ORIGINAL ARTICLE

Does tympanic membrane perforation have a protective effect on the inner ear in blast-injured patients?

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ABSTRACT

BACKGROUND: Blast-induced hearing loss is an acoustic trauma commonly caused by high-energy explosions of improvised explosive devices, and the auditory system may be affected by blast damage. This study aims to evaluate the protective effect of tympanic membrane perforation (TMP) on the inner ear against blast injury.

METHODS: In this study, 43 adult patients who had suffered blast injury were divided into three subgroups: intact tympanic membranes in both ears, unilateral TMP, and bilateral TMP. Each patient underwent a comprehensive audiogram, including bone conduction, in the audiology department.

RESULTS: Evaluation was performed on 43 (100%) males with a mean age of 31.44±8.01 years (range, 18–52 years). When the type of hearing loss was evaluated separately for each ear, sensorineural hearing loss (SNHL) was observed in 31 (36%), high-frequency SNHL in 26 (30.2%), conductive hearing loss in eight (9.3%), and mixed type hearing loss in 21 (24.4%) ears. TMP was detected in 21 (48.8%) of 43 blast-injured patients, on the right side in four (9.3%) patients, on the left side in seven (16.3%), and bilateral in 10 (23.3%). When the type of acoustic trauma was evaluated, 15 (34.9%) patients were observed to have suffered from the explosion of an IED, 12 (30.2%) from weapon explosion, six (14%) were a vehicle bomb explosion, three (7%) were projectile missile explosion, three (7%) were mortar explosion, two (4.7%) were mine explosion, and two (4.7%) were exposed to the explosion in an armored vehicle (Table 1).

CONCLUSION: No significant difference was observed in the majority of the frequencies whether the tympanic membrane was perforated or not in the blast-injured patients and it was concluded that tympanic membrane perforation caused by blast injury had no protective effect on the inner ear.

Keywords: Blast injury; high frequency; protective effect; sensorineural hearing loss; tympanic membrane perforation.

INTRODUCTION

Blast-induced hearing loss is an acoustic trauma commonly caused by high-energy explosions of improvised explosive devices (IEDs).[1] These explosions have a wide spectrum of effects, from minor injuries treatable with simple medical intervention to fatal injuries. When an explosion occurs, first supersonic and short-term positive pressure waves appear, followed by a relatively long-term negative pressure wave, and the pressure changes that occur in this short time, with obvious differences relative to atmospheric pressure, are primarily responsible for blast injury.[1] Furthermore, the severity of the injury is directly proportional to the duration, intensity and duration of the blast wave. The ear and auditory system can be easily and frequently affected by blast damage.[2] Acoustic trauma following the blast injury and burns secondary to explosion can contribute to the blast injury. The blast wave may cause sensorineural

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hearing loss (SNHL), conductive, or mixed type hearing loss as a result of tympanic membrane perforations (TMP), ossicular or cochlear damage.[3,4] TMP is seen in 16% to 32% of patients after blast injury,[3] and the initial positive blast wave is mostly responsible for the injury.[5,6] Although it has been suggested in the literature that conductive hearing loss caused by TMP may prevent inner ear damage by limiting the energy transporting into the cochlea, this theory remains unclear.[1,7–9]

The present study aims to evaluate the protective effect of TMP on the inner ear against blast injury by evaluating the hearing levels of patients with different types of hearing loss due to blast injury in both ears. The relationship between TMP and hearing loss was evaluated by comparing the hearing levels at different frequencies in blast injured ears with or without tympanic membrane perforation. In addition, the effects of TMP size on hearing level were also investigated as it not mentioned in the literature yet.

MATERIALS AND METHODS

This study was conducted according to the tenets of the Declaration of Helsinki and was approved by the Local Review Board before the study taking place (KAEK-15-1314/25.01.2017). All data were collected prospectively from March 2015 to December 2018. Written informed consent was obtained from all study participants. In this study, 43 adult patients who had suffered blast injury were divided into three subgroups as, intact tympanic membranes in both ears, unilateral TMP and bilateral TMP. The 86 tympanic membranes were also evaluated in two subgroups as non-perforation and perforation groups. In the perforation group, patients were categorized into three subgroups according to TMP size (1–3 mm, 4–7 mm, and 8–10 mm). Each patient underwent a comprehensive audiogram, including bone conduction, in the audiology department. The data also included the type of IEDs that caused the blast injury, the presence of tinnitus and dizziness, the patient's location when the injury occurred, comparative audiogram, and hearing thresholds at frequencies of 250–8000 Hz, and bone conduction hearing thresholds of 500–4000 Hz. Different pure-tone averages (PTA), including 500, 1000, and 2,000 Hz, 500–4000 Hz, 6000 Hz and 8000 Hz, were examined separately, classified into three subgroups and described as PTA1, PTA2, and PTA3, respectively.

Inclusion/Exclusion Criteria

This study only included adult patients with blast injury. It was confirmed from the medical history that before the blast injury, both TM had been intact and there was no hearing loss. The exclusion criteria included a diagnosis of any acute or chronic infection of the external auditory canal, obliteration of the external auditory canal by any benign or malignant neoplasm, ear drainage, blood, cerebrospinal fluid, ear wax plugs, foreign bodies in the ear canal, or history or clinical evidence of ear surgery before the blast injury.

Statistical Analyses

The results were presented as percentages, mean, standard deviation (SD) and the number (%) of patients. A paired t-test was used to evaluate the differences between the hearing thresholds of the sides of patients with and without TMP. The strength of the linear relationship between the TMP size and comprehensive audiogram results was measured using Pearson's correlation analysis. A value of $p<0.05$ was accepted as statistically significant. Data obtained in the study were analyzed statistically using the Statistical Package for Social Sciences 17.0 software (SPSS for Windows; IBM, Armonk, NY, USA).

RESULTS

Evaluation was performed on 43 (100%) males with a mean age of 31.44±8.01 years (range, 18–52 years). When the type of hearing loss was evaluated separately for each ear, SNHL was observed in 31 (36%), high-frequency SNHL in 26 (30.2%), conductive hearing loss in eight (9.3%), and mixed type hearing loss in 21 (24.4%) ears. TMP was detected in 21 (48.8%) of 43 blast-injured patients, on the right side in four (9.3%) patients, on the left side (Fig. 1) in seven (16.3%), and bilateral in 10 (23.3%). In the perforation group, SNHL was observed in eight (19%), high-frequency SNHL in 12 (28.6%), conductive hearing loss in eight (19%), and mixed type hearing loss in 14 (33.3%) ears. In 22 (51.2%) patients, the TM was intact, 36 (83.7%)

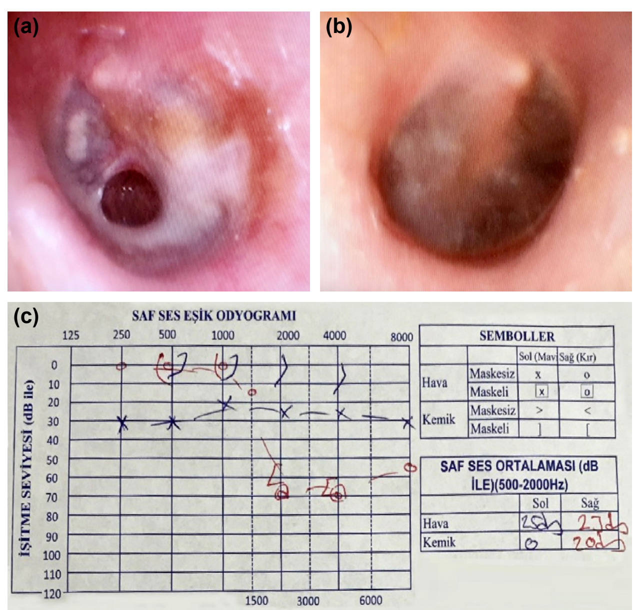

Figure 1. (a) Left tympanic membrane perforation (TMP) was seen in a blast-injured patient, **(b)** intact right tympanic membrane of the same patient, **(c)** conductive hearing loss was observed in the left side with TMP, and high-frequency sensorineural hearing loss was observed in the right ear of the patient according to pure-tone audiometry.

Table 1. Demographic data, characteristics of physical examination, types of acoustic trauma and additional symptoms of the blast injured patients

	n (%)
Number of patients	43 (100)
Age (range), years (mean±SD)	31.44±8.01 years (18–52)
Gender	
Male	43 (100)
Female	–
Perforation side	
Right	4 (9.3)
Left	7 (16.3)
Bilateral	10 (23.3)
Intact tympanic membrane	22 (51.2)
Type of acoustic trauma	
Projectile missile explosion	3 (7)
Improvise explosive devices	15 (34.9)
Fired weapon noise	12 (30.2)
Mine explosion	2 (4.7)
Mortar explosion	3 (7)
Bombed vehicle explosion	6 (14)
Explosion exposure in armored vehicle	2 (2.3)
Additional otologic symptoms	
Tinnitus	36 (83.7)
Dizziness	11 (25.5)

SD: Standard deviation.

patients had tinnitus and 11 (25.5%) had dizziness. At the time of the blast injury, two (4.6%) patients were in a vehicle, 25 (58.1%) were in an open area, and 16 (37.2%) were in a residential area. When the type of acoustic trauma was evaluated, 15 (34.9%) patients were observed to have suffered from the explosion of an IED, 12 (30.2%) from weapon explosion, six (14%) were a vehicle bomb explosion, three (7%) were projectile missile explosion, three (7%) were mortar explosion, two (4.7%) were mine explosion, and two (4.7%) were exposed to the explosion in an armored vehicle (Table 1).

According to the separate comparisons of no-perforation and perforation groups, there was no statistically significant difference in hearing outcomes at any of the bone thresholds, air thresholds at 2000–8000 Hz, at PTA 2, and PTA 3 ($p>0.05$). The difference was significant between the groups at the air thresholds of 250, 500, and 1000 Hz and at PTA 1 ($p<0.05$) (Table 2). When the hearing thresholds of the blast injury patients with unilateral TMP were evaluated, no statistically significant difference was observed between the non-perforation and perforation groups ($p>0.05$) (Table 3).

When perforation diameters were evaluated, 23 (26.7%) of 42 TMP were between 1–3 mm, 9 (10.5) were between 4–6 mm, and 10 (11.6%) were between 7–10 mm. The Pearson correlation scores between perforation size and pure tone average scores were very weak at the air thresholds of 250, 4000, 6000, and 8000 Hz, at the bone threshold of 4000 Hz, and at PTA 3, and weak at air thresholds of 500, 1000, and 2000 Hz, at all of the bone thresholds except 4000 Hz, and at PTA 1, and PTA 2 (Table 4).

Table 2. Tympanic membranes (n=86) were evaluated separately in two subgroups as non-perforation and perforation groups in blast injured patients and pure tone averages were compared with each other

Hearing level (Hz)		No perforation group (n=55)		Perforation group (n=31)		p
		Mean (db)	SD (db)	Mean (db)	SD (db)	
Air threshold	250 Hz	24.27	19.18	36.94	19.57	<0.05
	500 Hz	19.91	18.82	34.84	23.08	
	1000 Hz	18.27	18.84	35.65	23.51	
	2000 Hz	26.09	24.43	25.16	20.55	0.858
	4000 Hz	35.82	30.17	30.48	24.47	0.403
	6000 Hz	37.27	28.59	33.39	26.53	0.536
	8000 Hz	36.73	27.39	34.52	27.85	0.722
Bone threshold	500 Hz	15.04	11.98	19.90	13.85	0.091
	1000 Hz	14.04	12.60	18.13	13.01	0.157
	2000 Hz	22.13	20.33	20.55	14.49	0.704
	4000 Hz	29.13	24.42	27.32	16.38	0.714
PTA 1		21.42	19.05	31.88	19.71	<0.05
PTA 2		25.02	20.51	31.53	18.98	0.151
PTA 3		37.00	27.73	33.95	26.99	0.622

SD: Standard deviation; db: Decibel; PTA: Pure-tone averages.

Table 3. Comparison of hearing levels of the blast injured patients with monaural tympanic membrane perforation

Hearing level (Hz)		No perforation group (n=11)		Perforation group (n=11)		p
		Mean (db)	SD (db)	Mean (db)	SD (db)	
AAir Threshold	250 Hz	30.91	35.97	42.73	28.32	>0.05
	500 Hz	27.27	36.01	37.73	29.95	
	1000 Hz	25.45	35.17	37.73	29.70	
	2000 Hz	33.18	35.73	35.91	30.15	
	4000 Hz	47.73	36.01	48.64	29.84	
	6000 Hz	49.55	30.04	50.45	33.72	
	8000 Hz	47.73	29.70	51.36	33.10	
Bone Threshold	500 Hz	16.55	18.45	21.09	18.50	
	1000 Hz	17.00	18.47	18.82	18.82	
	2000 Hz	22.45	22.79	18.36	19.38	
	4000 Hz	35.64	29.15	34.27	21.84	
PTA 1		28.64	34.09	37.12	29.48	
PTA 2		33.41	32.91	40.00	28.58	
PTA 3		48.64	29.52	50.91	33.30	

SD: Standard deviation; db: Decibel; PTA: Pure-tone averages.

Table 4. The Pearson correlation scores between perforation size, and pure tone averages scores

		r	p
Air threshold	250 Hz	-0.184	0.245
	500 Hz	-0.231	0.142
	1000 Hz	-0.292	0.142
	2000 Hz	-0.202	0.198
	4000 Hz	-0.046	0.773
	6000 Hz	-0.016	0.917
	8000 Hz	-0.001	0.993
Bone threshold	500 Hz	-0.206	0.190
	1000 Hz	-0.317	<0.05
	2000 Hz	-0.390	
	4000 Hz	-0.086	0.589
PTA 1		-0.267	0.087
PTA 2		-0.222	0.157
PTA 3		-0.009	0.955

PTA: Pure-tone averages.

DISCUSSION

All types of hearing loss, conduction type, sensorineural type or mixed type may occur after a blast injury. TMP is responsible for conductive hearing loss and cochlear damage for SNHL. SNHL can be explained by damage of the basilar membrane as a result of inner and outer hair cells rupture and by a change in the integrity of the tight cell junctions of the reticular lamina of the organ of Corti, resulting in a mixture of cochlear fluids.[3,4] Finally, mixed hearing loss may occur with the combination of these pathological processes. In this study, 36% of the blast-injured ears had mild to moderate SNHL, 30.2% had high-frequency SNHL, and 24.4% had mixed type, similar to other studies in the literature.[1,7,10] In addition, in the evaluation of hearing levels of the perforation group, 47.6% patients had SNHL, 33.3% had mixed type hearing loss, while only 8% had conductive hearing loss. These data show that conductive hearing loss was quite limited in both the perforation and non-perforation groups following blast injury, meaning that inner ear damage cannot be prevented and cochlear damage occurs despite TMP.

When armies are evaluated demographically, they are predominantly composed of male personnel, and men are more often employed in the combat area.[11] This explains why the majority of patients in studies investigating blast injury are male. The patients included in this study consisted mostly of male and young military patients, similar to other studies in the literature.[1,11,12] Rates of TMP due to blast injury vary in the literature. Shah et al.,[1] Ritenour et al.[10] and Harrison et al.[13] evaluated blast-injured patients admitted to military hospitals and reported 16% perforation, and 8%, 8% and 7% bilateral perforation rate, respectively. In the present study, 48% of the blast-injured patients suffered TMP, which was much higher than the rates reported in the literature; thus, the differences between groups with similar numbers of patients were evaluated more successfully.

In recent studies, it has been stated for many years that TMP may have a protective effect on the inner ear and prevent further hearing loss in blast-injured patients.[7,8] TMP is believed to protect the inner ear by preventing energy transfer to the cochlea as a result of shock waves.[1,7–9] However, there is still no consensus on this issue in the literature, and different results have emerged.[1,14] Shah et al.[1] evaluated pure-tone averages of 110 blast-injured patients and 18 (16%) of these patients had TMP, of which nine (8%) patients were bilateral TMP. No statistically significant difference was determined between perforation and non-perforation groups of blast-injured patients, and it was concluded that TMP did not provide protection against hearing loss. Kerr et al.[14] also evaluated patients injured in a bomb attack and reported that TMP had no protective effect on the inner ear, contrary to popular belief. Similar to the study conducted by Shah et al.,[1] perforated (n=31) and non-perforated (n=55) ears were compared with each other in the current study of blast-injured patients and TMP was determined to have a protective effect on the inner ear. In the evaluation of these groups separately, there was no significant difference between the two subgroups except at low frequencies (250, 500, 1000 Hz). Hearing loss was also evaluated in patients (n=11) with monaural TMP, and similarly, no significant difference was found at any frequency, which supported the main outcome. Moreover, when the effect of TMP diameter on hearing loss was evaluated, there was a very weak or weak correlation. Thus, there was no significant difference between the perforated and non-perforated subgroups except at low frequencies, and it can be concluded that the effect of TMP on hearing is very weak. However, according to the comparison of the perforation and non-perforation groups, there was a significant difference in low frequencies, which could be explained by the pathological process of the tympanic membrane formed by the traumatic perforation. Despite the damage in these areas, the energy of the blast waves did not decrease and continued to cause damage to the basal aspect of the cochlea and the round window membrane. Consequently, moderate hearing loss that affects high frequencies develops whether or not the tympanic membrane is perforated.

Limitations

The precise determination of the intensity, direction and distance of trauma, a more detailed and specific examination of the factors that cause blast effects, and the assessment of long-term hearing outcomes after treatment were not available. In addition, there was no evaluation of neurological symptoms, such as headache, confusion, amnesia, short-term memory loss, sleep disturbance, and anxiety, and their relationship with hearing thresholds and these data could have made a further contribution to the literature. Further studies with larger case series are needed to evaluate the effects of TMP on the inner ear following a blast injury.

Conclusion

According to the present study, no significant difference was observed in the majority of the frequencies whether the tympanic membrane was perforated or not in the blast-injured patients and it was concluded that tympanic membrane perforation that arises from blast injury had no protective effect on the inner ear.

Informed Consent: Written informed consent was obtained from all subjects who participated in this study.

Ethics Committee Approval: Approved by the local ethics committee (KAEK-15-1314/25.01.2017).

Peer-review: Internally peer-reviewed.

Authorship Contributions: Concept: H.T., M.C.G.; Design: H.T., Ö.K.; Supervision: Z.N., Ö.K.; Resource: M.C.G., V.K.Ç.; Materials: M.C.G., V.K.Ç.; Data: H.T., M.C.G.; Analysis: H.T., C.N.; Literature search: V.K.Ç., Z.N.; Writing: H.T., M.C.G.; Critical revision: H.T., Ö.K.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZET*

Blast yaralanması hastalarında kulak zarı perforasyonunun iç kulağı koruyucu etkisi var mıdır?

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AMAÇ: Blast etki ile gerçekleşen işitme kaybı, yaygın olarak el yapımı patlayıcı cihazların yüksek enerji patlamalarından kaynaklanan akustik travmadır ve işitme sistemi patlama hasarından etkilenebilir. Bu çalışmanın amacı, kulak zarı perforasyonunun (KZP) iç kulak üzerindeki blast yaralanmasına karşı koruyucu etkisini değerlendirmektir.

GEREÇ VE YÖNTEM: Blast yaralanması olan toplam 43 yetişkin hasta, her iki kulağındaki sağlam kulak zarı, tek taraflı KZP ve iki taraflı KZP olarak üç alt gruba ayrıldı. Her hastaya odyoloji bölümünde kemik iletimi dahil olmak üzere kapsamlı bir odyogram uygulandı.

BULGULAR: Toplam 43 (%100) erkekten oluşan hastaların yaş ortalaması 31.44±8.01 yaş (18–52 yıl) idi. İşitme kaybı tipi her kulak için ayrı ayrı değerlendirildiğinde, 31 (%36) sensörinöral, 26 (%30.2) yüksek frekanslı sensörinöral, 8 (%9.3) iletim tipi ve 21 (%24.4) mikst tip işitme kaybı gözlendi. Kırk üç hastanın 21'inde (%48.8) KZP izlendi. Bu hastalarda KZP dördünde (%9.3) sağ tarafta, yedisinde (%16.3) sol tarafta ve 10'unda (%23.3) iki taraflı idi. Akustik travma türü değerlendirildiğinde, el yapımı patlayıcı patlamasından 15 (%34.9), silah patlamasından 12 (%30.2), bomba yüklü araç patlamasından altı (%14), roket atışından üç (%7), havan patlamasından üç (%7), mayın patlamasından iki (%4.7) ve zırhlı araçta patlamaya maruz kalma travmasından iki (%4.7) hasta etkilenmişti.

TARTIŞMA: Blast yaralanmalı hastaların neredeyse tamamında, kulak zarı perfore olsun veya olmasın, işitme eşiklerinde anlamlı fark izlenmedi ve blast yaralanmasından kaynaklanan kulak zarı perforasyonunun iç kulak üzerinde koruyucu bir etkiye sahip olmadığı sonucuna varıldı.

Anahtar sözcükler: Blast yaralanması; koruyucu etki; kulak zarı perforasyonu; sensörinöral işitme kaybı; yüksek frekans.

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