, cautioning against its use beyond a pass/fail tool for dead region detection (17).

Table 1. Studies Included in the Review and Their Results.

Year	Researchers	Type of Study	Number of People/Studies Included	Test Method	Conclusions
2020	Vinay et al.	Original Article	n_s=36	TEN(HL)	TEN(HL) thresholds did not vary with TEN severity levels or test frequencies, and were found to be higher in elderly individuals.
2020	Choi et al.	Original Article	n_s=130	TEN(HL)	Use of the TEN(HL) test has been suggested for evaluating the prognosis of SSNHL patients.
2020	Kara et al.	Original Article	n_p=9, n_C=30	Unspec.	The TEN test has been reported to be a valuable tool for evaluating cochlear dead regions in normal hearing individuals with tinnitus.
2021	Chang et al.	Original Article	n_p=380	TEN(HL) SMOTE	Machine learning models developed with TEN test data have been reported to be an artificial intelligence-based predictive tool beyond the clinical tool.
2022	Stone et al.	Original Article	n_s=112	TEN(HL)	It has been reported that the TEN(HL) test reflects outer hair cell dysfunction.
2022	Cinar et al.	Original Article	n_p=25	Unspec.	It has been reported that cochlear dead regions cannot be detected early in SARS-CoV-2 infection using the TEN test.
2023	Can et al.	Original Article	n_p=31, n_C=21	Unspec.	The TEN test has been suggested as an important and complementary tool for evaluating tinnitus in normal hearing individuals with tinnitus.
2025	Pavlidis et al.	Original Article	n_p =40, n_C=20	Unspec.	It has been reported that the TEN test can be used to evaluate inner hair cell function in normal hearing individuals with tinnitus.
2025	Zoghba et al.	Original Article	n_p=25, n_C=25	Unspec.	It has been reported that the TEN test may be insufficient in detecting cochlear dead regions in normal hearing individuals with tinnitus.
2025	Schelenz et al.	Original Article	n_s=23	TEN(HL)	It has been suggested that the development of frequency-dependent ACC norms is necessary for evaluating individuals for whom the TEN test cannot be administered.

Abbrevations: *ns; number of studies included, np; number of patients, nC; number of control, Unspec.; Unspecified, TEN; Threshold-equalizing noise, TEN(HL); Threshold-equalizing noise (hearing level), SSNHL; Sudden sensorineural hearing loss, SARS-CoV-2; Severe acute respiratory syndrome coronavirus 2, ACC; Auditory change complex*

Schelenz et al. (18) compared three methods of detecting the Auditory Change Complex (ACC) for objective identification of cochlear dead regions, given the limited applicability of TEN testing in infants, young children, and some adults. In normal-hearing adults, the bootstrap method proved the most efficient and rapid. They emphasized the importance of developing frequency-dependent ACC norms for patients in whom TEN testing is not feasible (18).

In recent years, the TEN test has emerged as an important complementary tool in the evaluation of cochlear dysfunction in individuals with tinnitus. Kara et al. (19) found cochlear dead regions in 75% of normal-hearing tinnitus patients using the TEN test, suggesting that inner hair cell damage may contribute to tinnitus, even when conventional audiometry shows normal thresholds. Can et al. (20) reported differences in TEN test outcomes between tinnitus patients with and without hearing loss, with dead regions also detected in normal-hearing tinnitus subjects, underscoring the limitations of standard audiometry. Pavlidis et al. (21) highlighted the complementary role of TEN testing and otoacoustic emissions (OAE) in detecting degeneration of both inner and outer hair cells in tinnitus patients.

Zoghba et al. (22), in patients with tinnitus and normal hearing, found no cochlear dead regions via TEN testing, suggesting that dead regions may not be directly related to hidden hearing loss (HHL). Despite negative TEN results, synaptopathy was evident in other electrophysiological measures, indicating that TEN may be insufficient for diagnosing hidden hearing loss (22).

Chang et al. (23) developed a machine-learning model using TEN test data to predict cochlear dead regions. Analyses with oversampled balanced datasets demonstrated that the TEN test could serve not only as a clinical tool but also as an artificial intelligence (AI)-supported predictive method (23). The included studies and their key features are summarized in Table 1.

CONCLUSION

The Threshold Equalizing Noise (TEN) test can be used as an important diagnostic tool in the evaluation of cochlear dead regions. In the literature, it has been reported that the TEN threshold does not vary according to TEN intensity level or test frequency, but reaches higher values in older individuals; that it may be used to determine

prognosis in patients with SSNHL; that data from the TEN test can serve as an AI–based predictive tool; that ACC norms should be established for individuals in whom the TEN test cannot be administered; and that the test may aid in detecting cochlear dead regions in normal-hearing individuals with tinnitus and in evaluating inner hair cell function. Furthermore, it has been suggested that the TEN test may also reflect outer hair cell dysfunction. However, it has been stated that the TEN test is insufficient for detecting cochlear dead regions in the early stage of SARS-CoV-2 infection. Although it has been stated that the test can be used as a complementary tool in the evaluation of tinnitus in normal-hearing tinnitus patients, it has also been reported that it may be inadequate in determining cochlear dead areas in some cases. While these findings demonstrate that the TEN test can provide valuable information in a variety of clinical situations, its limitations must also be considered.

A limitation of this review is that it only includes studies from the past five years. The literature reveals that there is a limited number of studies on the use of the TEN test in the evaluation of cochlear dead regions. Moreover, no studies have been identified regarding the use of the TEN test in determining cochlear dead regions in hearing aid or cochlear implant users. Further research in this field is needed, and it is recommended that the use of the TEN test in clinical practice be expanded.

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