GMJ 2025;36:58-64

DOI: http://dx.doi.org/10.12996/gmj.2024.4153

The Importance of Detailed Audio-Vestibular Monitoring in Familial Non-Syndromic Hearing Losses: A Longitudinal Study

Genetik Non-sendromik İşitme Kayıplarında Kapsamlı İşitsel-Vestibüler Takibin Önemi: Boylamsal Bir Çalışma

Burak Kabiş, Nuriye Yıldırım Gökay

Department of Audiology, Gazi University Faculty of Health Science, Ankara, Türkiye

Objective: This study aimed to evaluate the audiological and vestibular findings of two family members with progressive sensorineural-type hearing loss at high frequencies according to age.

Methods: Pure tone audiometry, speech audiometry, and immittancemetry tests were performed for audiological evaluation of the two families participating in the study. A total of 11 volunteers were included: the mother, father, and three children from the first family; and the mother-father and four children from the second family. A videonystagmography was performed to rule out neurological diseases. A computerized dynamic posturography (CDP) was performed to evaluate postural control. Audiovestibular findings were recorded by year and analyzed using SPSS v.24. program.

Results: Sensorineural-type hearing loss, which was evident at high frequencies, was detected in all family members. A significant progressive deterioration was observed in the hearing thresholds of family members and in the CDP results over the years.

Conclusion: This study revealed that audiovestibular follow-up is essential for genetic hearing loss. The findings demonstrated the importance of follow-up and genetic counseling in terms of progressive hearing loss, even when newborns undergo hearing screening.

Keywords: Hearing loss, vestibular, genetic, gene mutation, early intervention, computerized dynamic posturography

Amaç: Bu çalışmada, yüksek frekanslarda progresif sensörinöral tip işitme kaybı olan iki aile bireylerinin yaşlara göre odyolojik ve vestibüler bulgularının değerlendirilmesi amaçlanmıştır.

Yöntemler: Çalışmaya katılan iki ailenin odyolojik değerlendirmesi için saf ses odyometrisi, konuşma odyometrisi ve immitansmetri testleri yapılmıştır. İlk aileden anne, baba ve üç çocuk; ikinci aileden anne-baba ve dört çocuk olmak üzere toplam 11 gönüllü çalışmaya dahil edilmiştir. Nörolojik hastalıkları ekarte etmek için videonistagmografi yapılmıştır. Postüral becerileri değerlendirmek için bilgisayarlı dinamik postürografi (CDP) yapılmıştır. Odyostestibüler bulgular yıllara göre kaydedilmiş ve SPSS v.24. programı kullanılarak analiz edilmiştir.

Bulgular: Tüm aile bireylerinde yüksek frekanslarda düşüş gösteren sensörinöral tip işitme kaybı tespit edilmiştir. Aile bireylerinin işitme eşiklerinde ve CDP sonuçlarında yıllar içinde belirgin progresif bir düşüş gözlenmiştir.

Sonuç: Bu çalışma, odyovestibüler takibin genetik işitme kaybı için önemli olduğunu ortaya koymuştur. Yenidoğan işitme taramasından geçilse bile progresif işitme kaybı açısından takibin ve genetik danışmanlığın önemi ortaya konmuştur.

Anahtar Sözcükler: İşitme kaybı, vestibüler, genetik, gen mutasyonu, erken müdahale, bilgisayarlı dinamik postürografi

Cite this article as: Gökay NY, Kabiş B. The Importance of detailed audio-vestibular monitoring in familial non-syndromic hearing losses: a longitudinal study. GMJ. 2025;36:58-64

Address for Correspondence/Yazışma Adresi: Nuriye Yıldırım Gökay, Department of Audiology, Gazi University Faculty of Health Science, Ankara, Türkiye
E-mail / E-posta: nuriye.yildirim94@gmail.com
ORCID ID: orcid.org/0000-0003-2161-6579

Received/Geliş Tarihi: 24.03.2024
Accepted/Kabul Tarihi: 25.08.2024
Publication Date/Yayınlanma Tarihi: 09.01.2025

INTRODUCTION

Many studies on genetics and hearing have revealed that more than 95 genes are associated with non-syndromic hearing loss (1). Congenital hearing loss is a common problem affecting approximately 12 out of 1000 live births. Hereditary forms of hearing loss can be viewed as syndromic, with other additional concerns, or as non-syndromic forms (causing only hearing loss). Some epidemiological studies on this issue have indicated that approximately 50% of congenital hearing losses are genetic hearing losses (2,3). Approximately 20% of non-syndromic sensorineural hearing loss cases are autosomal dominant (DFN-A). This type of hearing loss usually has a delayed onset. Approximately 80% of non-syndromic sensorineural hearing loss cases are autosomal recessive (DFN-B), which is usually congenital, but some forms may occur later in life (4). Until now, a total of 125 deafness (DFN) mutations have been described in the literature, including 58 DFN-A loci and 63 DFN-B loci (4,5). Several genes play a role in many inner ear functions, such as hair cell movement, hair cell stimulation, intracellular transport, neurotransmitter release, and ionic homeostasis. The physiology and structure of the inner ear are more unique than those of other anatomical regions and are encoded by many genes. Some mutations in these related genes can result in sensorineural hearing loss (6-8). A number of studies have investigated the impact of genetic mutations on vestibular function (9-11). In individuals with *DFN* gene mutations, it has been reported that vestibular functions, as well as hearing performance, are adversely affected (9,10). In particular, in certain gene mutations, such as DFN-1, substantial loss of Scarpa ganglion cells can negatively affect the functions of vestibular cells (9). The close relationship between genetics and hearing loss has been a subject of interest for researchers for years. A review study showed that hearing loss affecting the inner ear is observed in people diagnosed with *DFN* gene mutations (2). A study on immigrants suggested that the Connexin protein, which is related to the *DFN* gene, causes congenital hearing loss (12). Genetic analysis of children with hearing loss born between certain years was performed, and hearing loss was observed in another study conducted in collaboration with the neonatal unit (13). A longitudinal analysis of hearing loss in a Dutch family revealed that mutations linked to the DFNA20/26 locus cause DFN-A sensorineural hearing loss (14). A longitudinal study of highly variable hearing loss due to POU4F3 (c.37del) across decades found early-onset and slowly worsening hearing loss (15). Many studies have been based on different loci regarding the characteristics and progression of *DFNA* genetically inherited sensorineural hearing loss (16,17). Some studies on audiological phenotype and progression have shown that *DFNA* gene mutations cause sensorineural and progressive hearing loss (18,19). Moreover, limited studies have been conducted on the vestibular skills of individuals with DFN-A inherited sensorineural hearing loss (10,20). The primary purpose of the current study was to present a longitudinal analysis of the audiological profile and vestibular skills of members of two families with *DFN* genetic hearing loss over the 5-year period. It is assumed that the current study will significantly contribute to the literature by evaluating vestibular performance along with the audiological phenotype and by following up the cases of two families for 5 years. To the authors' best knowledge, the current study may be helpful in counseling parents and their children regarding the prognosis of hearing loss, predicting recurrence in future children, and determining audiological intervention options.

MATERIALS AND METHODS

The Gazi University Rectorate Ethics Commission (approval number: 15, date: 05.09.2023). First, informed consent forms were obtained from the participants.

Participants

Two volunteer families with genetic hearing loss compatible with *DFN* gene transfer were included in the present study. A total of 11 volunteers were included: the mother, father, and three children from the first family; and the mother-father and four children from the second family. The audiological findings of the family members were followed at almost 1-year intervals for 4 years (three measurements). The vestibular results of the family members were also followed at nearly 1 year intervals for 5 years (four measurements). The socioeconomic and educational levels of families are moderate. The hearing aid use ranged from 2 to 3 years. In addition, all participants received limited benefit from hearing aids and did not use them regularly despite optimum fitting practices. The newborn hearing screening results of only two children and parents with hearing loss were unknown; the other children passed. The demographic characteristics of the volunteer family members are presented in Table 1.

Methods

The study design is longitudinal. The volunteer family members with genetic hearing loss were evaluated by air conduction and bone conduction hearing thresholds, speech recognition score, and uncomfortable sound separately for the right and left ears. The octave frequencies between 125 and 8000 Hz were examined using pure-tone audiometry. Pure tone hearing thresholds and speech audiometry were evaluated with supra-aural headphones, a B71 bone vibrator, and a GSI audiometer by a single researcher in a quiet-insulated cabin. The average pure-tone hearing thresholds (21) were taken as the mean air-conduction hearing thresholds at 500, 1000, 2000, and 4000 Hz (22). All volunteers were diagnosed with sensorineural hearing loss; no air-bone gap was detected in their hearing thresholds. In addition, a difference of at most 10 dB HL was observed between the right and left ears in terms of the average pure-tone hearing thresholds, and the volunteers' hearing losses were found to be symmetrical. Also, the MRI findings of all participants were reported as normal. The speech recognition test was performed using supra-aural headphones with a standard three-syllable word list (22). Although the volunteers did not complain of vertigo, they did complain of dizziness and imbalance. On the other hand, computerized dynamic posturography (CDP) and videonystagmography (VNG) tests were used to evaluate the vestibular skills of participants with hearing loss. The VNG ensures that clinicians can track and record eye movements in real-time. Eye movements were measured and analyzed using computer software and a video monitor. VNG refers to the center of the pupils, and the components of horizontal and vertical eye flicker were recorded in this study (23,24). VNG was used to rule out central vestibular pathologies. Since the VNG findings were not directly related to the study hypotheses, they were not analyzed in detail, and the

Table 1. Demographic information

CASES		Age	G	NHS	IHLC	MRI/CT (Cochlear/nerve anomalies)	HA	V/D
F-1	F1S1	13	F	P	Three years ago	N	One year	No
	F1S2	19	F	P	Five or six years ago	N	Two years	D
	F1S3	24	M	Unknown	Six or seven years ago	N	Two years	V/D
	F1F	59	M	Unknown	Since ten years old	N	Twenty years	V/D
	F1M	55	F	Unknown	No	Unknown	No	No
F-2	F2S1	12	M	P	Three years ago	N	Five years	No
	F2S2	13	F	P	Three or four years ago	N	Three years	No
	F2S3	17	F	P	Seven years ago	N	Three years	D
	F2S4	19	F	Unknown	Since eight years old	N	Three years	V/D
	F2M	44	F	Unknown	Since twelve or thirteen years old	N	No	V/D
	F2F	42	M	Unknown	No	Unknown	No	No

G: Gender, NHS: Newborn hearing screening, IHLC: Initial of hearing loss complaints, MRI: Magnetic resonance imaging, CT: Computer tomography, HA: Hearing aids, V: Vertigo, D: Dizziness, F-1: First family, F-2: Second family, S1: First sibling, S2: Second sibling, S3: Third sibling, S4: Fourth sibling, F1M: Mother in the first family, F2M: Mother in the second family, F1F: Father in the first family, F2F: Father in the second family, F: Female, M: Male, P: Pass, N: Normal

findings of all participants were obtained at normal reference values. The volunteers were invited to the clinic for their baseline vestibular assessment, where they underwent sensory organization testing (25) using the dynamic posturography system. The SOT test comprises six conditions, each performed in two replicates. These conditions are as follows: 1) eyes open, fixed visuality, and surface 2) eyes closed, fixed surface 3) eyes open, moving visual environment, and fixed surface 4) eyes open, fixed visual environment, and moving surface 5) eyes closed, moving surface 6) eyes open, moving visual environment, and moving surface. The CDP software calculates the scores for each condition and the composite score. During the posturography test, volunteers were supported with a seat belt as a precaution against falling (26,27). Accordingly, the VNG values of all the volunteers were normal with regard to the central vestibular system pathologies.

Statistical Analysis

The case data are presented as descriptive statistics. Descriptive statistics are presented as mean and direct numerical values. The averages of the siblings in each family were calculated to show the change in audiovestibular values over time. However, parental values with and without hearing loss were not included in the average and were presented separately in the graphs. While three measurements (1^{st}: First measurement, 2^{nd}: First-year measurement, 3^{rd}: Fourth year measurement) were used for pure tone audiometry thresholds, four measurements (1^{st}: First measurement, 2^{nd}: First-year measurement, 3^{rd}: third-year measurement, 4^{th}: fifth-year measurement) were used for vestibular evaluation.

RESULTS

The results of the study are presented according to progressive data and the results of each individual. Table 1 shows details about age, gender, newborn hearing screening, initial hearing loss, anomalies of the cochlear and/or acoustic nerve, duration of using hearing aids, and complaints related to vertigo and/or dizziness for a total of 11 individuals in both families. Most newborn hearing screenings were "pass" for hearing loss, and concerns about hearing loss in both families began in the post-lingual (>six age) period. Furthermore, no cochlear or nerve abnormalities were discovered based on the MRI and CT scan results.

Figure 1 shows an alteration in the individuals' pure-tone audiometry thresholds between 0.125 and 8 kHz for both families. The average of the mother's and father's hearing thresholds from the three measurements are shown separately in both graphs. The siblings' hearing thresholds at all frequencies were averaged and presented as three different measurements. As observed in both families, thresholds decreased at 1 kHz; however, this pattern was apparent in the second family. Observing the mother's threshold in the second family and the father's threshold in the first, it is found that while both thresholds of the mother and father were comparable to those of their siblings, the mother's threshold had more notable drops in the middle frequencies in the first family. Furthermore, Table 2 presents the average thresholds between 0.5-4 kHz and speech audiometry (speech recognition threshold, speech discrimination (SD), and loudness discomfort level) information about each member of the families. In relation to these findings, significant declines in SD scores were noted in conjunction with hearing progression in both families. The CDP results for general vestibular system functions are presented in Table 2. Figure 2 also shows the variation in the CDP SOT findings for the parents and siblings in both families according to the four measurements. Likewise, according to audiological data, the vestibular results differ by years and between family members. Proprioceptive and composite scores showed progression, particularly in vestibular scores, but somatosensory and visual scores showed no change. Figure 2 shows the average number of children, with the progression over time highlighted. However, the vestibular scores of each individual are presented in Table 2.

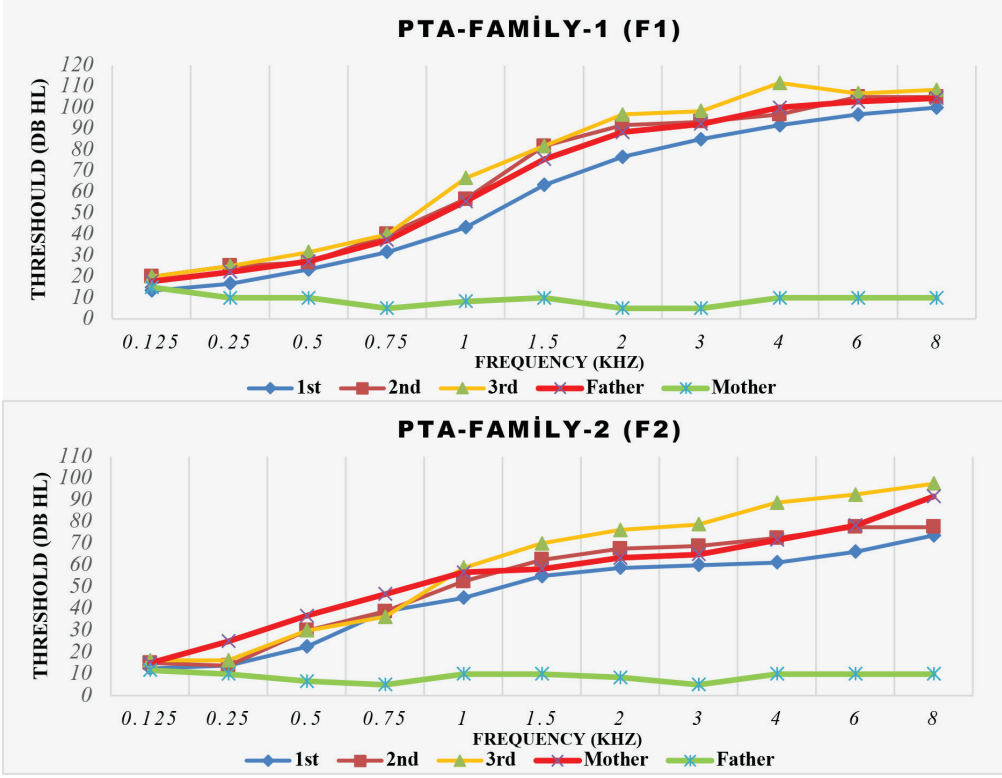

Figure 1. Pure tone audiometry hearing thresholds between 0.125-8 kHz of individuals in two families

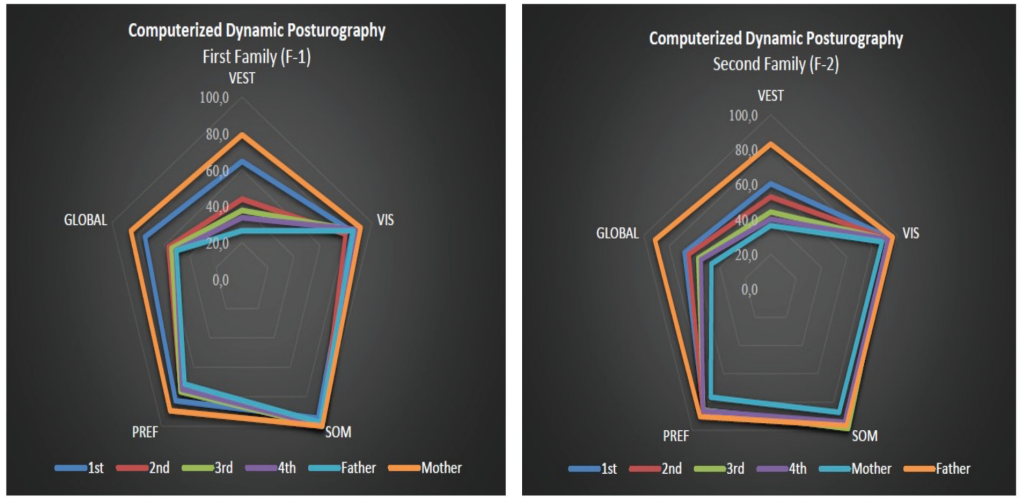

Figure 2. Computerized dynamic posturography sensory organization Test findings of families

DISCUSSION

This study examined post-lingual progressive sensorineural hearing loss with high-frequency slopeing longitudinally in two families with *DFN* gene mutations. In addition, follow-up data on the participants' vestibular performance were also presented. Although the genetic factors related to hearing are not fully understood, studies on this subject have been ongoing for 26 years. As in every disease group, a detailed evaluation of hearing is critical in the presence of genetic hearing loss. Although clinics have different practices in the assessment of genetic hearing loss, pure tone audiometry, tympanometry, otoacoustic emission, and auditory brainstem response are frequently used audiological evaluation tools in routine (28,29). The current study similarly evaluated participants longitudinally using pure tone audiometry, speech audiometry, immitanmetry, and vestibular tests. Accordingly, progressive and

Table 2. The average 0.5-4 kHz pure tone audiometry thresholds of individuals in both families, speech audiometry results, and sensory organization test results in computerized dynamic posturography

Cases		Audiometry				CDP				
		PTA dB	SRT dB	SD	LDL dB	SOM	PREF	VIS	VES	CS
F-1	S1	62.50	70	24	90	100	80	94	40	59
	S2	75	65	12	85	100	75	80	41	54
	S3	75	75	8	80	98	70	90	20	40
	F	75	95	0	80	90	64	85	20	41
	M	8.50	10	100	100	100	90	95	80	88
F-2	S1	67.50	50	70	100	97	85	88	35	52
	S2	56.25	35	52	90	100	82	96	51	57
	S3	67.75	45	50	90	90	88	96	25	49
	S4	60.75	45	60	85	90	90	90	50	62
	M	68.75	45	34	80	86	81	89	30	40
	F	8.75	10	100	100	92	91	94	90	94

CDP: Computerized dynamic posturography, PTA: Pure tone audiometry threshold (dB), SRT: Speech recognition threshold (dB), LDL: Loudness discomfort level (dB), SOM: Somatosensory score, VIS: Vısual score, HA: Hearing aids, V: Vertigo, D: Dizziness, F-1: First family, F-2: Second family, S1: First sibling, S2: Second sibling, S3: Third sibling, S4: Fourth sibling, M: Mother, F: Father, SD: Speech discrimination

low-frequency sensorineural-type hearing loss in the participants is similar to other genetically inherited non-syndromic hearing loss studies (30,31). It is known that genes related to hearing, such as *GJB2, GJB6, TECTA, POU3F4,* and *MYO7A*, play a role in many areas, such as forming the tectorial membrane in the inner ear, controlling neurotransmitter release, and coding transmembrane proteins, etc (30,32-36). Therefore, obtaining postlingual, progressive, sensorineural-type hearing loss, as in our current study, is compatible with this physiological function of the genes in the inner ear. Negative effects on the cochlea and related proteins lead to sensorineural-type hearing loss.

Another study investigating hearing loss transmitted by *DFNA41* gene mutation longitudinally revealed progressive bilateral postlingual hearing loss, but reported gender differences, and the age at onset of hearing loss was between 25 and 35 years of age (37). The current study differs in that there were no significant gender differences in the audiovestibular findings and the age at onset of hearing loss. This may be due to the effects of different gene loci. In a study conducted on twins (38), it was emphasized that there was more interference in the high-frequency region, similar to the current findings. This may be because proteins located in the basal region of the cochlea are more susceptible to mutation. In addition, hearing deterioration, starting first in the high-frequency region (6 kHz, 8 kHz), can be a key indicator in the diagnosis of genetic hearing loss. These findings demonstrate the importance of monitoring high-frequency hearing thresholds in the general population (38,39). This approach may enable earlier recognition and rehabilitation of hearing loss. Similar to our current study, another study presented a profile of the genetic etiology of hearing loss in families with hearing loss. The five most common hearing loss genes are *SLC26A4, MYO7A, GJB2, CIB2,* and *HGF,* respectively (36,40). There should be more studies on genetic hearing loss, including the current study. Genetic screenings and counseling services are essential for the early diagnosis and treatment of hearing loss (29,41,42). Because genetic hearing loss is progressive, this study demonstrates the importance of monitoring patients for genetic hearing loss even if they pass the newborn hearing screening. On the other hand, to the best of the authors' knowledge, there are limited studies (43,44) investigating vestibular skills in people with genetic hearing loss. The possible reason for this may be that the mutation in the relevant gene also affects the vestibular pathways. Vestibular diseases may also occur due to genetic congenital hearing loss and inner ear anomalies (44). Due to the limited number of studies investigating vestibular progression in genetic hearing loss, there are limitations in interpreting the findings (45). On the other hand, assuming that hearing is one of the senses that provide postural control, hearing loss is an expected explanation for the current worse posturography results. Additionally, according to the authors, this study significantly contributes to the literature by revealing progressive vestibular deterioration. One of the strengths of the current study is that the hearing and vestibular skills of volunteer families were followed over the years without loss of data. The results of the present study will allow the development of more effective genetic diagnostic tools, assist in accurate genetic counseling, and guide experts. These findings are also valuable for interpreting the pathogenicity of variants potentially associated with hearing loss. On the other hand, more studies are needed to ensure the best treatment and follow-up of genetic hearing loss. In addition, it is essential to implement vestibular screening protocols in addition to hearing screening in newborns and to include genetic counseling and consultations in newborn screening protocols, even if the newborn has undergone hearing screening. In non-syndromic progressive hearing loss, it is crucial for audiologists and otolaryngologists to recommend genetic consultation for early diagnosis and treatment. Referring to family members for genetic testing provides valuable information about the inheritance pattern and risk factors of the disease. Audiological monitoring should include comprehensive assessments, such as high-frequency audiometry, vestibular evaluation, and auditory

perception assessment. Monitoring audiological and vestibular functions, genetic counseling, psychosocial support, and technological interventions are beneficial recommendations for improving patients' quality of life.

Study Limitations

The limitations of the study are that the patients could not receive complete genetic counseling, genetic screening, genetic counseling services are not widespread in our country, and auditory electrophysiological tests could not be included.

CONCLUSION

In non-syndromic progressive hearing loss, it is crucial for audiologists and otolaryngologists to recommend genetic consultation for early diagnosis and treatment. Referring to family members for genetic testing provides valuable information about the inheritance pattern and risk factors of the disease. Audiological monitoring should include comprehensive assessments, such as high-frequency audiometry, vestibular evaluation, and auditory perception assessment. Monitoring audiological and vestibular functions, genetic counseling, psychosocial support, and technological interventions are beneficial recommendations for improving patients' quality of life.

Ethics

Ethics Committee Approval: Gazi University Rectorate Ethics Commission approved this study (approval number: 15, date: 05.09.2023).

Informed Consent: Informed consent forms were obtained from the participants.

Footnotes

Authorship Contributions

Surgical and Medical Practices: B.K., N.Y.G., Concept: B.K., N.Y.G., Design: B.K., N.Y.G., Supervision: B.K., N.Y.G., Resources: B.K., N.Y.G.,

Material: B.K., N.Y.G., Data Collection or Processing: B.K., Analysis or Interpretation: B.K., N.Y.G., Literature Search: B.K., N.Y.G., Writing: B.K., N.Y.G., Critical Review: B.K., N.Y.G.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study received no financial support.

REFERENCES

1. Shearer AE, Hildebrand MS, Smith RJ. Hereditary hearing loss and deafness overview. 2017. (https://europepmc.org/article/nbk/nbk1434)
2. Hema Bindu L, Reddy P. Genetics of aminoglycocide-induced and prelingual non-syndromic mitochondrial hearing impairment: A review. Int J Audiol. 2008; 47: 702-7.
3. Morton N. Genetic epidemiology of hearing impairment. Ann N Y AcaD Sci. 1991; 630: 16-31.
4. Stelma F, Bhutta M. Non-syndromic hereditary sensorineural hearing loss: review of the genes involved. J Laryngol Otol. 2014; 128: 13-21.
5. Marková S, Brožková DŠ, Mészárosová A, Neupauerová J, Groh D, Křečková G, et al. Mutations in eight small DFNB genes are not a frequent cause of non-syndromic hereditary hearing loss in Czech patients. Int J Pediatr Otorhinolaryngol. 2016; 86: 27-33.
6. Chatterjee S, Kraus P, Lufkin T. A symphony of inner ear developmental control genes. BMC genetics. 2010; 11: 68.
7. Delmaghani S, El-Amraoui A. Inner ear gene therapies take off: current promises and future challenges. J Clin Med. 2020; 9: 2309.
8. Hilgert N, Smith RJ, Van Camp G. Forty-six genes causing nonsyndromic hearing impairment: which ones should be analyzed in DNA diagnostics? Mutat Res. 2009; 681: 189-96.
9. Merchant SN, McKenna MJ, Nadol Jr JB, Kristiansen AG, Tropitzsch A, Lindal S, et al. Temporal bone histopathologic and genetic studies in Mohr-Tranebjaerg syndrome (DFN-1). Otol Neurotol. 2001; 22: 506-11.
10. Street VA, Kallman JC, Strombom PD, Bramhall NF, Phillips JO. Vestibular function in families with inherited autosomal dominant hearing loss. J Vestib Res. 2008; 18: 51-8.
11. Yoon J, Song MS, Lee S-Y, Park MK, Lee JH, Oh SH, et al. Patterns of vestibular function in patients with dizziness after COVID-19 vaccination; dual tertiary referral center study. Acta Otolaryngol. 2022; 142: 668-74.
12. Aldè M, Cantarella G, Zanetti D, Pignataro L, La Mantia I, Maiolino L, et al. Autosomal Dominant Non-Syndromic Hearing Loss (DFNA): A Comprehensive Narrative Review. Biomedicines. 2023; 11: 1616.
13. Riza A-L, Alkhzouz C, Farcaș M, Pîrvu A, Miclea D, Mihuț G, et al. Non-Syndromic Hearing Loss in a Romanian Population: Carrier Status and Frequent Variants in the GJB2 Gene. Genes. 2022; 14: 69.
14. Kemperman MH, De Leenheer EM, Huygen PL, van Wijk E, van Duijnhoven G, Cremers FP, et al. A Dutch family with hearing loss linked to the DFNA20/26 locus: longitudinal analysis of hearing impairment. Archives Otolaryngol Head Neck Surg. 2004; 130: 281-8.
15. Singh S, Penney C, Griffin A, Woodland G, Werdyani S, Benteau TA, et al. Highly variable hearing loss due to POU4F3 (c. 37del) is revealed by longitudinal, frequency specific analyses. Eur J Human Genet. 2023: 31; 815-823.
16. Pennings RJ, Bom SJ, Cryns K, Flothmann K, Huygen PL, Kremer H, et al. Progression of low-frequency sensorineural hearing loss (DFNA6/14-WFS1). Arch Otolaryngol Head Neck Surg. 2003; 129: 421-6.
17. van Beelen E, Schraders M, Huygen P, Oostrik J, Plantinga R, van Drunen W, et al. Clinical aspects of an autosomal dominantly inherited hearing impairment linked to the DFNA60 locus on chromosome 2q23. 1–2q23. 3. Hear Res. 2013; 300: 10-7.
18. Simi A, Perry J, Schindler E, Oza A, Luo M, Hartman T, et al. Audiologic Phenotype and Progression in Pediatric STRC-Related Autosomal Recessive Hearing Loss. The Laryngoscope. 2021; 131: 2897-903.
19. Verstreken M, Declau F, Schatteman I, Van Velzen D, Verhoeven K, Van Camp G, et al. Audiometric analysis of a Belgian family linked to the DFNA10 locus. Am J Otol. 2000; 21: 675-81.
20. Schraders M, Oostrik J, Huygen PL, Strom TM, van Wijk E, Kunst HP, et al. Mutations in PTPRQ are a cause of autosomal-recessive nonsyndromic hearing impairment DFNB84 and associated with vestibular dysfunction. Am J Hum Genet. 2010; 86: 604-10.
21. Gupta S, Eavey RD, Wang M, Curhan SG, Curhan GC. Type 2 diabetes and the risk of incident hearing loss. Diabetologia. 2019; 62: 281-5.
22. Katz J, Chasin M, English KM, Hood LJ, Tillery KL. Handbook of clinical audiology: Wolters Kluwer Health Philadelphia, PA; 2015.
23. Ganança MM, Caovilla HH, Ganança FF. Electronystagmography versus videonystagmography. Braz J Otorhinolaryngol. 2010; 76: 399-403.
24. McCaslin DL. Electronystagmography and Videonystagmography (Eng/Vng): Plural Publishing; 2019.

25. Valdés-Baizabal C, Soto E, Vega R. Dopaminergic modulation of the voltage-gated sodium current in the cochlear afferent neurons of the rat. PLoS One. 2015; 10: 0120808.
26. Assal S, Morsy HM, Almagassbi NM, Eldeeb M. Assessment of sensory organization testing in benign paroxysmal positional vertigo patients before and after repositioning manoeuvre. Acta Otorrinolaringologica (Eng Ed). 2022; 73: 210-8.
27. David EA, Shahnaz N. Dynamic posturography after computerized vestibular retraining for stable unilateral vestibular deficits. Acta Otolaryngol. 2023; 143: 396-401.
28. Usami Si, Nishio Sy, Moteki H, Miyagawa M, Yoshimura H. Cochlear implantation from the perspective of genetic background. Anat Rec. 2020; 303: 563-93.
29. Božanić Urbančič N, Battelino S, Tesovnik T, Trebušak Podkrajšek K. The importance of early genetic diagnostics of hearing loss in children. Medicina. 2020; 56: 471.
30. Kim BJ, Kim AR, Lee C, Kim SY, Kim NK, Chang MY, et al. Discovery of CDH23 as a significant contributor to progressive postlingual sensorineural hearing loss in Koreans. PLoS One. 2016; 11: 0165680.
31. Lemaire FX, Feenstra L, Huygen PL, Fransen E, Devriendt K, Van Camp G, et al. Progressive late-onset sensorineural hearing loss and vestibular impairment with vertigo (DFNA9/COCH): longitudinal analyses in a Belgian family. Otol Neurotol. 2003; 24: 743-8.
32. Battelino S, Klancar G, Kovac J, Battelino T, Trebusak Podkrajsek K. TMPRSS3 mutations in autosomal recessive nonsyndromic hearing loss. Eur Arch Otorhinolaryngol. 2016; 273: 1151-4.
33. Hildebrand MS, Morín M, Meyer NC, Mayo F, Modamio-Hoybjor S, Mencía A, et al. DFNA8/12 caused by TECTA mutations is the most identified subtype of nonsyndromic autosomal dominant hearing loss. Hum Mutat. 2011; 32: 825-34.
34. Scott HS, Kudoh J, Wattenhofer M, Shibuya K, Berry A, Chrast R, et al. Insertion of β-satellite repeats identifies a transmembrane protease causing both congenital and childhood onset autosomal recessive deafness. Nat Genet. 2001; 27: 59-63.
35. Verhoeven K, Laer LV, Kirschhofer K, Legan PK, Hughes DC, Schatteman I, et al. Mutations in the human α-tectorin gene cause autosomal dominant non-syndromic hearing impairment. Nat Genet. 1998; 19: 60-2.
36. Mishra S, Pandey H, Srivastava P, Mandal K, Phadke SR. Connexin 26 (GJB2) mutations associated with non-syndromic hearing loss (NSHL). Indian J Pediatr. 2018; 85: 1061-6.
37. Liu XZ, Yan D, Mittal R, Ballard ME, Feng Y. Progressive Dominant Hearing Loss (Autosomal Dominant Deafness-41) and P2RX2 Gene Mutations: A Phenotype–Genotype Study. Laryngoscope. 2020; 130: 1657-63.
38. Bogo R, Farah A, Johnson A-C, Karlsson KK, Pedersen NL, Svartengren M, et al. The role of genetic factors for hearing deterioration across 20 years: a twin study. J Gerontol A Biol Sci Med Sci. 2015; 70: 647-53.
39. Linssen AM, van Boxtel MP, Joore MA, Anteunis LJ. Predictors of hearing acuity: Cross-sectional and longitudinal analysis. J Gerontol A Biol Sci Med Sci. 2014; 69: 759-65.
40. Richard EM, Santos-Cortez RLP, Faridi R, Rehman AU, Lee K, Shahzad M, et al. Global genetic insight contributed by consanguineous Pakistani families segregating hearing loss. Human Mutat. 2019; 40: 53-72.
41. Wu C-C, Tsai C-H, Hung C-C, Lin Y-H, Lin Y-H, Huang F-L, et al. Newborn genetic screening for hearing impairment: a population-based longitudinal study. Genet Med. 2017; 19: 6-12.
42. Zhou X, Wang L, Jin F, Guo Y, Zhou Y, Zhang X, et al. The prevalence and risk factors for congenital hearing loss in neonates: A birth cohort study based on CHALLENGE study. Int J Pediatr Otorhinolaryngol. 2022; 162: 111308.
43. Gommeren H, Moyaert J, Bosmans J, Mertens G, Cras P, Engelborghs S, et al. Evaluation of hearing levels and vestibular function and the impact on cognitive performance in (pre)-symptomatic patients with DFNA9: protocol for a prospective longitudinal study (Rosetta study). BMJ open. 2023; 13: 075179.
44. Kimura Y, Masuda T, Kaga K. Vestibular function and gross motor development in 195 children with congenital hearing loss-assessment of inner ear malformations. Otol Neurotol. 2018; 39: 196-205.
45. Wang A, Shearer AE, Zhou GW, Kenna M, Poe D, Licameli GR, et al. Peripheral vestibular dysfunction is a common occurrence in children with non-syndromic and syndromic genetic hearing loss. Front Neurol. 2021; 12: 714543.