Degree of Hearing Threshold in Patients with Type 2 Diabetes Mellitus

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Abstract

Background: Type 2 diabetes mellitus (T2DM) leads to multiple chronic complications in the body including sensory functions. **Aim:** The aim of this study was to determine the hearing threshold in middle-aged patients with T2DM and categorize it according to the presence or absence of hearing loss. **Materials and Methods:** A prospective, cross-sectional study was performed with 40 patients with T2DM (mean age 58 ± 8.6 years and mean time of T2DM evolution 11.9 ± 8.2 years) and 40 nondiabetic subjects (mean age of 52.4 ± 10.9 years). Pure tone audiometry was performed with a Grason-Stadler GSI 18 screening audiometer, 11 frequencies (0.125–8 kHz) were evaluated and classified as low, medium, and high. Hearing loss was defined as a hearing threshold >20 decibels (dB) and was classified as: mild: 21–40 dB, moderate: 41–70 dB, severe: 71–90 dB, and profound: > 90 dB. **Results:** Compared to the control group, diabetic patients presented a significant increase in the hearing threshold at medium ($P < 0.05$) and high ($P < 0.0001$) audiometric frequencies. When hearing loss was present, it was almost entirely mild (>80%) in the control group, whereas diabetic patients presented moderate, severe, and even profound levels of hearing loss. A linear correlation was found between the diagnosis time of T2DM and the degree of hearing loss at high frequencies ($P = 0.04$) as well as at medium frequencies ($P = 0.01$). **Conclusions:** T2DM affects hearing from the early stages of the disease; routine evaluation of hearing function should be considered in this population.

Keywords: Audiometry, hearing threshold, type 2 diabetes mellitus

Introduction

According to the World Health Organization's World Diabetes Report, the number of people with type 2 diabetes mellitus (T2DM) increased from 108 million in 1980 to 422 million in 2014, representing an increase in global prevalence from 4.7% to 8.5% in that year.[1] In Mexico, according to the 2018–2019 National Health and Nutrition Survey (ENSANUT), the diabetes prevalence in the adult population is as high as 10.3%.[2]

It is well-known that T2DM leads to chronic complications such as retinopathy, nephropathy, neuropathy, cardiovascular disease, peripheral vascular disease, and bone disorders such as osteopenia and diabetic osteoporosis.[3-6] However, the degree of dysfunction generated by the disease in some body functions, such as hearing, remains unknown, and therefore, its impact on the quality of life of patients with diabetes is underestimated.[7]

In 1894, Jordão[8] proposed the relationship between hearing loss and T2DM, and it has been demonstrated that in patients with diabetes, in the same age range as people without such disease, have greater hearing loss than would be expected because of degenerative changes related to age.[7,9,10] However, some authors have shown that patients

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with T2DM have greater hearing loss at high frequencies (3–8 kHz),[11-13] whereas others have reported greater loss at low frequencies (0.25–1 kHz)[14] or that hearing loss is not selective.[15] Furthermore, clinical reports have demonstrated that hearing loss can be equitable between both ears, or can affect the dominant ear with greater intensity.[11,12,14]

T2DM is a multisystemic disease, and its prevalence has increased in recent years, especially in young adult populations, who are associated with a sedentary lifestyle. This has created a critical public health problem because of the increase in chronic complications due to a longer development time of the illness.[16,17] Hearing loss as a chronic complication of this disease is an underexplored subject that requires necessary attention, because it can seriously affect the patients' quality of life and potentially lead to other complications, such as depression.[18,19] The aim of this study was to set the hearing threshold in middle-aged patients with T2DM by performing audiometry to identify the presence of hearing loss and classify it according to its intensity, as compared with results from healthy people.

Materials and Methods

Study design

This prospective, cross-sectional study was performed at the Laboratory of Physiology, Faculty of Medicine, Autonomous University of the State of Mexico (UAEMéx), Toluca, Mexico, between January and March 2018.

Subjects

Patients with a confirmed diagnosis of T2DM living in Toluca, Mexico, and their relatives without the disease were invited to take part in the study. Inclusion criteria were a confirmed diagnosis of T2DM by their physician, age between 40 and 65 years, and at least 1 year with the disease. Exclusion criteria were a history of head trauma or hearing surgery, congenital hypoacusia or confirmed hearing loss before the T2DM diagnosis, cognitive alterations, and smoking or prolonged use of ototoxic drugs. Patients who did not complete the physical examination were excluded from the final analysis.

Sample

Subjects who gave their consent were included in the study. The sample calculation was based on the following formula:[20]

$$\text{Sample size} = \frac{2SD^2\left(Z_{\alpha/2} + Z_{\beta}\right)^2}{d^2}$$

where SD indicates the standard deviation, d is the difference to find, $Z_{\alpha/2}$ = 1.96 at type I error of 5%, and Z_{β} = 0.842 at 80% power. In this survey, SD = 8, and the difference to find was 5 dB. The patients were divided into two groups of 40 patients. The first group included subjects (cases) with a diagnosis of T2DM, and the second group was the control group of relatives without the disease who were of an age range similar to the subjects of the previous group.

Data collection

In both groups, the next data was collected age, gender, and body mass index (BMI) as well as the time since diagnosis from patients with T2DM.

Glucometry

Before starting audiometry, fasting capillary glucometry was performed in both groups at the distal phalanx of the index finger of the nondominant hand with an Accu-Chek Active Glucose Measurement System (Roche, Swiss).

Audiometry

The audiometry test was performed using a GSI 18 screening audiometer (Grason–Stadler, Eden Prairie, Minnesota). The minimum hearing threshold of each of the frequencies evaluated was quantified in decibels (dB) and registered by a red "O" for the values corresponding to the right ear and a blue "X" for the values corresponding to the left ear on the Audiometric Evaluation Sheet.

For the hearing loss analysis, 11 frequencies were evaluated, being divided into the following three groups: (1) low frequencies: 125, 250, 500, and 750 Hz; (2) medium frequencies: 1000, 1500, and 2000 Hz; and (3) high frequencies: 3000, 4000, 6000, and 8000 Hz. Hearing loss was defined as a minimum hearing threshold >20 dB and categorized[21-23] as mild, 21–40 dB; moderate, 41–70 dB; severe, 71–90 dB; and profound, >90 dB.

Protocol

The audiometric test was performed by delivering pure tones with a frequency range between 125 and 8000 Hz. The intensity of each tone was adjusted in steps of 5 dB, from −10 dB to 120 dB. Once in the exploration room, subjects were provided an explanation as to what the protocol consisted of. Subjects were then instructed to raise their hand when perceiving the sound and to lower their hand when they stopped perceiving it.

The first frequency evaluated was 1000 Hz; the sound stimulus was sent at medium intensity (40 dB) to the right ear. If the subject did not perceive the stimulus, the intensity was increased in 20-dB steps until it was perceived. Once the stimulus was perceived by the subject, the intensity was progressively decreased at 10-dB intervals until the subject did not perceive the stimulus, then an increase of 5 dB was set to achieve the minimum threshold of auditory perception. This procedure was repeated with each set of low, medium, and high frequencies, starting with the higher frequencies and then the lower frequencies. The same procedure was performed for the left ear.

Data processing

Data from both groups were organized and analyzed using GraphPad Prism 5.0 software (GraphPad Software, San Diego, California) and results are reported as mean and standard deviation. The auditory thresholds for each set of frequencies and for the left ear and the right ear for each subject were analyzed. The prevalence and severity of hearing loss were evaluated in both patient groups and subclassified by its severity.

To contrast the values between both groups, we performed a Student's *t* test. In addition, we applied multivariable logistic regression analysis to determine the adjusted odds ratios (ORs) and 95% confidence intervals (CIs). Finally, we performed a linear regression test to evaluate the relationship between diabetes duration and hearing threshold. In all cases, a value of $P < 0.05$ was considered significant.

Ethical implications

The research protocol was approved by the Coordination of the Center for Research and Advanced Studies in Health Sciences of the Faculty of Medicine, UAEMéx. Study participants received an explanation of the study and asked to provide written consent.

The following ethical–legal norms were considered in this study: Declaration of Helsinki, the Mexican General Health Law, Federal Law of Transparency and Access to Public Information, Mexican Official Rule NOM-004-SSA3-2012, and Mexican Official Rule NOM-012-SSA3-2012.

Results

General characteristics

The T2DM group included 22 women and 18 men, with a mean age of 58 ± 8.6 years and mean time of T2DM evolution of 11.9 ± 8.2 years. The control group included 32 women and 8 men, with a mean age of 52.4 ± 10.9 years. The mean fasting glucose level in the control group was 98.7 ± 12.8 mg/dL and in patients with diabetes was 205.1 ± 105.7 mg/dL. The control group had a mean BMI of 28.97 ± 3.48 kg/m^2, and in the diabetic population, the BMI was 28.07 ± 4.18 kg/m^2.

Audiometry

As compared with the control group, patients with diabetes showed a significant increase in the auditory threshold at medium (1–2 kHz) and high frequencies (3–8 kHz) but not at low frequencies in measurements obtained from both ears [Table 1 and Figure 1], as well as in the individual analysis by ear (not shown). The comparison of the auditory threshold between the left and right ear in the diabetic population ($P > 0.05$) and in those without diabetes ($P > 0.05$) did not show significant differences (data not shown).

Hearing loss at low frequencies (125–750 Hz) was present in 28 (70%) patients with diabetes and in 27 (68%) nondiabetic participants. No relationship between T2DM and hearing loss was demonstrated: OR 1.12 (CI 0.44–2.89). Hearing loss at medium frequencies (1–2 kHz) was present in 21 (53%) patients with diabetes and in 13 (33%) nondiabetic participants; a 2-to-1 probability of hearing loss due to T2DM was demonstrated: OR 2.58 (CI 1.03–6.46). Finally, hearing loss at high frequencies (3–8 kHz) was present in 32 (80%) patients with diabetes and in 24 (60%) nondiabetic participants; a 3-to-1 probability of hearing loss due to T2DM was demonstrated: OR 2.96 (CI 1.1–8.01). In participants without diabetes, hearing loss was categorized as mild in most cases; the other cases were classified as moderate. Patients with T2DM presented a greater severity of hearing loss, with several cases of severe hearing loss and even profound hearing loss at high frequencies. Surprisingly, only four subjects with diabetes reported noticing some hearing impairment at the time of the study, and none of the subjects from the control group reported that condition.

In the diabetic population, the auditory threshold was also categorized by the elapsed time after diagnosis,

Table 1: Auditory threshold of diabetic and nondiabetic patients in both ears

Frequency	Minimum threshold average		*P* Value
	Diabetic	Nondiabetics	
125 Hz	25.96 dB (±1.41 SD)	25.87 dB (±1.24 SD)	$P = 0.9500$
250 Hz	27.82 dB (±1.27 SD)	26.35 dB (±1.07 SD)	$P = 0.3700$
500 Hz	28.53 dB (±1.17 SD)	28.17 dB (±1.14 SD)	$P = 0.8300$
750 Hz	29.94 dB (±1.22 SD)	26.83 dB (±1.07 SD)	$P = 0.0500$
1000 Hz	27.24 dB (±1.54 SD)	22.88 dB (±1.04 SD)	$P = 0.0200$
1500 Hz	25.19 dB (±1.64 SD)	19.42 dB (±1.07 SD)	$P = 0.0040$
2000 Hz	27.05 dB (±2.05 SD)	17.6 dB (±1.33 SD)	$P = 0.0002$
3000 Hz	39.17 dB (±2.3 SD)	23.46 dB (±1.34 SD)	$P < 0.0001$
4000 Hz	42.44 dB (±2.43 SD)	25.19 dB (±1.53 SD)	$P < 0.0001$
6000 Hz	44.04 dB (±2.47 SD)	27.6 dB (±1.47 SD)	$P < 0.0001$
8000 Hz	43.78 dB (±2.64 SD)	27.98 dB (±1.67 SD)	$P < 0.0001$

Hz = hertz, dB = decibel, SD = standard deviation

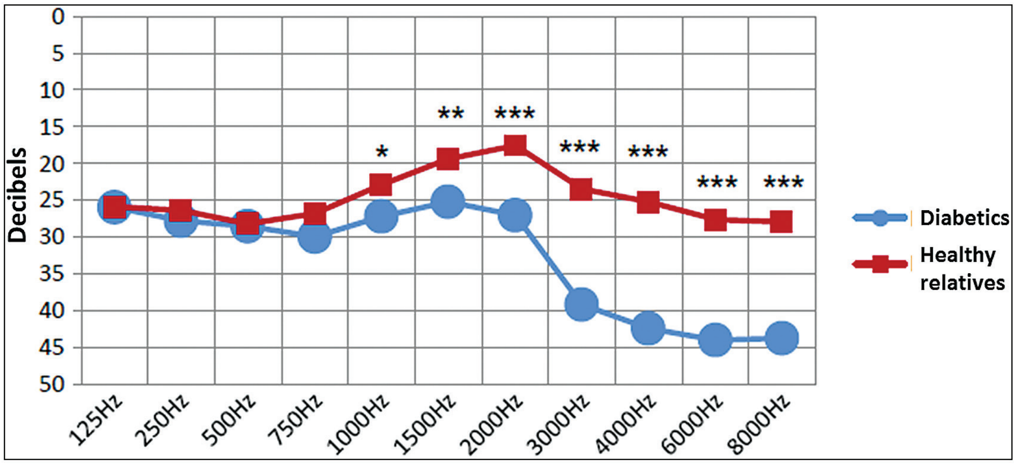

Figure 1: Mean and standard deviation of the hearing threshold in the control group and the diabetic patients in both ears for all the frequencies evaluated. $*P < 0.05$, $**P < 0.01$, and $***P < 0.001$

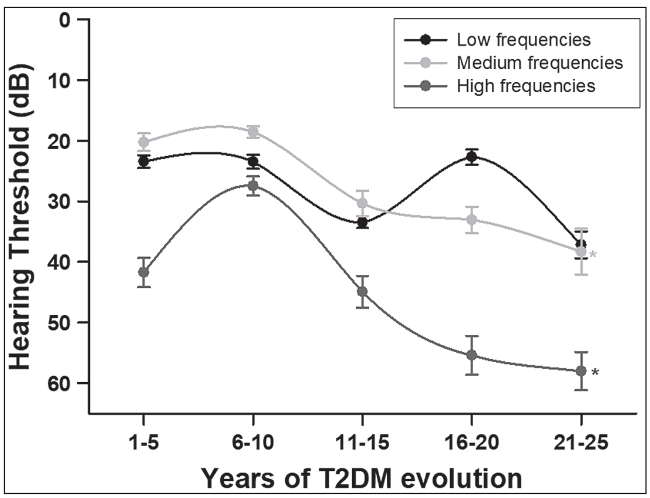

Figure 2: Correlation between years of type 2 diabetes mellitus evolution and hearing threshold in the three groups of audiometry frequencies evaluated. $*P < 0.05$

T2DM = type 2 diabetes mellitus

resulting in five groups of 5-year intervals. In addition, a linear regression test was performed for the three types of frequencies, which revealed a correlation between medium frequencies ($r^2 = 0.9024$, $P = 0.01$) and high frequencies ($r^2 = 0.79$, $P = 0.04$) with disease duration [Figure 2].

Discussion

We found an increase in the hearing threshold of T2DM patients at medium (1000–2000 Hz) and high frequencies (3000–8000 Hz), which is consistent with the findings of previously published studies.[11,12] Typical aging-related degenerative changes (i.e., atherosclerosis, oxidative stress) can damage the microvasculature of the inner ear, generating a decrease in the number of synapses, lesions, and loss of hair cells as well as accumulation of cellular debris in the spiral ganglion beams.[24,25] These abnormalities lead to a decline in the amount of nerve fibers of the auditory nerve, manifesting as presbycusis, which mainly affects high frequencies.[26,27] Thus, it is possible that T2DM accelerates this aging process and therefore increases the hearing threshold at these frequencies.

In a previous study carried out in Mexico,[11] researchers found that hearing loss affects both ears equally in the diabetic population, similar to the results obtained in our research. In postmortem studies in patients with diabetes, researchers observed significant thickening of the vascular walls of the basilar membrane and atrophy of the stria vascularis;[28] thus, bilateral hearing impairment could imply indirect damage, possibly caused by an inner ear irrigation decrease resulting from T2DM. Therefore, future experiments should be conducted to explore vascular damage in the inner ear of patients with diabetes who have hearing loss as well as to detect the biomarkers of vascular dysfunction.

In our study, it was observed an audiometric pattern in the diabetic population group that mainly affected high frequencies. This pattern, which was classified by Schuknecht as a sensory pattern,[25] is due to the loss of outer hair cells at the level of the cochlea, which causes irreversible and progressive damage.[26,29] A significant loss of outer hair cells was observed in animal models of diabetes and in postmortem studies of people with diabetes, without significant changes in inner hair cells or spiral ganglion cells.[28,30] In patients with diabetes, prior researchers observed an inverse relationship between serum antioxidant levels and the degree of hearing loss, suggesting that oxidative stress is involved in this complication development.[31,32] In fact, the outer hair cells at the base of the cochlea, which are responsible for perceiving high auditory frequencies, have a greater vulnerability to oxidative stress–induced damage, because they present a significant decrease in the amount of the antioxidant glutathione, as compared with the apex cells.[33] Therefore, in T2DM, hearing loss at high frequencies could also be due to an increase in oxidative stress associated with this pathology.

The results of this research show that patients with diabetes have a greater proportion of mild and moderate hearing loss, a finding that is in contrast to that reported by Frisina *et al.*[14] However, in their study, the patients studied were older (mean age 73 years), so it would be expected that both study groups had a higher hearing threshold related to the presbycusis development.[14] This research, which was carried out in middle-aged adults, demonstrated the presence of hearing loss related to T2DM from the initial stages, at which time prevention could determine the progress or remission of hearing loss.

A relevant finding of this study is that, despite the high prevalence of hearing loss in the diabetic population, only four patients reported the subjective presence of hearing loss, a fact that has been reported previously in other studies.[11,12] This implies that the hearing loss associated with T2DM may be initially subclinical; however, because of the disease progression, this complication tends worsen, and when patients become aware of their hearing loss, the therapeutic possibilities that can be offered will be very limited. As a preventive measure, screening of the auditory threshold is suggested at the time of diagnosis of the disease and follow-up during the condition.

As in previous studies,[11,13] we detected a linear correlation between the time of T2DM diagnosis and the degree of hearing loss at both high and medium frequencies. However, a linear slope was observed that increases only after 10 years of diagnosis, which may suggest that, before that time, the disease is less strongly related to hearing loss. Therefore, in the first years of the T2DM diagnosis, it is essential to begin therapeutic strategies that delay the onset of hearing loss and progression related to this disease.

A limitation of this study is the treatment heterogeneity of the patients with T2DM and the relative low number of studied cases, if one considers the disease severity in Mexico. Notwithstanding, the need to perform constant hearing evaluations in patients with T2DM is clear and mandatory. Longitudinal studies should be carried out to confirm the temporary relationship between this disease and hearing loss. In addition, it is necessary to clarify the pathophysiological mechanisms involved in hearing loss secondary to this disease and to determine the biomarkers that can be used to identify the population at risk at an early stage.

Conclusion

In conclusion, T2DM affects the auditory process, even in middle-aged patients with a short time of diagnosis. Thus, to find the presence and progression of hearing loss, routine and continuous review of this organ in the diabetic population should be considered. The results of the present study suggest a relationship between T2DM and hearing loss, as demonstrated by the increase in the hearing threshold in patients with diabetes as compared with age-matched direct relatives without the disease.

Pure-tone audiometry is a noninvasive, objective, economical, and effective method for the auditory threshold detection, and its use is therefore recommended for the early detection of hearing loss in both diabetic and nondiabetic populations.

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Conflicts of interest

There are no conflicts of interest.

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