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Impact of Explosion on Hearing

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ABSTRACT

There is many civilians and soldiers who exposed to explosions in Iraq each month and they need an otolaryngological and audiological assessment. To recognize the possible auditory insults and the recovery period of the acquired damages that may resulted from explosion and help for planning of optimal management strategies of otological manifestations and prevent undesirable consequences. A prospective, descriptive study included forty-seven patients who were exposed to blast injuries within two weeks came to otolaryngology unit in Basrah Teaching Hospital complaining from otological symptoms from July 2015 tell January 2017. Three periodic assessment were done for each patient. An initial evaluation was done in the 1st visit included a detailed history and examination to evaluate the symptoms and assess the associated non-otological injury. An otological examination were done for all patients in the three visits, included microscopic ear examination, photos for the perforated tympanic membrane were taken to grade the perforations depending on their surface area, Pure tone audiometry and tympanometry. Thirty-eight patients were available to follow up in the 2nd and 3rd visits. All of the 47 patients were young and middle age male, hearing loss and tinnitus were the most presenting symptoms, which improved with time. Hearing impairment mostly in the high frequencies however there was improvement in the subsequent visits. The majority of patients (93.6%) presented with tympanic membrane perforation mostly grade I which usually healed spontaneously. There was a statistically significant association between the degree of tympanic membrane perforation and associated non-otological injuries and with the explosions if occurred in closed space. Blast related otological injury constitute the main cause of morbidity as the ear is the most sensitive organ to explosive blast injury. Hearing loss was the dominant symptoms at presentation mainly in high frequencies, but fortunately most of patients improved with time. Tympanic membrane perforation constituted the mostly seen sign, however spontaneous healing can be expected in the majority of cases.

1. INTRODUCTION

Acute acoustic trauma indicate injuries to the ear due to blast or impulse noise. While blast injury of the ear designate the various effects of explosive forces on the auditory which might be either Explosive (refers to otological trauma due to the detonation of explosives) or Non-explosive blast injury to the ear (otological trauma caused by a blow (pressure) to the ear that seals the external auditory meatus, causing a shock wave to be transmitted along the auditory canal) [1]. A blast wave generated by an explosion starts with a single pulse of increased air pressure that lasting a few milliseconds. The negative pressure of the blast wave follows immediately the positive wave as shown in figure [1]. The duration, velocity and intensity of the blast wave depends on the type of explosive material and the distance from the point of detonation [2].

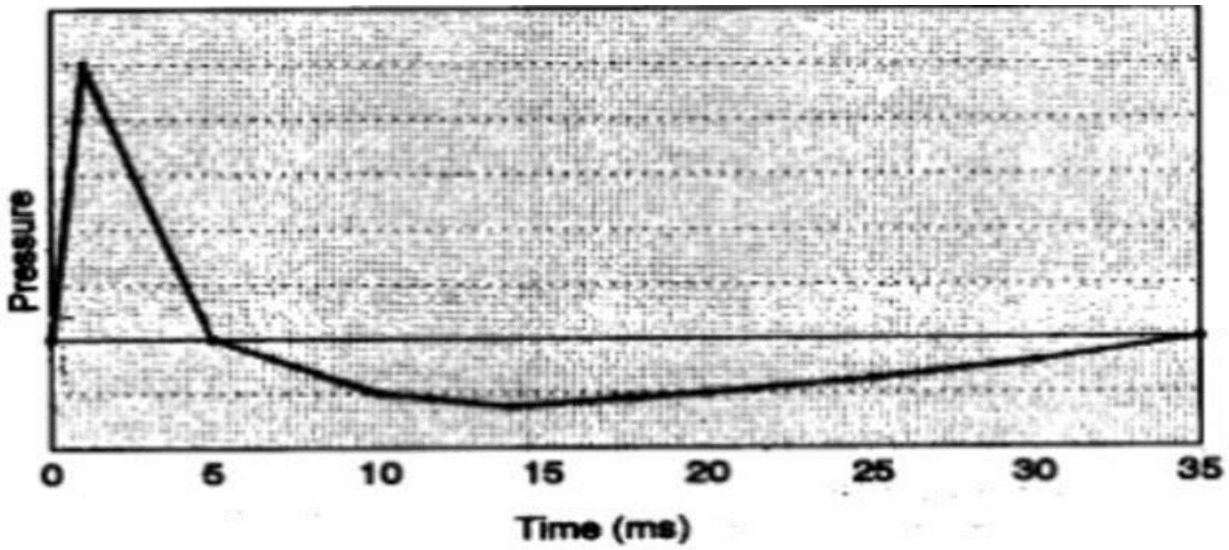

Figure (1) pressure profile of the explosive blast wave (Friedman curve) from bomb blast injuries to the ear: The London Bridge incident series, Journal of Accident and Emergency Medicine, 1995, 12, p194-198. [3]

Nature of the explosive in an explosion, the conversion of solid or liquid material into a gaseous form is accompanied by the release of large amounts of energy. The characteristics of this process differ according to the explosive involved and agents, for example; gunpowder release energy slowly, while high-energy explosives such as trinitrotoluene (TNT) produce a very rapid release of energy [1]. Different stages of injury occur after blast explosion; primary injuries caused by overpressure or shock waves. The ears are most often affected by the blast overpressure, followed by the lungs and the hollow organs of the gastrointestinal tract [4]. Secondary injuries are caused by objects propelled by the explosion. Most cases of casualties are caused by secondary injuries due to a larger geographic area affected by this form of injury than the primary blast site and debris can easily be propelled for hundreds or even thousands of meters [5]. Tertiary injuries results from displacement of the air by explosion which creates a blast wind that can throw victims against a solid objects. Children are at a higher risk due to their relatively smaller body weight [5], [6]. The last type is Quaternary injuries or miscellaneous injuries, are all other injuries not involved in the first three classes. These include flash burns and psychiatric injury like post-traumatic stress disorders, is the most common quaternary injury may affect people who are otherwise completely uninjured [6].

2. PATIENTS AND METHODS

A prospective study carried out in otolaryngology department of Basra Teaching Hospital from July, 2015 to January, 2017. Fifty-nine patients attended the otolaryngology unit seeking for medical care to alleviate

their new otological symptoms that developed after the exposure to explosion were examined for this study. Twelve patients were excluded from the study due their previous history of aural fullness, hearing loss and prolong exposure to noise. Forty-seven male patients, their age range from 21-55 years who exposed recently (within two weeks) to explosive blast injury were included in this study.

Demographic data for all patients were obtained on initial visit that include:
name, age, complaining otological symptoms, distance from the explosion site, type of explosion and whether the explosion occurred in open or closed space.

Associated non-otological musculoskeletal, soft tissue or orthopedic injuries were categorized according to Hamdan classification system for injured causality [7].

Patients were checked three times at the time frame from initial blast injury shown below:

- First visit was within the 2 weeks from initial blast exposure.
- Second visit was within four to six week from initial blast exposure.
- Third visit within six months from initial blast exposure.

Each visit, the patients were subjected to complete otolaryngological examination emphasizing on otological assessment which include:

A. General otological examination:
otoscopic examination and microscopic examination of the ear for cleaning of external auditory canal from wax, foreign body, blood clots and for searching for any tympanic membrane perforation. An image was taken for each perforation. This task was facilitated by using Entermed Holland 174009ES rigid nasendoscopy 0 degree. The images were analyzed by Autodesk Design Review 2013 program to calculate the surface area of tympanic membrane perforation. The surface area of the tympanic membrane perforations was calculated in percentage (not in millimeter) to overcome the mathematical effect of the difference in the surface area of tympanic membrane among subjects.

The following equation was used to calculate the surface area of tympanic membrane perforation:

$$(SA\ \%) = P/T * 100\%$$

SA %: Percentage of the surface area of tympanic membrane perforation to the surface area of the whole tympanic membrane of same ear including the perforation.
P: the surface area of tympanic membrane perforation.
T: the surface area of the whole tympanic membrane of same ear.

Then after calculation of the surface area of perforation in percentage to the entire tympanic membrane, the perforations were categorized into 4 Grades according to previous standardization of [8]:

1. Grade 1 = <25%
2. Grade 2 = 25%- 50%
3. Grade 3 = > 50% or subtotal perforation
4. Grade 4 = 100% or total perforation

B. Assessment of the Hearing done by:
1. Tuning fork tests: Rinne, Weber and Absolute bone conduction tests was done as part of aural examination using a 512 hertz tuning fork.

2. Pure tone audiometry and Tympanometry: was done by using an AA222 diagnostic audiometer to measure hearing threshold for the following frequencies of 500 Hz, 1000 Hz, 2000 Hz ,4000 Hz and8000 Hz.

The average of thresholds of the three speech frequencies (500Hz, 1000Hz and 2000Hz) was calculated to determine hearing impairment in speech frequency and the average of the two high frequencies (4000Hz and 8000Hz) was calculated to assess hearing loss in high frequencies.

Depending on the results of pure tone audiometry in speech and high frequency for each ear hearing loss was categorized into conductive hearing loss, sensory neural hearing loss and mixed hearing loss. The hearing loss categorized according to severity into mild, moderate, severe and profound according to the British Society of Audiology [9].

Tympanometry was done for patients with no tympanic membrane perforation and for patients with healed perforations in the 2 subsequent visits, to diagnose the ossicular discontinuation if present.

3. Results

47 male patients enrolled in this study, their age ranged from 21-56 years old as shown in figure [2].

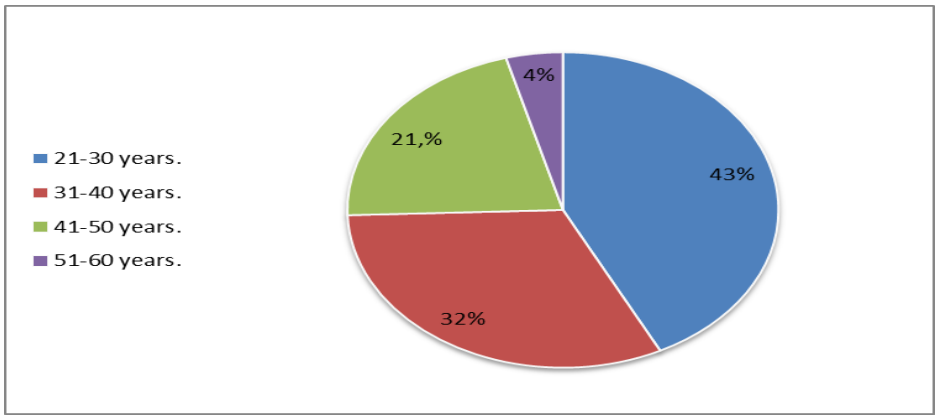

Figure [2]: Age distribution of the studied patients in percentage.

45 patients were a military or paramilitary member and only 2 patient were civilians. The type of explosion each patient suffer from is shown in figure [3]. Majority of patients suffer from impressive explosive device (72.3%).

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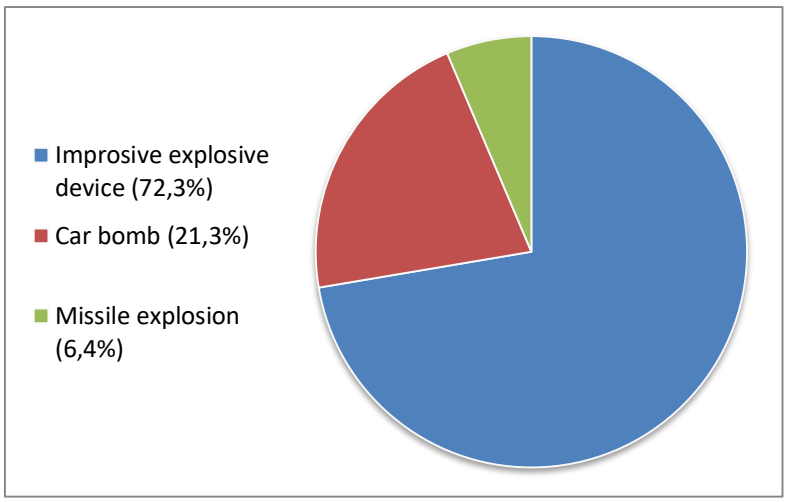


Figure [3]: the explosion types the studied patients suffer from.

The complaining otological symptoms of patients suffer from explosive blast injuries are listed in table [1].

Table [1]: The complaining symptoms of the studied patients with their percentages.

Symptoms at presentation	**Number & Percentage of patients**
Hearing loss	40 (85%).
Tinnitus	37 (78.7%).
Otalgia	23 (48.9%).
Aural fullness	11 (23.4%).
Vertigo	8 (17%).

The main complains of the studied patients were hearing loss and tinnitus. The type of hearing loss resulted from explosive blast injury in all 3 visits is shown in table [2].

Table [2]: Types of hearing loss in subsequent visits (Kruscal Willas test) P-value in speech frequency 0.002 / P.value in high frequency 0.001

Visits	Speech frequency					Total	High frequency					Total
	CHL	MIXHL	SNHL	normal	Lost		CHL	MIXHL	SNHL	normal	Lost	
1st. visit	24 25.5%	41 43.6%	4 4.3%	25 26.6%	----	94 ears	17 18%	42 44.7%	21 22.3%	14 14.9%	----	94 ears
2nd. visit	21 27.6%	18 23.7%	1 1.3%	36 47.4%	18	76 ears	17 22.4%	19 25%	13 17.2%	27 35.5%	18	76 ears
3rd. visit	10 13.2%	14 18.4%	2 2.6%	50 65.7%	18	76 ears	7 9.2%	14 18.4%	14 18.4%	41 54%	18	76 ears

The severity of hearing loss in each group (speech and high frequency) of the studied patients is listed in table [3].

Table [3]: The severity of hearing loss in the three visits.

Severity of	Speech frequencies	High frequencies

HL.	1st.visit	2nd.visit	3rd.visit	1st.visit	2nd.visit	3rd.visit
normal	25 ears (26.6%)	36 ears (47.4%)	50 ears (65.7%)	14 ears (14.9%)	27 ears (35.5%)	41 ears (54%)
mild	49 ears (52.1%)	31 ears (40.8%)	20 ears (26.3%)	33 ears (35.1%)	31 ears (40.8%)	19 ears (25%)
moderate	19 ears (20.2%)	8 ears (10.5%)	5 ears (6.6%)	33 ears (35.1%)	9 ears (11.8%)	8 ears (10.5%)
sever	---	1 ear (1.3%)	1 ear (1.3%)	5 ears (5.3%)	1 ear (1.3%)	----
profound	1 ear (1.07%)	---	-----	9 ears (9.6%)	8 ears (10.5%)	8 ears (10.5%)
Total	94 ears	76 ears	76 ears	94 ears	76 ears	76 ears

The relation between explosive blast injuries and the mean of hearing loss for both speech and high frequencies in the 3 visits is shown in table [4].

Table [4]: Difference between speech frequency and high frequency hearing loss in the subsequent visits. (One sample T test.)

Ear	Mean of Speech frequency HL	Mean of High frequency HL	P. value
Rt ear 1st visit	25.9 db.	55.6 db.	<0,001
Lt ear 1st visit	31.7 db.	49.0 db.	<0,001
Rt.ear2nd.visit	22.5 db.	33.95 db.	<0,001
Lt.ear2nd.visit	28.95 db.	36.3 db.	<0,001
Rt.ear3rd.visit	18.56 db.	27.37 db.	<0,001
Lt.ear3rd.visit	21.3 db.	29.0 db.	<0,001

Assessment of tympanic membrane perforation for each patient in the 3 visits by calculating the surface area of the perforation to the whole surface area of the tympanic membrane is shown in table [5].

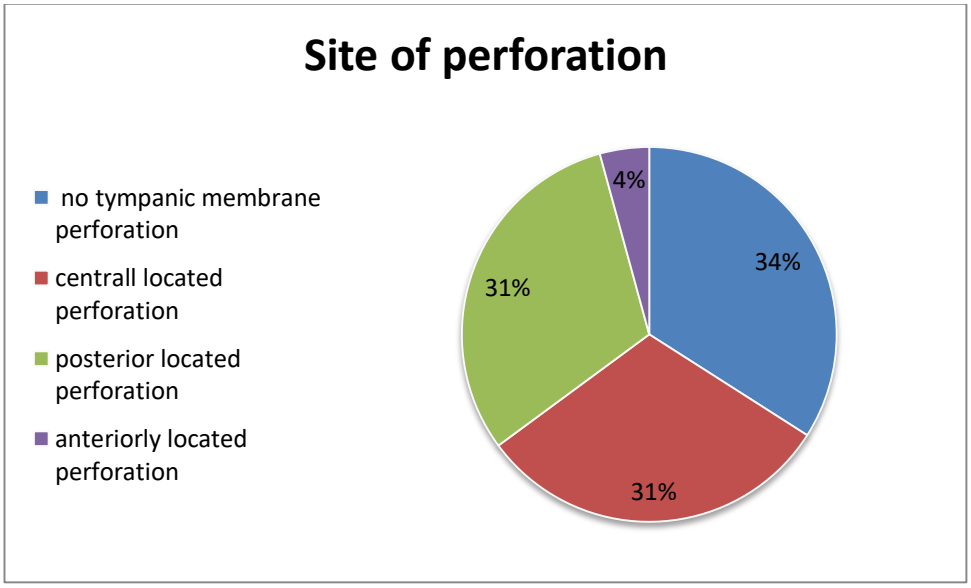
Table [5]: Tympanic membrane perforations (TMP) in the subsequent observations.

	Grade1 TMP	Grade2 TMP.	Grade3 TMP.	Grade4 TMP	normal
Right ear 1st visit	23	5	3	1	16
Left ear 1st visit	21	7	2	0	16
Total (Rt + LT ear in1st.visit)	44 (70.97%)	12 (19.35%)	5 (8.06%)	1 (1.61%)	32
Healed spontaneously in 2nd visit	12	1	0	---	
Healed spontaneously in 3rd. visit.	15	4	1	---	
Lost from clinical follow up	9	0	0	1	
Persistent TMP.	8	7	4	---	

As shown in table [5], the majority of tympanic membrane perforation surface area grades was in grade [1]

and least in grade [4] with the right ear affected slightly more (32 right ear perforation and 30 left ear perforation). There is a strong relationship between the degree of tympanic membrane perforation surface area and hearing loss that result from explosive blast injuries (P-value = 0.0001). No correlation found between hearing loss result from explosion and ear preference (right or left) as P-value = 0.469.

The position of the tympanic membrane perforation that result from explosive blast injury is shown in figure [4].



As shown in figure [4], the majority of tympanic membrane perforations caused by explosive blast injuries are centrally and posteriorly located perforation (31% and 31%) respectively. There a strong relation between the degree of hearing loss and the location of tympanic membrane perforation.

The relation between tympanic membrane perforation and the associated non-otological injuries that result from explosive blast injury is shown in table [6].

Table [6]: Association between non otological injuries and tympanic membrane perforation.

Associated non- otological injury		Tympanic membrane perforation			total
		Unilateral	bilateral	No perforation	
1	No associated injury	12 (75%)	1 (6.25%)	3 (18.75%)	16 (100%)
	Minor injury	12 (46.15%)	14 (53.85%)	0	26 (100%)
2	Moderate injury	2 (40%)	3 (60%)	0	5 (100%)
3	total	26 (55.32%)	18 (38.3%)	3 (6.38%)	47 (100%)

There is a strong correlation between the associated non-otological injuries and tympanic membrane perforation (P-value = 0.0001) and with degree of hearing loss that result from explosion (P-value = 0.0001). Lastly, there is a strong relation between the type of explosive blast injuries that patients suffer from and the degree of hearing loss resulted (P-value = 0.0001) and with the resulted tympanic membrane perforation (P-value = 0.0001).

4. Discussion

Because our country was and still in a war against terrorism and ISIS, all of patients that included in this study were males with age range from 21-56 years old. This was similar to the findings of study [10], [11]. Where in the study of [12] there were 14 females and 15 males as the explosion occurred in shopping mall. Most of the patients presented to Basrah Teaching Hospital complained from hearing loss and tinnitus (85% and 78.7%) respectively, otalgia, aural fullness and vertigo were less common, a similar results were found in [10], [12]. While, [13] noted that only 60% of blast victims suffer from hearing loss. This might be attributed to the nature of the blast they suffer from as the mentioned study deal with terrorist blast booming in a church near Paris using different explosive devices. The type of hearing loss resulted from explosive blast injuries showed a wide heterogenisity as it could be conductive, mixed or sensorineural hearing loss with the mixed hearing loss seems to be more frequent in this study as the blast affect both the middle and inner ears. [14] also showed a predominant mixed hearing loss, however in [12] study showed that sensorineural hearing loss is more common and in [15] study there were a great heterogeneity so no type of hearing loss appeared to be predominant. This study showed that hearing loss mostly affect high frequencies (4KH & 8KH) as there is a significant difference between hearing loss in speech and high frequencies (P-value = 0.001). This loss in both speech and high frequencies demonstrate a statistically significance improvement in the means of thresholds in the successive visits. A similar results were seen in the study of [10], [12], the study of [14] and in the study of [16]. Where, in [15] Study showed a statistically significant improvement in the high frequencies only.

Most of hearing loss cases in this study were mild in severity in the speech frequencies and mild to moderate in high frequencies, also [12], [10] report the same results.

Ear drum perforation was the most common finding on microscopic ear examination as the blast wave causes stretching and displacement of the tympanic membrane. The perforations that resulted from explosion in this study is of different sizes, the grade I perforation appeared to be predominant. There was a good rate of spontaneous healing in grade I perforations in the 2^{nd} and 3^{rd} visit as (12 /44) 27.3% and (15/44) 34.1% of grade I perforations healed spontaneously in 2^{nd} and 3^{rd} visits respectively. Whereas, grade II perforation appeared to heal more slowly as only (1/12) 8.3% of grade II perforation healed in 2^{nd} visit and (4/12) 33.3% healed in the 3^{rd} visit. Regarding grade III perforation there was one perforation healed in the 3^{rd} visit. In our study there was one patient presented with total perforation and he was unfortunately lost from clinical follow-up. This results were similar to [15] study, while the study of [16] reported that 2/3 subtotal perforations healed after six months.

Most of perforations were either posteriorly located or centrally located, only 4% were anteriorly located perforations. This results is similar to the study of [10], while the study of [16] showed that perforations usually located in the anteroinferior part of pars tensa and in the study of [13] most of the perforations were centrally located. The non-otological associated injuries can give us an impression regarding the extent of ear damage due to blast injury, there was a statistically significant relationship between tympanic membrane perforation and the extent of associated non ontological injury, this result is consistent with [15] study and with [12] study.

5. Conclusion

Blast related otological injuries constitute the main source of morbidity as the ear is the most sensitive organ to explosive blast injury. Hearing loss is the dominant symptom at presentation, however, most of the blast related symptoms resolved spontaneously.

Explosion affects the middle and inner ear so that hearing loss usually preset and mainly in high frequencies, but fortunately most of patients improved with time. Tympanic membrane perforation constituted the mostly seen sign in victims of explosions, however, spontaneous healing can be expected in the majority of cases. The sustained soft tissue or orthopedic injuries were significantly associated with blast related tympanic membrane perforation.

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None

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Verbal consent from all patients had been taken to share and discuss their findings.

7. References

[1] Fisher T, synopsis of causation, blast injury of the ear, https://www.gov.uk/government/publications/synopsis-of-causation-blast-injury-to-the-ear, Edinburgh, September 2008, p3-9.

[2] Marks, ME. The Emergency Responder's Guide to Terrorism. Red Hat Publishing Co., Inc. (2002) pp. 30–2.

[3] Pressure profile of the explosive blast wave (Friedman curve) from R.M. WALSH et.al, bomb blast injuries to the ear: The London Bridge incident series, Journal of Accident and Emergency Medicine, 1995, 12, p194-198.

[4] David G. Burris et-al Chapter 1: Weapons Effects and Parachute Injuries, in Emergency War Surgery (2004) pp. 1–15.

[5] Wolf Stephen, "Blast injuries", The Lancet, (July 23, 2009) 374: 405-15.

[6] Keyes, Daniel C., "Medical response to terrorism: preparedness and clinical practice". Lippincott Williams & Wilkins (2005): 201–202.

[7] Hamdan T.A., Medical lesson from the operation Iraqi freedom, Bas.j.surg, septemper,9,2003.

[8] Saliba I, hyaluronic acid fat graft myringoplasty: how we do it. Clin. otolaryngolog 2008, 33:610-4.

[9] Warner G., Burgess A, Patel S., Martinez-Devesa P. and Corbridge R., Audiology, In: Oxford specialist handbook of otolaryngology head and neck surgery OXFORD UNIVERSITY PRESS2009: p284-299.

[10] R.Persaud, Hajioff D, Wareing M, Chevretton E. Otological trauma resulting from the Soho nail bomb in London, April 1999. Clin Otolaryngol 2003; 28:203-6.

[11] Sridhara SK, Rivera A, Littlefield P. Tympanoplasty for blast-induced perforations: the Walter Reed experience. Otolaryngol Head Neck Surg. 2013 Jan;148(1):103-7.

[12] R. Mrena, R.Paakkonen ,L.Back ,U.Pirvola and J.Ylikoski, Otologic Consequences of Blast Exposure : Afinish case study of a shopping mall bomb explosion .Acta otolaryngol,2004, 124,946-952.

[13] Ballivet de Régloix S, Crambert A, Maurin O, Lisan Q, Marty S, Pons Y. Blast injury of the ear by massive explosion: a review of 41 cases. J R Army Med Corps. 2017 Oct;163(5):333- 338. doi: 10.1136/jramc-2016-000733. Epub 2017 Feb 16. PMID: 28209807.

[14] Chohen J.T. et al., Blast injury of the ear in a confined space explosion: Auditory and Vestibular Evaluation, IMAJ. 2002,4,559-562.

[15] Makhlouf, A.-M. A.., Mahmoud, A. M.., Ibrahim, R. G.., & Abdel Aziz, Y. S. (2021). Effects of Vitamin D and Simvastatin on Inflammatory and Oxidative Stress Markers of High-Fat Diet-Induced Obese Rats. Journal of Scientific Research in Medical and Biological Sciences, 2(3), 39-50. https://doi.org/10.47631/jsrmbs.v2i3.297

[16] Remenschneider A. K et,al. Otologic Outcome after Blast Injury :The Boston Marathon Experience J.of Otolog & neurology,2014 ,35.1825-1834.

[17] WALSH R.M. et.al,bomb blast injuries to the ear:The London Bridge incident series,Journal of Accident and Emergency Medicine,1995,12,p194-198.

[18] Shoukry, L. R.., Mohamed, A. N.., Sharaf, A. E. A.., & Osman, O. B. S. (2021). Diagnostic Markers for Early Detection of Neonatal Sepsis. Journal of Scientific Research in Medical and Biological Sciences, 2(3), 13-26. https://doi.org/10.47631/jsrmbs.v2i3.319