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HEARING LOSS IN CHILDREN AFTER TYMPANIC MEMBRANE PERFORATION: CLUSTER ANALYSIS OF 27 CASES

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Introduction: Tympanic membrane perforation (TMP) may be caused by several factors but commonly leads to conductive hearing loss. This study aims to characterize the profiles of hearing loss in pediatric patients with TMPs.

Material and methods: A retrospective analysis of the medical charts of 27 patients was conducted. Otoscopy of the TM was done and pure tone audiometry was used to assess hearing loss. Cluster analysis was applied to evaluate the profiles of hearing loss and to find possible relations between profiles of hearing loss and the location of the perforation on the TM.

Results: Cluster analysis revealed three types of hearing loss. The mean hearing loss in cluster 1 (6 cases) was above 30 dB, mainly as the result of perforation after chronic otitis media. Hearing loss in clusters 2 (9 cases) and 3 (12 cases) was less than 30 dB. In cluster 2 the perforation was mostly located in the posterior quadrants, while in cluster 3 it was most commonly in the inferior quadrants. In clusters 2 and 3, perforation was usually caused by slap of the open hand, injury, or past ventilation tube.

Conclusions: Three different profiles (clusters) of hearing loss resulting from TMP were identified. Force of injury, etiology of the injury, and inflammation produce different sizes of perforations. Conductive hearing loss increases with perforation size and is independent of TM location. In general, hearing loss classification methods have the potential to improve diagnostic procedures, surgery, and rehabilitation of patients with TMPs.

Key words: tympanic membrane perforation • hearing loss profile • ear injury

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NIEDOSŁUCH U DZIECI PO PERFORACJI BŁONY BĘBENKOWEJ: ANALIZA SKUPIEŃ 27 PRZYPADKÓW

Streszczenie

Wprowadzenie: Perforacja błony bębenkowej (*tympanic membrane perforation*, TMP) może mieć różne przyczyny i zwykle powoduje niedosłuch przewodzeniowy. Celem tego badania było opracowanie profili niedosłuchów u pediatrycznych pacjentów z TMP.

Materiał i metody: Przeprowadzono retrospektywną analizę historii medycznych 27 pacjentów. Wykonano otoskopię i audiometrię tonalną w celu oszacowania niedosłuchu. Zastosowano analizę skupień celem oceny profili niedosłuchów i znalezienia potencjalnych zależności między profilem niedosłuchu a lokalizacją perforacji błony bębenkowej.

Wyniki: Analiza skupień wykazała występowanie trzech typów niedosłuchu. Średnia wartość niedosłuchu w grupie 1. (6 przypadków) była powyżej 30 dB, a niedosłuch był przede wszystkim skutkiem perforacji po chronicznym zapaleniu ucha środkowego. Niedosłuch w grupach 2. (9 przypadków) i 3. (12 przypadków) był poniżej 30 dB. W grupie 2. perforacja przeważnie znajdowała się w tylnych kwadrantach błony bębenkowej, a w grupie 3. – najczęściej w dolnych kwadrantach. W grupach 2. i 3. perforacja była przeważnie (lub: w większości przypadków) spowodowana uderzeniem otwartą dłonią, zranieniem lub uprzednio założonym drenem wentylacyjnym.

Wnioski: Zidentyfikowano trzy różne profile (grupy) niedosłuchów wynikających z TMP. Za różne rozmiary perforacji odpowiadają: siła urazu, jego etiologia i stan zapalny. Poziom niedosłuchu przewodzeniowego był większy w przypadku większych perforacji, niezależnie od ich położenia. Ogólnie rzecz biorąc, metody klasyfikacji niedosłuchu mogą podnieść jakość procedur diagnostycznych i chirurgicznych w rehabilitacji pacjentów z TMP.

Słowa kluczowe: perforacja błony bębenkowej • profil niedosłuchu • uraz ucha

Introduction

The tympanic membrane (TM) vibrates when hit by sound waves. Proper conductive sound transmission depends on several factors such as thickness, elasticity, and stiffness of the membrane. The tympanic membrane moves as a whole in phase with the stimulus at low frequencies, and at higher frequencies the pattern is more complex and involves vibrations of nodes at different phases [1]. Fay and colleagues describe how sound conduction through the middle ear depends on both the material properties of the fibers that course through the middle lamina of the TM and its shape [2].

Several factors can lead to tympanic membrane perforation (TMP). TMP is commonly caused by traumatic injury to the ear. TMPs may occur after sudden changes in air pressure in the ear canal. If the ear is slapped with an open hand, or there is a nearby explosion, the pressure can tear the TM. A sharp object inserted into the ear can also cause rupture [3]. According to Cayir [4], the most common cause of TMP in children is blunt trauma, barotrauma, or insertion of a foreign object. In children, TMP can often result from otitis media, or sometimes after prolonged ventilation tube placement.

Interestingly, the causes of TMPs vary among different populations. In China, TMPs are dominated by slap injury which is the reason for 78.5% of cases [3], whereas in the USA the major cause is insertion of an object, often a cotton bud, in the ear (60.6% of cases) [5]. Disease, previous injury, Eustachian tube dysfunction, and inadequate pneumatization can weaken the TM [4]. In up to 80% of TMP cases, the TM heals spontaneously, although sometimes surgery is needed [3].

TMPs usually result in hearing loss. According to the literature, hearing loss may be up to 50 dB [6]. No research has examined the degree of hearing loss in groups of patients having different TMP etiology, especially in children. Hearing loss can be classified into categories using the WHO classification for hearing impairment [7]. There are several studies concerning hearing loss in different clinical situations [8–10] but in the case of TMP there are few which classify cases on the basis of degree of hearing loss.

This study aims to explore and characterize profiles of hearing loss from TMP in a pediatric population. We wished to examine whether children with TMP can be classified into groups having similar values of hearing loss at particular frequencies, and then establish whether a distinctive hearing loss profile correlates with the location of the perforation in the tympanic membrane.

Material and methods

Patient characteristics

A retrospective chart review was conducted in the Department of Otolaryngology of Children's Clinic Hospital. The examined group consisted of 32 children admitted to the ENT ward from 2016 to 2021. However, 5 patients were not included in the study because they were too young to perform PTA, leaving 27 subjects as the basis of our study. All had been admitted to the Department for observation or treatment due to severe pain after an ear injury. The study does not include patients who were admitted to the emergency department but were not qualified for hospitalization and were discharged. The criteria for admission limited the number of patients who could be included in our study.

The final data therefore comes from medical examinations and procedures during a hospital stay for which the legal guardians or patients gave written consent. The data included the sex, age, etiology of the ear injury, location of the perforation on the TM, and the PTA. The age ranged from 3 to 17 years old, with a mean of 13.2 years, median of 13.9, and standard deviation of 3.5. The group consisted of 4 girls (15%) and 23 boys (85%). TMP affected the left ear in 17 cases and the right ear in 10 cases. Patients spent an average of 4 days in hospital.

Treatment methods

Some 60% of the 27 children received antibiotics intravenously (i.v.), 19% received local antibiotics applied in the ear, 15% received corticosteroids i.v., and 8% received NSAIDs orally or i.v. Different approaches were used to surgically treat the damaged TM. In 26% of patients Spongostan with saline was inserted in the external acoustic meatus. Another 26% of children required myringoplasty either with an EpiDisc or with a temporal muscle fascia. Edges of the TM wounds of 7% of patients were rejuvenated. 30% of patients did not receive surgical treatment and were left for observation. 63% of children showed up at follow-up visits after 1 month and 71% of this group still had TM perforation.

To measure hearing loss, pure tone audiometry using an Interacoustics AC40 clinical audiometer was employed to determine air and bone conduction thresholds at frequencies from 0.5–6 kHz, which cover the range of speech frequencies [6]. The results were marked on an audiogram chart. The audiogram helped to determine not only the degree of hearing loss but also the type of hearing loss (sensorineural, conductive, or mixed). An air-bone gap of > 25 dB (averaged over 0.5, 1, 2, 4, and 6 kHz) [11–15] was considered as diagnostic of conductive hearing loss in our study. Hearing loss was classified using the WHO grading system [7].

Samples of blood were also taken to perform basic laboratory examinations such as morphology or C-reactive protein ratio test.

The tympanic membranes of all children were evaluated. The tympanic membrane can be divided into four quadrants: antero-superior, antero-inferior, postero-inferior, and postero-superior (**Figure 1**). Perforations can occur in either of these quadrants, as well as in the centre or the pars flaccida. In this study, the location of perforation was classified based on this reference system.

Cluster analysis

Our work involved using cluster analysis to find out whether the audiograms could be classified into a few distinct

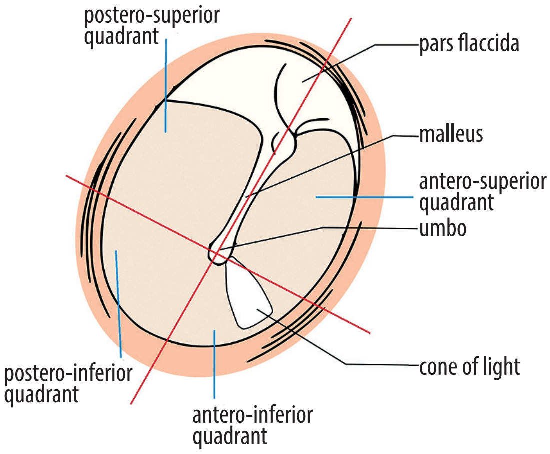

Figure 1. The tympanic membrane divided into four quadrants. Modified from Wikipedia (user Madhero88 under CC BY SA 3.0)

profiles. Frequencies from the PTA and the values of hearing loss in decibels were the variables by which specific cases could be categorized into clusters. Later, we also investigated whether these profile types were related to the location of the tympanic membrane perforation.

There are two main approaches to cluster analysis – partitional and hierarchical [16–19]. The hierarchical approach classifies cases into increasingly large groups, while the partitional approach divides groups into successively smaller groups. In this study, both methods were applied. First, in the hierarchical approach the cases were agglomerated using Ward's method [18]. This method connects the cases which have the most resemblance and assembles them into bigger groups. The result is given as a dendrogram.

Subsequently, the partitional approach was also used, where the distance between cases was measured using Euclidean distance. There are several indexes that can be used to define the distance, including the silhouette index [16]. An alternative is k-means clustering, and here we used the indices of Krzanowski and Lai [20] and Caliński and Harabasz [17]. The multiple algorithms each pointed to the data as belonging to three clusters, as shown in the results below.

Results

Cluster analysis

On the basis of hearing thresholds, the dendrogram presented in **Figure 2** suggests that the data can be divided into three or five clusters. Given the small size of the sample, three clusters were adopted for further analysis (observe the dashed vertical line in **Figure 2** which intersects three branches).

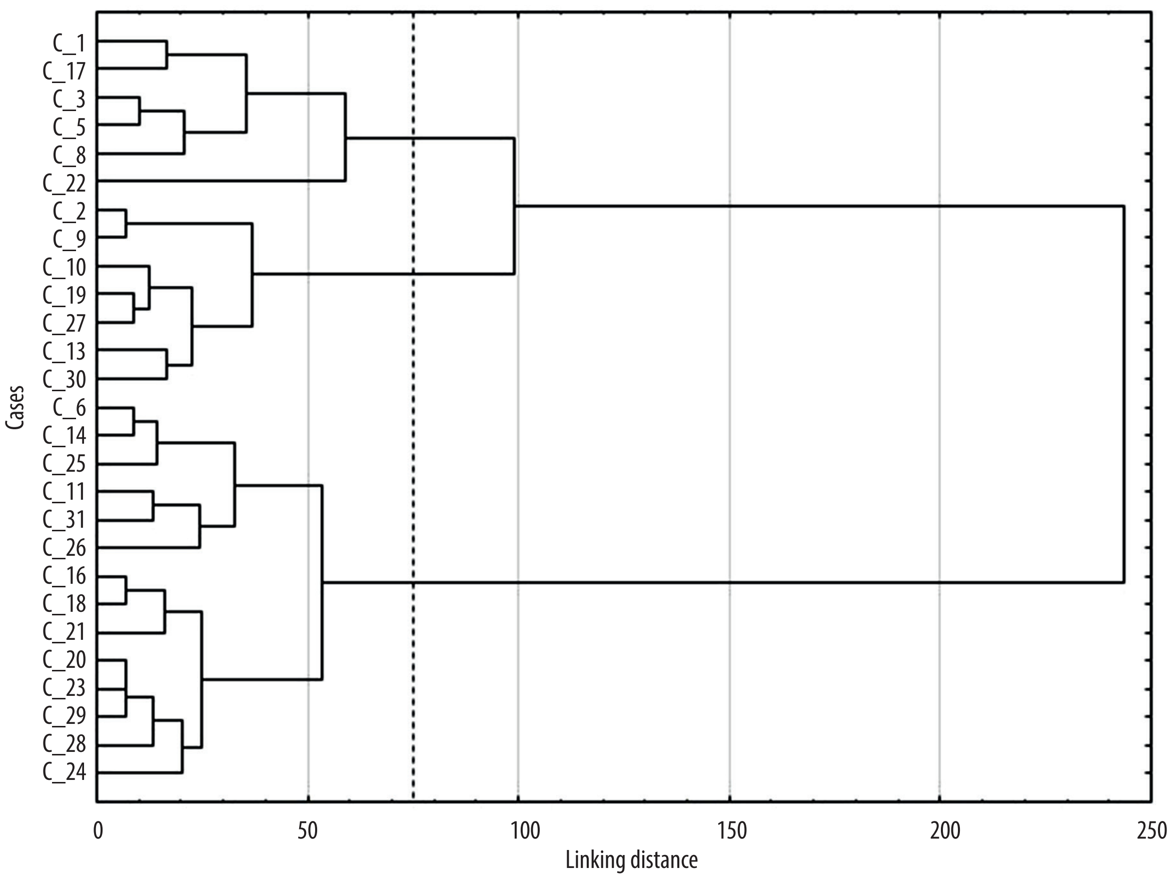

Figure 2. Hearing threshold data linked with a dendrogram. The vertical dotted line indicates aggregation into three major clusters

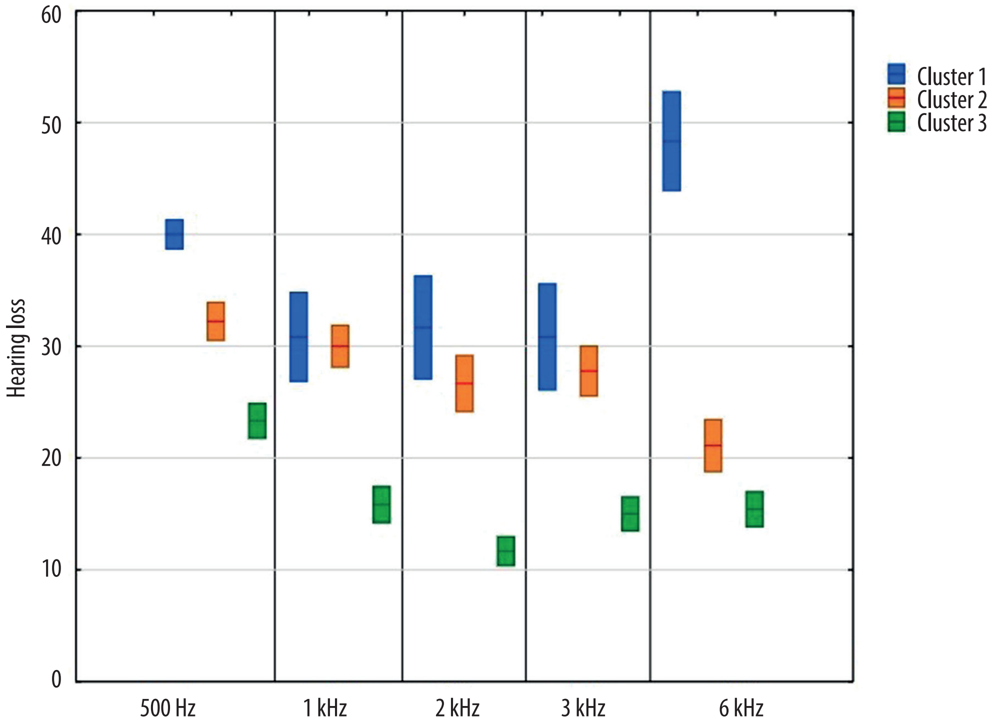

Figure 3. Cluster analysis identifies that the children's hearing losses can be divided into three distinct clusters

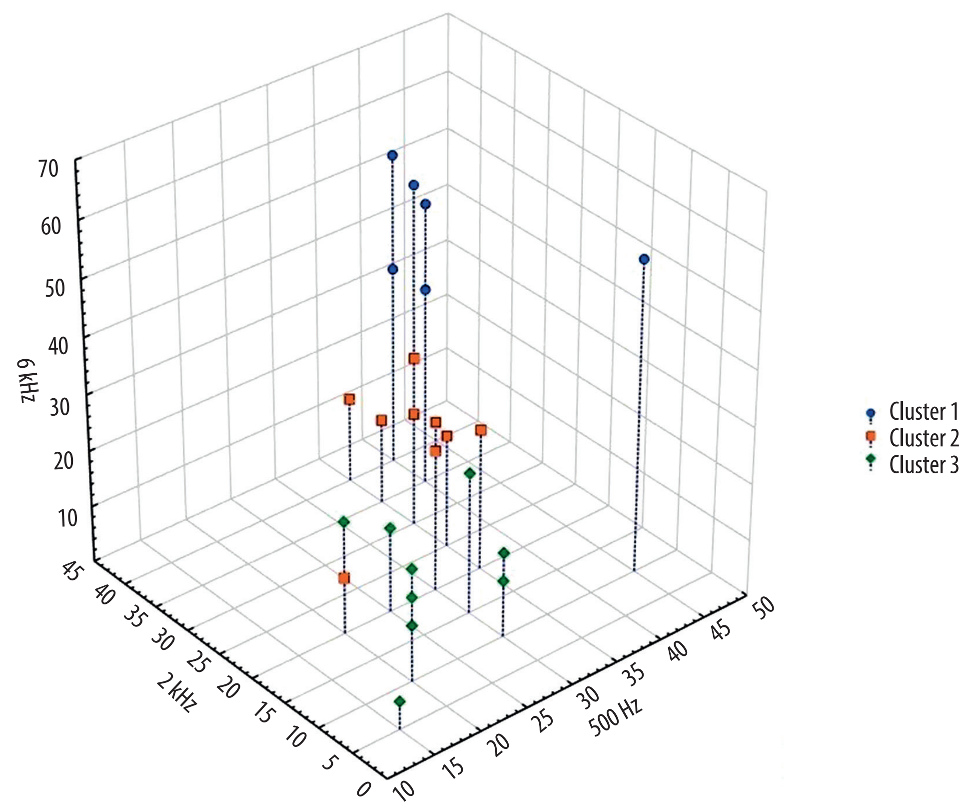

Figure 4. The same data as Figure 3 plotted in three frequency dimensions (0.5 kHz, 2 kHz, and 6 kHz)

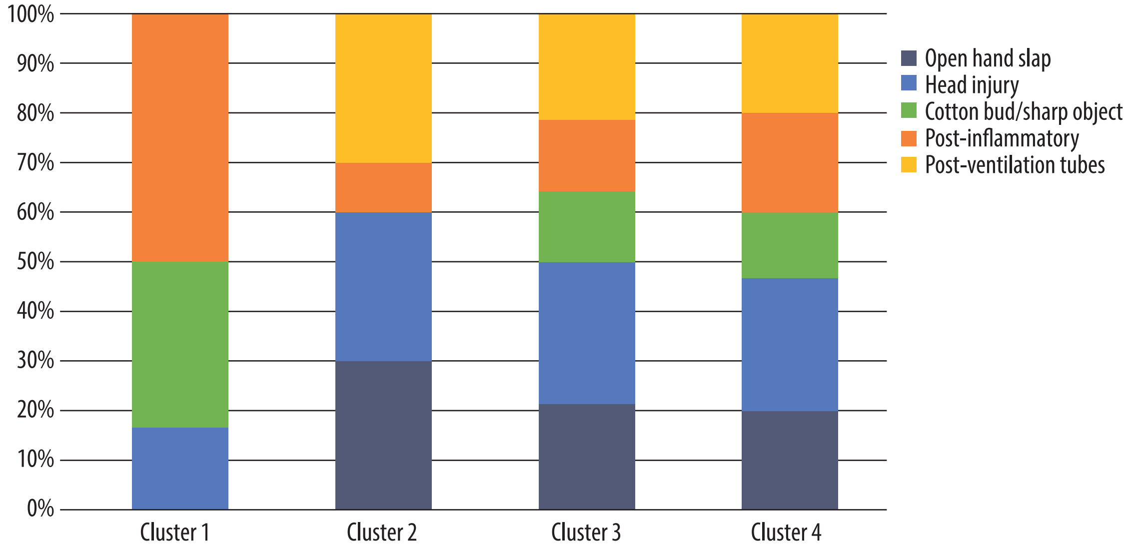

Figure 5. Etiology of injury according to cluster

Table 1. Magnitudes of hearing loss in each cluster

Frequency	Cluster 1		Cluster 2		Cluster 3		Complete sample	
	Mean of hearing loss (dB)	SD	Mean of hearing loss (dB)	SD	Mean of hearing loss (dB)	SD	Mean of hearing loss (dB)	SD
500 Hz	40.00	3.16	32.22	5.07	23.33	5.36	30.00	8.20
1 kHz	30.83	9.70	30.00	5.59	15.83	5.57	23.89	9.74
2 kHz	31.67	11.25	26.67	7.50	11.67	4.44	21.11	11.29
4 kHz	30.83	11.58	27.78	6.67	15.00	5.22	22.78	10.13
6 kHz	48.33	10.80	21.11	6.97	15.42	5.42	24.63	14.93
*n**	6		9		12		27	
% sample	22.2%		33.3%		44.4%		100.0%	

* *n* = number of cases in the sample.

When detailed cluster analysis was conducted on the hearing loss data, it resulted in three groups of patients which each had similar profiles of hearing loss. The results are presented in **Figure 3**. These groups comprise:

Cluster 1 (blue) – cases with hearing deficit of above 30 dB and in which there is a significant increase at the lowest and highest frequencies.

Cluster 2 (orange) – moderate hearing deficit spread over a wide range of frequencies.

Cluster 3 (green) – relatively small hearing deficit overall but more at the lowest frequency.

Table 1 shows the hearing losses for each cluster according to frequency.

The clusters are also visualized in **Figure 4**, which is a scatter plot in three-dimensional space, each dimension being the three frequencies at which the greatest differences between the variables were observed.

These preliminary results suggest that the character of the injury may affect the hearing loss profile. The proportion of causes is different in each cluster, as shown in **Table 2** and **Figure 5**. In cluster 1 the major cause of TMP was residual perforation after chronic simple otitis media, which was reported in 50% of cases. At the same time, as set out in **Table 3**, the most common location of the perforation in cluster 1 was the posteroinferior quadrant of the tympanic membrane (50% of cases). Likewise, in cluster 2 causes were fairly equal – slap by open hand, head injury, and post ventilation tube perforation (**Table 2**) – but the location of perforation was not. As **Table 3** indicates, the most common locations were the inferior quadrants (33% each, making 67%). In cluster 3, TMP was largely caused by head injury (33% of cases, **Table 2**) and **Table 3** shows that the anteroinferior quadrant was most often affected (33% of such cases).

Table 2. Causes of hearing loss in each cluster

	Cluster 1		Cluster 2		Cluster 3		Complete sample	
	n	%	*n*	%	*n*	%	*n*	%
Open hand slap	0	0.00	3	33.33	3	25.00	6*	22.22
Head injury	1	16.67	3	33.33	4	33.33	8	29.63
Cotton bud/sharp object	2	33.33	0	0.00	2	16.67	4	14.81
Post-inflammatory	3	50.00	1	11.11	2	16.67	6	22.22
Post ventilation tube	0	0.00	3	33.33	3	25.00	6	22.22

* There may be more than one possible reason for a TMP.

Table 3. Clusters by location of perforation on the TM

Quadrant	Cluster 1		Cluster 2		Cluster 3		Complete sample	
	n	%	*n*	%	*n*	%	*n*	%
Antero-inferior	0	0.00	3	33.33	4	33.33	7	25.93
Antero-superior	0	0.00	0	0.00	1	8.33	1	3.70
Postero-inferior	3	50.00	3	33.33	1	8.33	7	25.93
Postero-superior	1	16.67	1	11.11	3	25.00	5	18.52
Central	0	0.00	1	11.11	1	8.33	2	7.41
Pars flaccida	0	0.00	0	0.00	1	8.33	1	3.70

Note that in some cases it was not possible to identify the site of the injury (e.g. if there was a blood clot), so the number of locations seen (*n*) does not match the percentage of children in a cluster.

By summing up all the cases, the dominant etiology of perforation was head injury (nearly 30% of cases) and the dominant locations were the inferior quadrants (more than 50% of cases).

While we cannot provide a full explanation, it was interesting to note that the number of WBC in blood was significantly higher in cluster 1 (9.2×10^9/L) compared to cluster 2 (6.6×10^9/L) or cluster 3 (6.5×10^9/L). Perhaps there is an inflammatory etiology associated with TMP, and we have detected the presence of microbes and their metabolic products. There did not appear to be any significant differences in the C-reactive protein ratios.

Discussion

According to Rana [21], patients suffering from otitis with perforation in the posterosuperior quadrants and perforation involving all quadrants present the biggest hearing loss. Perforation of the antero-superior quadrant generates the minimum hearing loss. Posterior quadrants appear to be more susceptible to hearing loss [9].

In contrast, Mehta et al. [6] found no correlation between hearing loss and the location of the perforation. Research indicates that the location may have an effect, but only if the TMP disturbs the proper coupling of TM and the manubrium. It appears that the volume of the middle ear that is crucial – the smaller the middle ear volume the bigger the hearing loss [6]. Voss and colleagues believed that hearing loss does not depend on the location of the perforation [22]. Lerut claimed that the location of the perforation does not affect hearing, but if the umbo is involved then TMP may decrease hearing by 5–6 dB [23]. According to Castelhano the hearing loss resulting from a TMP depends on etiology, size, and location, so that large TMPs which affect posterior quadrants involving the manubrium result in the biggest hearing losses [24]. In the study by Salaimen of 792 patients, marginal TMPs, especially those located in the posteroinferior quadrant, resulted in hearing loss in 95.6% of cases, producing a pure tone average for air-conduction of 43.3 dB and an average air-bone gap of 28.7 dB [25].

Our findings are broadly consistent with these papers. In our study, the most common causes of TMPs were head injuries and slaps. Our work suggests that among older children (mean age 13.2 years old) head injuries are the most common reason for TMP, and in these cases the most common locations of the TMP were the inferior quadrants. Interestingly, the ear that is more affected by the slap is the left ear, perhaps because the dominant hand of the attacker is the right [26]. In younger children, sharp objects are the most common reason for a TMP [5].

Because of the different factors that can cause TMP, there is a diverse pattern of hearing loss. Generally, the stronger the force of injury, the bigger will be the perforation. Local inflammation may be the result of the applied force as well as colonization by microbes. Microbial activity can impede healing and thicken the TM and lead to the increased impedance of the TM. It can also tend to immobilize the chain of ossicles and decrease aeration of the middle ear. The post-inflammatory state may result in increased hearing loss above 60 dB, especially at lower frequencies (< 1 kHz) [27]. The results of this study are partially consistent with prior work. Both clusters 2 and 3 are dominated by injury, and hearing loss in these clusters rarely exceeded 30 dB.

According to Mehta et al. [6], conductive hearing loss increases with perforation size, but it is independent of the location within the TM and increases with the smaller ear volume. The explanation for the predominance of the posterior quadrants as sites of perforation is that these quadrants are more accessible from the outer ear and can be easily accessed by a sharp object.

Despite the fact that most TMPs heal spontaneously, there are still some cases that may lead to costly surgical procedures, especially in small children. Children under 9 years are associated with significantly higher rates of persistent and recurrent perforation [8] which require less invasive approaches to treating TMP.

Conclusions

In this study we found that there was a relation between TMP and the degree of hearing loss, and that the losses were grouped in specific clusters. These preliminary results are promising and could encourage further research along these lines. It may result in new approaches to diagnosis, surgery, and rehabilitation. This classification approach could help predict the success rate of TMP healing and create a standard pattern for proceeding with a highly diverse group of patients.

There are few papers on tympanic membrane perforations in children and their relation to hearing loss. The limitations of the study were the small number of patients, the inability to establish the exact degree of hearing loss in very young children, and a lack of complete medical records on previous hearing conditions. Middle ear volume and size of perforation should be examined in further study.

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