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Relationship of Metabolic Syndrome With Hearing Loss

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Abstract: The prevalence of hearing loss has risen making it a significant public health issue. Hearing loss is caused by complicated pathophysiological pathways, with various risk factors identified, such as hereditary factors, inflammatory processes, systemic disorders, noise exposure, medicines, oxidative stress, and age. Metabolic syndrome is a medical condition characterized by the presence of hypertension, central obesity, hyperlipidemia and diabetes. Metabolic syndrome has been linked to several clinical diseases, such as stroke, heart attack, cardiovascular disease-related death, and diabetes. A cross-sectional study was done on 100 patients with metabolic syndrome which used specific cut-off points of waist circumference, fasting glucose levels, blood pressure, triglyceride, and high-density lipoprotein cholesterol levels to diagnose the condition. Among these five criteria, at least three had to be met, and the presence of additional criteria indicated greater severity. Audiological evaluation with pure tone audiometry was done and recorded. Statistical analysis was performed to determine the significance of the results. The majority of the patients (62%) had unilateral hearing loss, amongst which sensory-neural type and moderately severe hearing loss were the most common type (67%) and severity (61%) of hearing loss respectively. Chi-square tests were done for the comparison of type, severity, and laterality of hearing loss with age, gender of the patients, and criteria fulfilled for metabolic syndrome. The severity of hearing loss had a statistically significant association with the age of the patients and the number of criteria fulfilled for metabolic syndrome with a p-value of 0.003. There was a statistically significant association between the severity of hearing loss and the age of the patients and the number of criteria fulfilled for metabolic syndrome with a p-value of 0.004. Metabolic syndrome affects the auditory system in several ways. It damages hearing and exacerbates presbycusis. Hearing loss worsens as components of the metabolic syndrome increase.

Introduction

According to the Global Burden of Disease Study, there has been a significant increase in the occurrence of hearing loss and it has become one of the most prevalent causes of disability in both developing and developed countries (Rim et al., 2021). Metabolic syndrome is characterized by the presence of three or more of the subsequent five elements in that order: hyperglycemia or diabetes, hypertension, obesity, increased triglyceride levels, and decreased HDL-C cholesterol. It is associated with a higher risk of developing diabetes mellitus, myocardial infarction, stroke, and mortality related to cardiovascular diseases (Jung et al., 2018). Metabolic Syndrome has emerged as a significant public health concern, impacting between 20 and 30 percent of the worldwide populace. The underlying abnormality in this condition is resistance to insulin (Madhual et al., 2023).

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The pathological and physiological mechanisms of hearing loss are intricate. However various risk factors, such as genetic factors, inflammatory processes, systemic disorders, noise, drugs, oxidative stress, and age, have been identified as contributors to the development of hearing loss (Rim et al., 2021). Recent research suggests that elements of metabolic syndrome can affect hearing through oxidative stress, the accumulation of advanced glycosylation products, microvascular imbalance, and cochlear mitochondrial dysfunction (Yi Xu et al., 2024). Recent studies have also found that the severity of hearing loss increases and the prognosis worsens with extensive microvascular damage, leading to complications (Joong Su Park et al., 2022). The present study aimed to investigate the associations of hearing loss with metabolic syndrome. There is a dearth of evidence on whether metabolic syndrome can cause conductive or mixed hearing loss in addition to sensorineural hearing loss, whether it affects bilaterally or causes single-sided deafness, and whether the increasing elements of metabolic syndrome have a quantifiable effect on hearing loss. Therefore, this study aimed to investigate these factors and whether there is a correlation between a higher incidence and severity of hearing loss with the presence of more components of metabolic syndrome.

Materials and Methods

This cross-sectional study was conducted at the otorhinolaryngology department and Department of General Medicine on 100 patients over a period of one year in a tertiary care center. Ethical clearance for the study was obtained from the institutional ethics committee prior to commencement. Informed consent was obtained from all participants, ensuring their voluntary involvement and confidentiality.

Inclusion criteria

1. Newly diagnosed patients with metabolic syndrome
2. Patients between the ages of 18 years and 70 years belonging to both gender

Exclusion criteria

1. Subjects with a history of tobacco and alcohol usage
2. Subjects with pre-existing hearing impairment in one or both ears based on the history of the patients
3. Subjects with a prior history of ear surgeries
4. Individuals with a history of occupational noise exposure

The criteria for metabolic syndrome were established based on the amended guidelines of the National Cholesterol Education Program Adult Treatment Panel III.

1. Waist circumference (WC) exceeding 102 cm for men or 88 cm for women.
2. Fasting blood sugar levels over 100 mg/dL or a confirmed diagnosis of diabetes. (3) Blood pressure levels surpassing 130/85 mmHg or a confirmed diagnosis of hypertension.

The triglyceride concentration is greater than 150 mg/dL, and the high-density lipoprotein-cholesterol (HDL-C) level is less than 40 mg/dL for men or less than 50 mg/dL for women. Individuals exhibiting 3 or more of the above 5 characteristics were classified as patients with metabolic syndrome.

In elderly patients, presbycusis may already be present to some degree. However, metabolic syndrome is thought to accelerate this age-related hearing loss, leading to a more severe impairment. Therefore, metabolic syndrome can affect hearing both directly and indirectly, warranting the inclusion of these patients in this study.

Sample Size

$$n = \frac{Z^2_{1-\alpha/2}\, p(1-p)}{d^2}$$

p : Expected proportion

d : Absolute precision

1-α/2: Desired confidence level

Sample size was estimated by using nMaster software Version 2.0 by applying the following details in the above formula, based on the study by Bhargava A (Bhargava et al., 2021), which compared the association in which 62% patients had hearing loss. So, with an expected proportion of 0.62, with an alpha of 0.05 (2 sided), precision level of 10%, desired confidence level of 95, the sample size was estimated using the sample size formula for single proportion. The above computation gives a sample size of 91 subjects. By considering the 10% of attrition rate, a total of 100 samples were included in this present study.

Procedure

Written and Informed consent from the participants were taken. The number of criteria fulfilled by the patients for metabolic syndrome was noted. A detailed history was taken and a thorough examination was done. Waist circumference and values of the blood investigations used to diagnose the patient with metabolic syndrome were noted. A Pure Tone Audiometry hearing test was conducted utilizing a precisely calibrated audiometer equipped with circumaural headphones at frequencies of 500, 1000, and 2000 Hz in sequential order for air conduction and then bone conduction.

Air conduction and bone conduction thresholds were calculated by adding the values obtained at the above three frequencies and dividing the total by 3.

Conductive hearing loss is characterized by bone-conduction thresholds within the normal range, but air-conduction thresholds that are at least 10 dB lower than normal, resulting in an air-bone gap in pure tone audiometry. Sensorineural hearing loss is characterized by both bone- and air-conduction thresholds that exceed 25 dbHL, with a difference of no more than 10 dB between them, resulting in the absence of an air-bone gap. Mixed hearing loss is characterized by both bone- and air-conduction thresholds that exceed 25 dbHL with a difference of more than 10 dB between them, resulting in an air-bone gap.

Qualitative data were represented using frequency distributions. Cross-tabulation of age and gender of the patients with characteristics of hearing loss was done, chi-square tests were performed and statistical significance was ascertained. Similarly, cross-tabulation between the number of criteria fulfilled for metabolic syndrome and type, severity, laterality, and side of hearing loss was done and chi-square tests were carried out in order to determine if there was any statistically significant association. By excluding study participants with a history of alcohol or tobacco use as well as occupational noise exposure, confounding variables were eliminated. The study process is shown schematically in the image below (Figure 1).

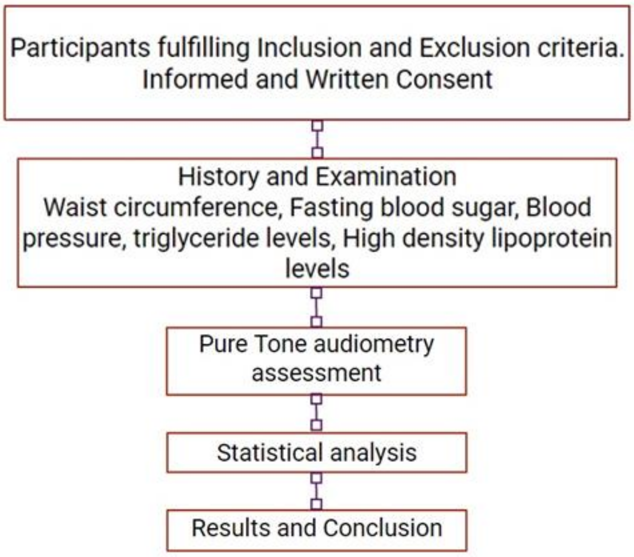

Figure 1. Schematic diagram of the study procedure

Result and Discussion

Demographic profile of the study participants

Out of 100 patients, 49 % of patients were more than 50 years and the remaining were less than 50 years of age. 63 % of the study participants were males and 37 % were females. The majority of the study participants were illiterate (68%) and unemployed (54%) (Figure 2). Out of the five criteria of the metabolic syndrome, 70% of the participants fulfilled three criteria, 26% fulfilled four criteria and only 4% fulfilled all five criteria (Table 1).

Attributes of auditory impairment

There was a predominance of unilateral hearing loss, which was present in 62% of the patients, while 28% had bilateral hearing loss and 10 % of patients were normal. Among the patients with hearing loss (N=90), majority of the patients had sensorineural hearing loss (67%), while 16% had conductive hearing loss and 7 % had mixed hearing loss. With regards to severity, 10% of patients with hearing loss had mild hearing loss, 8% had moderate hearing loss, 61 % had moderately severe hearing loss and 11% had severe hearing loss. In patients with hearing loss, 32 patients had hearing loss in the right ear and 30 patients had hearing loss in the left ear (Figure 3 & Table 2).

Comparison of type, severity, and laterality of hearing loss with age and gender

In the comparison of the association between type, severity, and laterality of hearing loss with age and gender, there was a statistically significant association between the severity of hearing loss and age of the patients, while other associations were statistically insignificant (Table 3). This result signifies that with advancing age, hearing loss becomes compounded due to the combined effect of metabolic syndrome and presbycusis

Comparison of characteristics of hearing loss with components of metabolic syndrome

In the comparison of the association of characteristics of hearing with the number of criteria fulfilled for metabolic syndrome, there was a statistically significant association between the severity of hearing loss and the number of criteria, while there were no statistically significant association between type and laterality of hearing loss with increasing criteria for metabolic syndrome (Figure 4 & Table 4). This suggests that the severity of hearing loss increases with the number of metabolic syndrome components. Still, they did not have any effect on the type of hearing loss. There is no correlation between the number of components and laterality, meaning that the increasing components only caused worsening of the hearing loss but did not make it a bilateral condition.

The average intensities of hearing loss at 500, and 1000, 2000 Hz and the threshold of Air conduction and bone conduction were compared (Table 5). Participants with all the components of metabolic syndrome had the highest bone conduction threshold values, further demonstrating the deteriorating effects of severe disease on hearing.

The phenomenon of aging is increasingly emerging as a significant worldwide health concern. The process of aging is linked to the development of chronic diseases, such as cardiovascular disease and metabolic syndrome, which negatively impact individuals' health and lead to dysfunction in many organs. Metabolic syndrome could cause hearing loss through various mechanisms.

Obesity, indicated by waist circumference, has been linked to hearing loss in studies conducted on both humans and animals (Hwang et al., 2013; Lalwani et al., 2013). Adipose tissue is classified as an endocrine organ because it releases hormones and cytokines, which have an impact on hunger, insulin resistance, and energy metabolism (Ahima et al., 2006). Adiponectin is a type of adipocytokine that is produced and released by adipose tissue. It is found in decreased amounts in persons who are obese or have Metabolic Syndrome (MetS) (Huang et al., 2004). Adiponectin concentrations have an inverse relationship with BMI, waist circumference, insulin resistance, and triglyceride levels. Conversely, adiponectin concentrations have a direct relationship with HDL-C concentration. Adiponectin has been shown to safeguard the function of peripheral hearing. Additional factors that influence the connection between obesity and hearing loss may include obesity-related atherosclerosis of the internal auditory artery and a decrease in blood flow to the cochlea.

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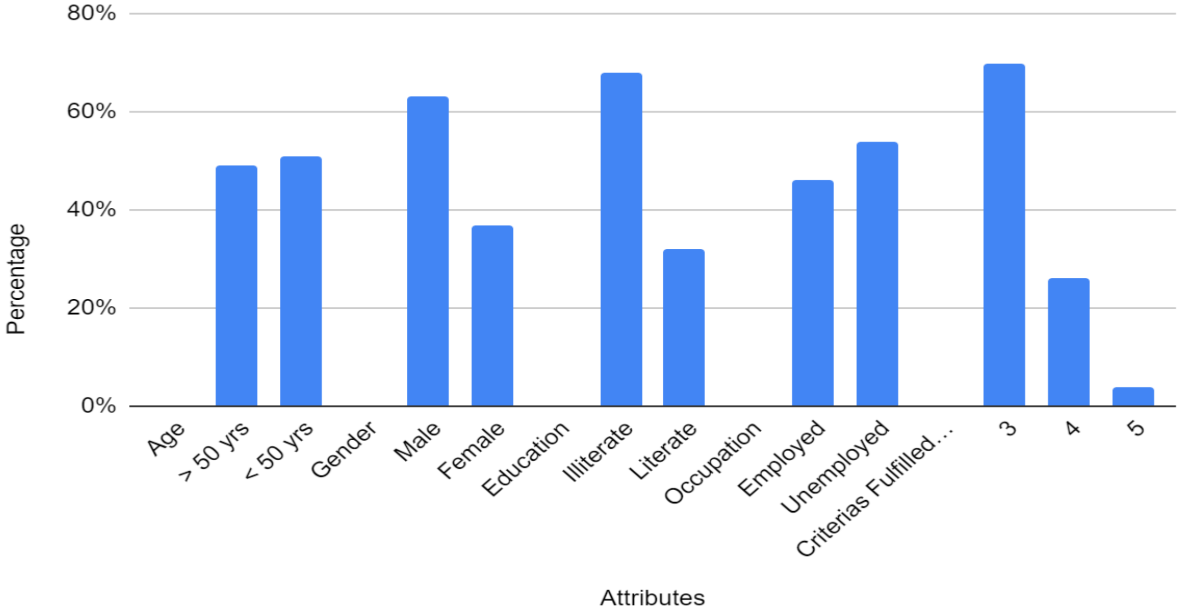

Figure 2. Characteristics of the participants.

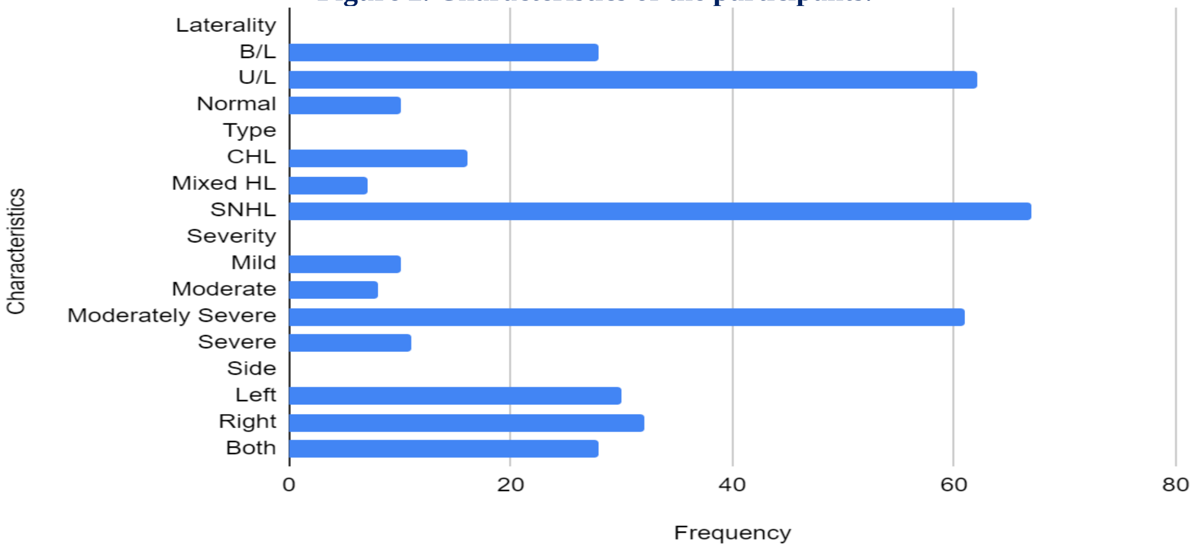

Figure 3. Characteristics of hearing loss among the study participants.

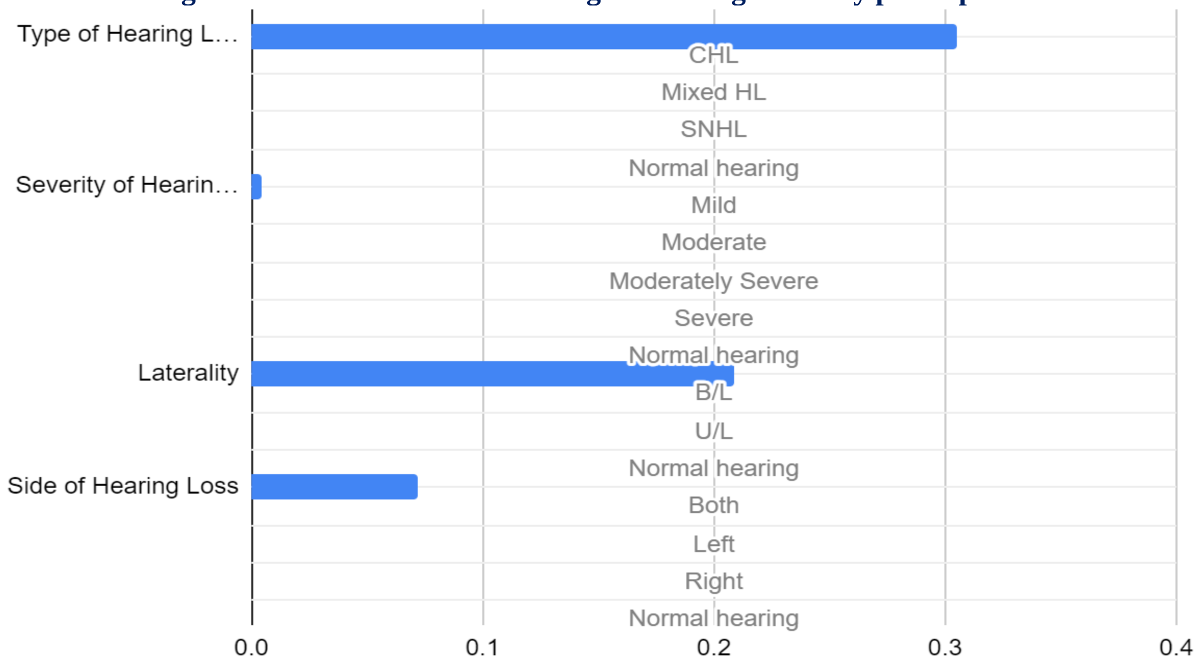

Figure 4. P-values for crosstabulation of characteristics of hearing loss with the number of components of metabolic syndrome. Note p-value for the association between the severity of hearing loss and components of metabolic syndrome is 0.004, making it statistically significant.

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Table 1. General characteristics of the population, N=100.

Characteristics	Frequency	Percentage
Age		
> 50 yrs	49	49%
< 50 yrs	51	51%
Gender		
Male	63	63%
Female	37	37%
Education		
Illiterate	68	68%
Literate	32	32%
Occupation		
Employed	46	46%
Unemployed	54	54%
Criterias Fulfilled For Metabolic Syndrome		
3	70	70%
4	26	26%
5	4	4.0%

Table 2. Characteristics of hearing loss.

Characteristics	Frequency	Percentage
Unilateral Or Bilateral (N=100)		
B/L	28	28.0
U/L	62	62.0
Normal	10	10.0
Type of Hearing Loss (N=90)		
CHL	16	17.7%
Mixed HL	7	7.7%
SNHL	67	74.4%
Severity of Hearing Loss (N=90)		
Mild	10	11.1%
Moderate	8	8.8%
Moderately Severe	61	67.7%
Severe	11	12.2%
Side of Hearing Loss (N=90)		
Left	30	33.3%
Right	32	35.5%
Both	28	31.1%

Hearing loss may occur as a result of reduced flow-mediated arterial dilation and damage to auditory epithelia caused by the accumulation of reactive oxygen species, particularly under situations of obesity-related oxidative stress (Cruickshanks et al., 2015).

The Kurabuchi study discovered a favorable correlation between glycosylated hemoglobin and hearing impairment in elderly Japanese individuals (Michikawa et al., 2014). Conversely, the Framingham study did not find any connection between hearing loss and either diabetes or reduced glucose tolerance. There are multiple molecular pathways that could clarify the connection between high blood sugar levels (hyperglycemia) and the impairment of hearing. Pathogenic alterations in the microvasculature and sensory nerves were observed in complications of diabetes, including retinopathy, nephropathy, and peripheral neuropathy (Ciulla et al., 2003). These abnormal modifications likely affect the blood vessels and nerve cells responsible for auditory sensation in the inner ear. Post-mortem examinations of individuals with hyperglycemia and diabetes reveal the thickening of capillaries in the stria vascularis (Fukushima et al., 2005). It also revealed alterations in the labyrinth artery, blood vessels of the cochlea, vestibulocochlear nerve, and in spiral ganglion (Makishima and Tanaka, 1971).

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Table 3. Association between Type, severity, and laterality of hearing loss with age and gender.

			Age		Chi-square value	P-Value	Gender		Chi-square value	P-Value
			<= 50 yrs	> 50 yrs			F	M		
Type of Hearing Loss	CHL	N	11	5	6.318a	.097	10	6	1.464a	.691
		%	21.6%	10.2%			15.9%	16.2%		
	Mixed HL	N	1	6			3	4		
		%	2.0%	12.2%			4.8%	10.8%		
	SNHL	N	35	32			44	23		
		%	68.6%	65.3%			69.8%	62.2%		
	Normal hearing	N	4	6			6	4		
		%	7.8%	12.2%			9.5%	10.8%		
Severity of Hearing Loss	Mild	N	7	3	15.770a	.003	4	6	9.093a	.059
		%	13.7%	6.1%			6.3%	16.2%		
	Moderate	N	6	2			8	0		
		%	11.8%	4.1%			12.7%	0.0%		
	Moderately Severe	N	34	27			36	25		
		%	66.7%	55.1%			57.1%	67.6%		
	Severe	N	0	11			9	2		
		%	0.0%	22.4%			14.3%	5.4%		
	Normal hearing	N	4	6			6	4		
		%	7.8%	12.2%			9.5%	10.8%		
Laterality of Hearing Loss	B/L	N	12	16	1.964a	.374	18	10	.059a	.971
		%	23.5%	32.7%			28.6%	27.0%		
	U/L	N	35	27			39	23		
		%	68.6%	55.1%			61.9%	62.2%		
	Normal hearing	N	4	6			6	4		
		%	7.8%	12.2%			9.5%	10.8%		
P-value < 0.05 : significant, p-value> 0.05 : non-significant										

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Table 4. Association of characteristics of hearing loss and criteria fulfilled for metabolic syndrome.

			Criteria Fulfilled For Metabolic Syndrome			Total	Chi-square value	P-Value
			3	4	5			
Type of Hearing Loss	CHL	N	12	4	0	16	7.172a	.305
		%	17.1%	15.4%	0.0%	16.0%		
	Mixed HL	N	4	3	0	7		
		%	5.7%	11.5%	0.0%	7.0%		
	SNHL	N	44	19	4	67		
		%	62.9%	73.1%	100.0%	67.0%		
	Normal hearing	N	10	0	0	10		
		%	14.3%	0.0%	0.0%	10.0%		
Severity of Hearing Loss	Mild	N	9	1	0	10	22.419a	.004
		%	12.9%	3.8%	0.0%	10.0%		
	Moderate	N	6	2	0	8		
		%	8.6%	7.7%	0.0%	8.0%		
	Moderately Severe	N	43	16	2	61		
		%	61.4%	61.5%	50.0%	61.0%		
	Severe	N	2	7	2	11		
		%	2.9%	26.9%	50.0%	11.0%		
	Normal hearing	N	10	0	0	10		
		%	14.3%	0.0%	0.0%	10.0%		
Laterality	B/L	N	17	9	2	28	5.873a	.209
		%	24.3%	34.6%	50.0%	28.0%		
	U/L	N	43	17	2	62		
		%	61.4%	65.4%	50.0%	62.0%		
	Normal hearing	N	10	0	0	10		
		%	14.3%	0.0%	0.0%	10.0%		
Side of Hearing Loss	Both	N	17	9	2	28	11.592a	.072
		%	24.3%	34.6%	50.0%	28.0%		
	Left	N	25	5	0	30		
		%	35.7%	19.2%	0.0%	30.0%		
	Right	N	18	12	2	32		
		%	25.7%	46.2%	50.0%	32.0%		
	Normal hearing	N	10	0	0	10		
		%	14.3%	0.0%	0.0%	10.0%		
P-value < 0.05 : significant, p-value> 0.05 : non-significant								

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Table 5. Average Intensities of hearing at various air conduction and bone conduction frequencies and at air conduction and bone conduction threshold.

Pure tone	Criteria fulfilled for metabolic syndrome		
	3	4	5
In Right Ear			
AC 500 Hz	8.2 ± 6.9	14 ± 14.2	6.3 ± 2.5
AC 1000 Hz	11.4 ± 7.8	18.1 ± 14.8	8.8 ± 4.8
AC 2000 Hz	14.5 ± 7.1	21.2 ± 14.3	11.3 ± 2.5
AC Threshold	11 ± 7	17.6 ± 14.5	8.3 ± 3.3
BC 500 Hz	23.9 ± 21.3	33.6 ± 21.4	53.8 ± 11.1
BC 1000 Hz	28.9 ± 23.5	39.4 ± 22.1	56.3 ± 10.3
BC 2000 Hz	34.9 ± 26.4	46.2 ± 26.2	63.8 ± 7.5
BC Threshold	28.9 ± 23.4	39.5 ± 23	57.8 ± 10
In Left Ear			
AC 500 Hz	6.9 ± 10.8	1.7 ± 2.8	2.5 ± 2.9
AC 1000 Hz	12.7 ± 10.3	7.3 ± 3.8	10 ± 0
AC 2000 Hz	17.3 ± 8.8	12.3 ± 3.2	13.8 ± 2.5
AC Threshold	12 ± 9.8	7 ± 2.7	8.5 ± 1
BC 500 Hz	23.7 ± 24.2	29.2 ± 27.2	25 ± 26.1
BC 1000 Hz	30.3 ± 24.9	34.6 ± 26	31.3 ± 24.6
BC 2000 Hz	37.5 ± 26	42.9 ± 27.3	41.3 ± 30.4
BC Threshold	30.2 ± 24.9	35.3 ± 26.8	32.3 ± 26.9

When there is increased sugar levels, there is evidence of demyelination in the eighth cranial nerve, namely in one of its branches responsible for transmitting auditory information from the cochlea to the brain stem (Li et al., 2015). The cochlea exhibits pathologic alterations such as thicker walls of the capillaries in the basilar membrane and a more significant loss of outer hair cells in the lower basal turn. In addition, there is a correlation between high levels of glucose in the blood and an increase in oxidative stress (Ceriello et al., 2001). The potential link between high blood sugar levels (hyperglycemia) and hearing loss may also be partially attributed to oxidative stress, which is elevated in individuals with hyperglycemia.

Hypertension can cause hearing loss through two mechanisms, either by inducing bleeding in the inner ear, which leads to decreased blood flow and oxygen delivery through the capillaries, or decreasing blood flow by narrowing the diameter of blood vessels in the inner ear due to atherosclerosis, thus ultimately causing gradual or abrupt sensorineural hearing impairment (Siegelaub et al., 1974; Bachor et al., 2001)

Recent research has indicated a strong correlation between elevated levels of triglycerides and a decline in auditory sensation and perception (Saito et al., 1986). This is because dyslipidemia causes a decrease in nitric oxide production and an increase in reactive oxygen levels causing auditory damage (Heinrich and Helling, 2012; Satar et al, 2001; Brechtelsbauer et al.,1994; Henderson et al., 2006). Moreover, it has been demonstrated that High-density lipoprotein has properties that mitigate inflammation and apoptosis caused by dyslipidemia (Lee et al.,2016; Rosenson et al., 2013). Consequently, the dual impact of elevated triglycerides and reduced high-density lipoprotein in metabolic syndrome exacerbates the effects of auditory impairment.

In addition to the direct adverse impact on auditory function, metabolic syndrome also exacerbates age-related auditory impairment (Guo et al., 2022; Zhao et al., 2015). Diabetes increases the likelihood of developing early presbycusis. In studies conducted on rodents, it was demonstrated that hyperglycemia significantly reduced the amplitude of distortion product otoacoustic emission at higher frequencies (Vasilyeva et al., 2009). Hyperlipidemia-induced atherosclerosis can result in hypoxic injury to the spiral modiolar artery and cochlear endothelium. This results in the intensification of injury to hair cells and spiral ganglion neurons which accelerates the progression of presbycusis (Kim et al., 2020; Guo et al., 2005; Lee et al., 2020). Adiponectin levels are negatively correlated with thresholds in hearing, particularly at high frequencies (Hwang et al., 2011). Hypertension is recognized for its ability to impair peripheral hearing, particularly at higher frequencies, as well as diminish the ability to localize sounds (Przewozny et al., 2016).

This study involved the selection of subjects who had recently been diagnosed with metabolic syndrome, and pure tone audiometry was performed on them. The majority of participants were under the age of 50, and there were more male patients (Table 1). On pure tone audiometry, 90% of the patients exhibited hearing loss, whereas only 10 patients had normal hearing (Table 2).

The study revealed a predominance of sensorineural hearing loss. Among the patients with hearing loss, the majority had unilateral hearing loss and the majority had a moderately severe type of hearing loss (Table 2).

There was a statistically significant relationship between the severity of hearing loss and the patient's age (Table 3). This can be attributed to the fact that as individuals age, the impact of presbycusis, which is further exacerbated by metabolic syndrome, will intensify the degree of hearing impairment.

The severity of hearing loss was statistically significantly correlated with the fulfillment of metabolic syndrome criteria, suggesting that the severity of hearing loss increases when more components of metabolic syndrome are present (Table 4). This was similar to the observation in a study by Shim H.S. (Shim et al., 2019), indicating that an increased number of criteria leads to a greater impact on the auditory system, resulting in more severe hearing loss. In another study done previously by Sahni D. (Sahni et al., 2024), the prevalence of hearing loss was found to be more when patients had more components.

When comparing the levels of hearing at different frequencies for air conduction and bone conduction, it was seen that there was greater hearing loss at higher frequencies for bone conduction (Table 5). This was apparent due to the higher number of patients exhibiting sensorineural hearing loss. The bone conduction thresholds were highest for patients with all components of metabolic syndrome. In a study by Rim (Rim et al., 2021), the average pure tone thresholds were higher in patients with metabolic syndrome compared to normal patients, thus attributing the disease to increasing the threshold values and thereby decreasing hearing.

Hence, metabolic syndrome leads to substantial harm to the auditory system, leading to the impairment of hearing. With an increase in components of metabolic syndrome in a patient, there is increased damage. It also accelerates and exacerbates the effects of presbycusis.

This study had limitations, including the absence of patient follow-up after starting medical therapy with repeating pure tone audiograms at various intervals. Therefore, the study could not assess whether treatment for metabolic syndrome halted, reversed, or had no effect on hearing loss. Also, the hearing status of the participants prior to the diagnosis of metabolic syndrome is unknown and patients could have had pre-existing hearing impairment without their knowledge due to other factors. Future studies can investigate the impact of treatment of metabolic syndrome on preventing further deterioration or improving the hearing status of the patients.

Conclusion

Thus, metabolic syndrome has a detrimental effect on auditory sensation through a variety of mechanisms. It induces auditory harm and it also exacerbates hearing loss due to presbycusis. As the number of components of metabolic syndrome increases, the severity of hearing loss also increases. Promoting lifestyle modifications and good health practices in adolescent and adult age groups could significantly reduce the burden of hearing loss in the future. Additional research is required to ascertain the precise pathogenic mechanisms of metabolic syndrome on hearing in order to more thoroughly investigate the prevention and treatment options for hearing loss and even presbycusis. The study's limitations included a lack of patient follow-up after therapy initiation, which impeded the evaluation of participant prognosis. This prevented determining whether the hearing loss was permanent and missed the chance to collect evidence on whether better treatment adherence could lead to improved outcomes, which could have been used to raise awareness. Future research can address this issue and also investigate which component has the greatest impact on hearing loss, allowing for more targeted and aggressive treatment of that specific aspect over others.

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Conflict of Interest

The authors have declared that no conflicting interests exist.

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