Otologic outcomes after blast injury : the Brussels bombing experience

Otologic Outcomes After Blast Injury: The Brussels Bombing Experience.

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ABSTRACT

Objective: After the suicide bombings in Brussels on March 22, 2016, many victims consulted our emergency department with otologic symptoms. The aim of this study was to report the otologic morbidity and outcome after acute acoustic trauma in these patients.

Study design: Prospective cohort study

Setting: Tertiary referral center

Patients: Patients reporting subjective hearing loss, tinnitus, feeling of pressure in the ear, vertigo or hyperacusis after witnessing these bombings were included.

Intervention: All included patients were treated with systemic corticosteroid therapy, concurrent HBOT was advised to each and every included patient.

Main outcome measures: Participants underwent a routine otologic work-up including otoscopy, liminal audiometry and subjective outcome measures related to tinnitus at baseline and at follow-up. Primary outcome was to describe the otologic morbidity after acute acoustic trauma (AAT). Secondary outcome was to evaluate the recovery of hearing loss, subjective symptoms, and tympanic membrane perforations.

Results: Fifty-six patients were included in our population with an average age of 27±13 years, and 46% female / 54% male. Thirty-two patients reported subjective hearing loss, 45 reported tinnitus, 45 reported a feeling of pressure in the ear, two patients experienced vertigo and 18 patients reported hyperacusis. Otoscopic examination revealed three TMP. Sensorineural hearing loss (SNHL) was observed in 41% (n=23) and mixed hearing loss in 3.6% (n=2). No conductive hearing loss (CHL) was observed. Follow-up was obtained in 76.8%, with the last follow-up available at 47±74 days. Two perforations closed spontaneously, while one persistent perforation was successfully reconstructed with complete air-bone gap closure. There was a significant improvement in subjective symptoms. SNHL improvement was observed in 52.6% (10/19), mixed hearing loss improved in both patients. Improvement in hearing thresholds was seen in patients treated with steroids and in those treated with steroids and HBOT, there was no significant difference in the degree of improvement between these two groups.

Conclusions: Blast-related otologic injuries have a significant impact on morbidity. Comprehensive otologic evaluation and state-of-the-art treatment may lead to a significant improvement in symptoms and hearing loss.

Introduction

On the morning of March 22, 2016, three improvised explosive devices (IED) -suitcases filled with Triacetone triperoxide (TATP) and carpenter nails- were detonated at two different sites in Brussels (Belgium). Two at Brussels Airport in Zaventem, Brussels, Belgium, and one at the metro station of Maalbeek, Brussels, Belgium. Official institutions report thirty-two people died and more than 300 were injured. In the hours and days following these bombings many victims consulted our emergency department with symptoms of otologic blast injury.

In primary blast injury, the auditory system is the organ most commonly damaged.[1] Although middle ear injury with tympanic membrane perforation (TMP) is the most frequent manifestation of blast injury, blast injury to the inner ear resulting in sensorineural hearing loss (SNHL) or tinnitus is a well-known consequence of blast injury.[2-10] Several studies have suggested that SNHL after blast injury is caused by rupture of basilar membrane causing changes in the membrane permeability, changes in the tight cell junctions of the reticular lamina and mixing of perilymph and endolymph eventually causing permanent loss of hair cells. This loss is mostly marked in the outer hair cells (OHC) and also more in the basal than in the apical turns of the cochlea.[11-15] However blast injury that is severe enough to result in basilar membrane rupture requires a considerable force and results in profound SNHL. A more recent article evaluating the effect of blast injury on mice cochlea states that moderate auditory disfunction is caused by a loss in spiral ganglion neurons and afferent nerve synapses in both basal and apical turns.[16]

The mechanisms of SNHL in humans after blast injury are poorly understood. Furthermore, established guidelines for the treatment of inner ear blast injury are lacking. In this study we aim to report on the otologic consequences of blast exposure after the Brussels Bombings of 2016 and discuss the outcomes of patients treated with steroids and hyperbaric oxygen therapy (HBOT).[17]

Material and methods

Patients who presented at the Antwerp University Hospital reporting subjective hearing loss, tinnitus, the sensation of pressure in the ear, vertigo or hyperacusis after witnessing these bombings were included in our study population. Patients who consulted for hearing level check-up after trauma without any persistent otologic complaints were excluded. Each patient underwent a clinical ENT work-up with otoscopic examination, pure-tone audiometry and patient-reported outcome measures (PROMs) related to tinnitus, at presentation and at every follow-up.

SNHL was defined as hearing thresholds of 30 dB or more at any measured frequency and no more than one frequency with an air-bone gap (ABG) of 15 dB or more. Conductive hearing loss (CHL) was defined as two or more frequencies demonstrating an ABG greater than 10 dB and no bone conduction (BC) threshold greater than 25 dB, mixed hearing loss (MHL) was defined as two or more frequencies demonstrating an ABG of 15 dB or more and one or more bone conduction thresholds of 30 dB or more. Pure-tone average was defined as the mean value of BC thresholds at 0.5, 1, 2 and 4 kHz. The tinnitus functional index (TFI), hyperacusis questionnaire (HQ) and visual analogue scale (VAS) for loudness for tinnitus questionnaires were used as PROMs.[18-20] The HQ is a questionnaire providing the measure of hypersensitivity to sound with higher scores indicating greater sensitivity. The mean global score ranges from 0 to 42 and a global score >28 indicates hyperacusis. VAS for loudness consists of an horizontal visual analogue scale for the mean tinnitus experience. This scale is verbally anchored at the endpoints, designated as not audible (0) and extremely loud (100).

All included patients were treated with systemic corticosteroid therapy in reduction schedule (methylprednisolone, day one to three 64 mg per day, day four to six 32 mg per day, and day seven to nine 16 mg per day). On the other hand, concurrent HBOT was advised to each and

every included patient, this consisted of 10 sessions of two hours of oxygen therapy with a pressure of 2.5 atmosphere absolute (ata), which is equivalent to a pressure at 15 meters below water surface. This therapy depended on the patients' choice, they were able to reject or stop this therapy if too traumatized or afraid.
Post-interventional follow-up was scheduled one week and one month after initial presentation. In patients complained of persisting subjective symptoms or hearing loss after this period, we provided additional follow-up. Initial presentation was defined as baseline and the last control was defined as follow-up.
Baseline and follow-up outcome were compared using Wilcoxon Signed Rank test and paired samples T-test to detect differences, this statistical analysis was performed using SPSS 24 for Windows (SPSS Inc. Chicago, IL, USA).

Results

Fifty-six patients, all presenting at the Antwerp University Hospital with otologic symptoms, were included in this study. All patients came from the Zaventem airport bombing site, there was no victim of the Maalbeek metro station bombing presenting at our center.The average age was 27 ± 13 years and the sex ratio was fairly equal with 26 females and 30 males. None of these patients mentioned having preexisting otologic morbidity or tinnitus. Baseline characteristics of the population are shown in table 1.

The average delay from the day of blast injury until the first presentation amounted to 4.1 (±4.3, range: 0-7, median: 1) days. Forty-eight (86%) of subjects presented within the first three days after trauma. Seven (12%) patients suffered concomitant physical damage, which was defined as non-ENT related trauma. Both tinnitus (80%) and pressure in the ear (80%) were the most common indicated subjective symptoms at baseline, 57% of patients reported subjective hearing loss, 32% patients reported hyperacusis and 4% of patients experienced vertigo. The mean total TFI at baseline was 31±22, mean VAS loudness at baseline amounted to 30±15 and total hyperacusis score on HQ amounted to 10. Otoscopic examination revealed three (5%) TMPs, one TMP was <25%, two of them were between 25 and 50% of total tympanic membrane size. Audiometric testing showed 23 cases with SNHL (41%), two cases with MHL in 93.6%2) and CHL was not seen. Out of the 23 patients suffering from SNHL at baseline, 12 of them suffered from SNHL on the right side, four patients on the left side and seven patients in both ears.

All cases received systemic corticosteroids and 22 opted for concurrent HBOT. Follow-up was obtained in 43 (77%) of them, 13 (23%) patients were lost to follow-up, 12 (35%) of the corticosteroid subgroup and 1 (5%) patient of the HBOT subgroup. On average, patients had their last follow-up appointment 47 (±74, range: 287, median: 11) days after trauma. Two out of three TMP's healed spontaneously, the other underwent myringoplasty with successful closure of the tympanic membrane till today. After treatment there was a statistically significant decrease in subjective symptoms, TFI total score (p=0.005), VAS loudness (p=0.001) and PTA hearing levels. Improvement of all these parameters was seen in both subgroups as seen in table 2. There was no significant difference in hearing improvement between patients in both subgroups. In Fig. 1 the evolution of pure-tone thresholds after treatment is shown, in the total population and in both subgroups. A significant decrease in mean threshold after therapy on 0.25 (p=0.000), .5 (p=0.009) 2 (p=0.000), 3 (p=0.002), 6 (p=0.000) and 8 (p=0.007) kHz was observed in the total population and in both subgroups. There was no significant difference in outcome based on time of presentation, all patients presented within the first seven days after trauma.

Discussion

In this study, we evaluated the otologic morbidity and outcome after blast injury in 56 patients. These patients presented with tinnitus (80%), pressure in the ear (80%), subjective hearing loss (57%), hyperacusis (32%) and vertigo (4%). The mean total TFI at baseline was 31±22, mean VAS loudness at baseline amounted to 30±15. Forty-one percent of patients were diagnosed with SNHL, two out of 56 patients with MHL. All patients received systemic corticosteroids while 22 opted for additional HBOT. A significant improvement in PTA hearing levels, TFI, VAS loudness and subjective symptoms was observed.

The prevalence of tinnitus in patients in this study is relatively high with a relatively low mean TFI at baseline. Patients might have given priority to other physical or psychological trauma and might have found less burden in the experienced tinnitus initially. This also is represented in the rather late time of consulting an ENT department.

Patients that opted for HBOT were significantly older and had a significant higher baseline TFI score, but both groups recovered to a mild tinnitus intrusion (i.e. TFI <25) at follow-up. While significant reduction in TFI was noted in total population as well as in both subgroups, there only was a 'meaningful change' (reduction of TFI score by 13 or more) in the HBOT subgroup, from 40 ± 23 at baseline to 24 ± 23 at follow-up. When comparing subjective symptoms and hearing levels of both subgroups after therapy it is necessary to bear in mind that the subgroup treated with both steroids and HBOT had more severe symptoms and more hearing loss at baseline. Patients with more subjective ENT-related symptoms, might tend to opt for every available therapy, despite experiencing important physical and psychological trauma in the previous hours. In contrast, patients with less severe ENT-related symptoms seemed to reject the more demanding HBOT.

After the Boston marathon bombings back in 2013, Remenschneider et al.[7], evaluated patients presenting with otologic injuries, in eight Boston hospitals. In this study 51% of included patients had TMP and almost 90% of hospitalized patients was found to have TMP, compared to 5% in our study population. The overall mortality and morbidity of the Brussels' bombings were worse when compared to the Boston marathon bombings. Our study population was limited to patients presenting at the Antwerp University Hospital, being a tertiary referral center for otovestibular disorders. We hypothesize that not being a local or regional referral center during the attacks resulted in a limited share in non ENT-related trauma and rather few TMPs. Probably the number of patients with TMP and otologic injury was much higher than reported in this study, but these patients likely presented to other institutions with non-ENT related trauma. This hypothesis was stated in recent studies[6,7], in which they found a correlation between distance from blast site and relative risk on TMP. Consequently, more patients presented with CHL and MHL after Boston marathon bombings and rather few patients with SNHL when compared to our study population. In their population, eight patients were treated with oral steroids, without HBOT and after therapy they found a non-significant improvement in bone conduction thresholds at 1, 2 and 4kHz.

We found a significant difference in SNHL on the right side (12 patients) when compared to SNHL on the left side (4 patients). This finding may have an architectural explanation as shown in figure 2. The first explosion took place at the right side of the terminal. Most people found themselves on the left side of this explosion and ran away towards the left side and towards the exit of the terminal. Nine seconds later, a second explosion went off on the other side of the terminal, again facing a majority of right ears. In the study of Remenschneider et al. 75% of patients reported that it was the right ear facing the blast. They found a striking difference in TMP in right ears (40) when compared to the left side (22). We suppose that in acute acoustic trauma (AAT), the head shadow effect does not only protect the contralateral ear against middle ear injury but also against SNHL.

Significant improvement in subjective and objective parameters was observed in both Steroids and Steroids + HBOT subgroups. It does not appear that one treatment is more successful than the other, although the comparison is limited by lack of randomization. It would be interesting to perform a randomized comparison between treatment with steroids combined with HBOT and steroids alone. Given the acute setting of these circumstances we were unable to do so. Also, we had to take into account that some patients were too traumatized to undergo HBOT. An evaluation of the natural course of recovery after blast injury would be interesting as well, but it would be ethically incorrect to do so. However, a previous study by Ylikoski et al.[21] found that treatment with HBOT in patients presenting with AAT resulted in significant better recovery in hearing and in less persisting tinnitus, when compared to a control group.
Recent studies show that speech-in-noise understanding might be a more sensitive approach to evaluate damage to the inner ear following acoustic trauma.[22,23] Therefore it might be interesting to include this in evaluating otologic damage after blast injury in the future.
Our study was limited with 13 patients being lost to follow up, this was mainly caused by foreign patients returning home after the initial work-up. Another limitation is the lack of randomization of the subgroups, making it impossible to make comparisons between treatment with and without additional HBOT. Average total follow-up amounted to 47 days after trauma. A new follow-up, two years after trauma, will be schedules in order to evaluate subjective symptoms and hearing thresholds in the long-term.

Conclusion

Despite its limitations, This study provides a clear summary regarding the otologic morbidity and short term treatment outcomes in a subset of patients exposed to the Brussel's bombings of 2016. We noticed an important decrease in every symptom but yet an important part of patients' experiences persisting symptoms. In our study population, we notice statistically significant decrease in PTA thresholds after treatment with steroids and HBOT as well as after treatment with steroids alone. Decrease in total TFI score in HBOT subgroup was remarkable greater when compared to TFI decrease in steroid subgroup. Our findings also suggest a protective "head shadow" effect on the contralateral ear. Understanding the exact circumstances of the blast might help interpret audiometric testing. To conclude, we suggest that prompt comprehensive ENT evaluation and state-of-the-art treatment may lead to a significant improvement in symptoms and hearing loss in acute setting.

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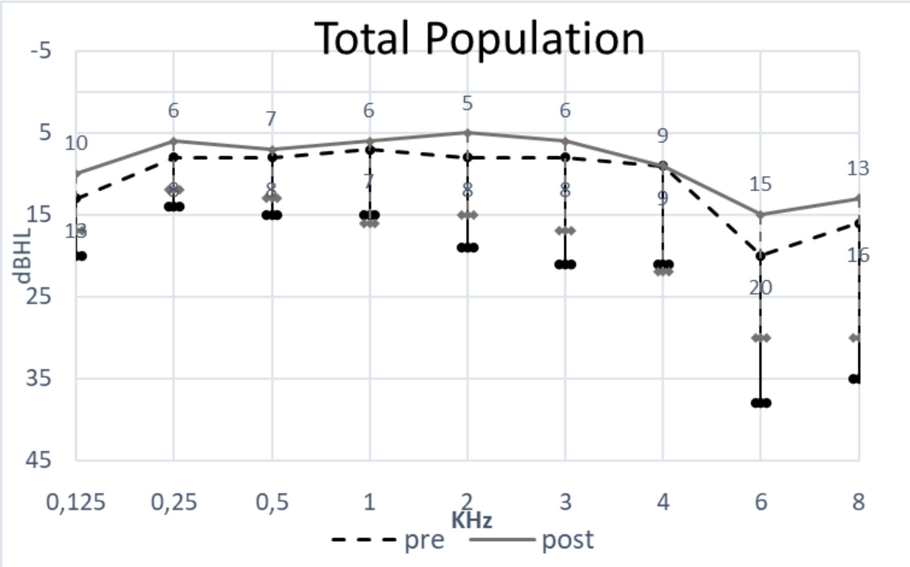
List of figures

Fig 1. Mean thresholds on pure tone audiometry (dB HL), before and after treatment, in the total population and in both subgroups. HBOT: subgroup treated with hyperbaric oxygen therapy and steroids. All thresholds in dBHL. Pre standard deviations positively marked as ●, post standard deviations positively marked as ♦.

Fig 2. Floor plan of the departure terminal of Zaventem airport. Location of explosions in chronological order (red numbers) at the respective check-in units (black box, white numbers). Red arrow indicates the flight route most victims used after the first explosion. © 2018, Van Haesendonck G.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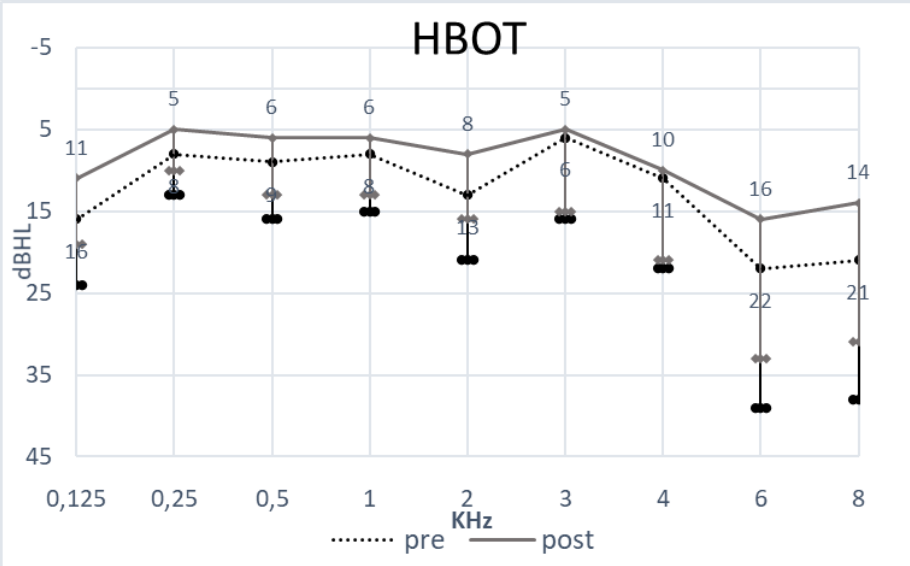
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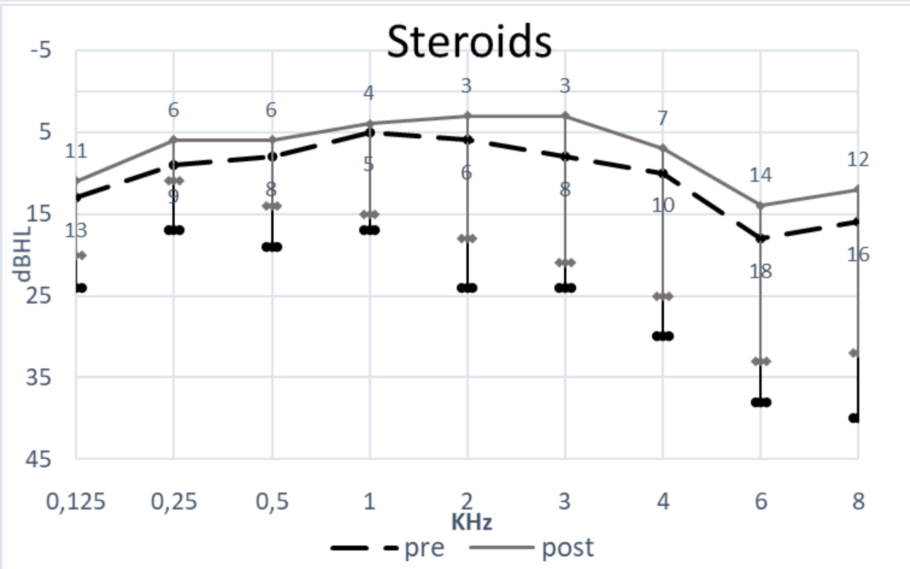
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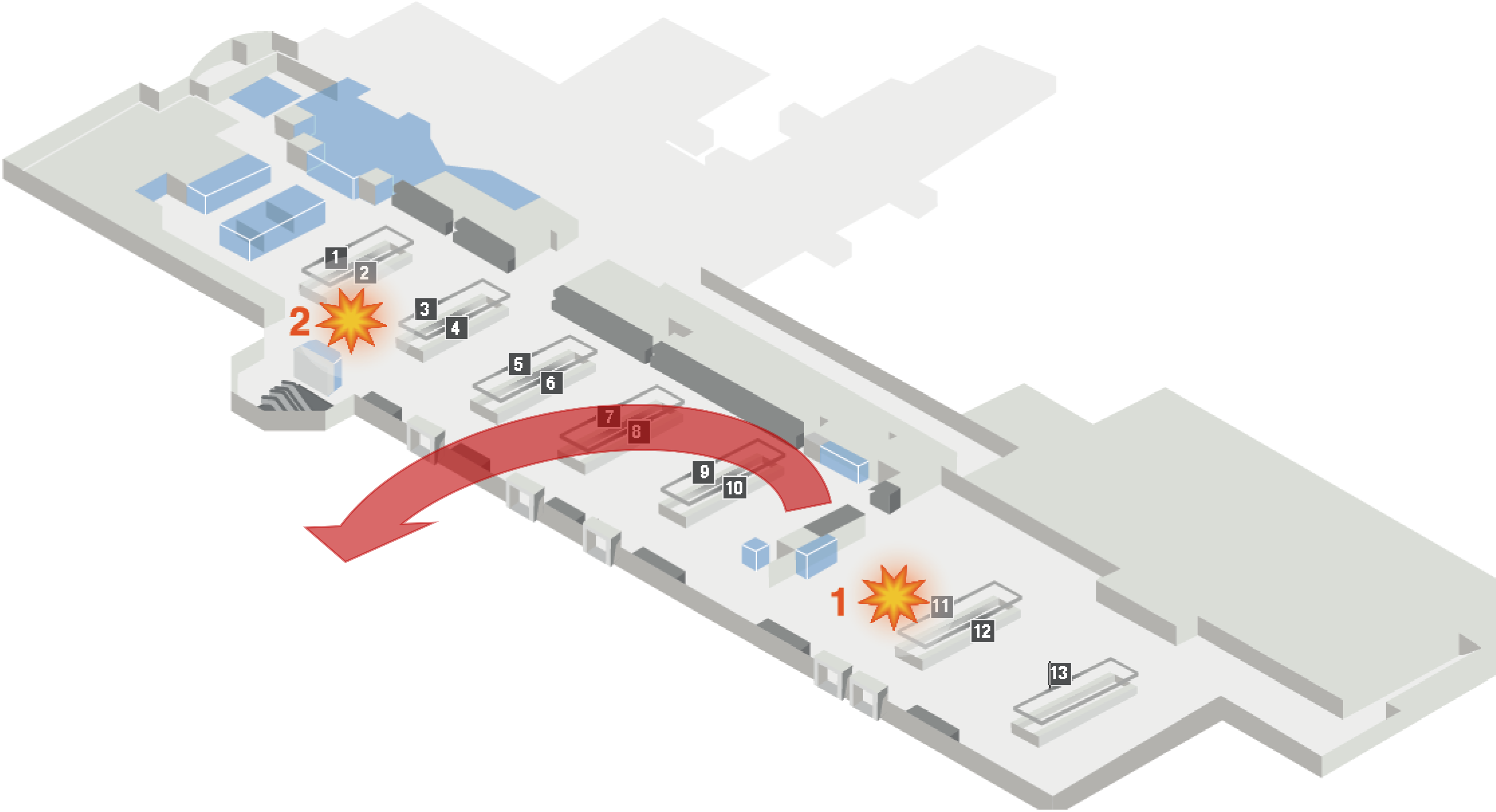

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Table 1. Baseline characteristics of population with HBOT and non-HBOT subgroups

	Total population (n=56)	Steroids + HBOT (n=22)	Steroids only (n=34)	p-value
Age (years)	27 ± 13	35 ± 15	22 ± 9	.001
Gender (F/M)	30/26	10/12	20/14	.327
Baseline TFI total score	28 ± 21	39 ± 24	24 ± 16	.008
% of patients complaining of:				
Subjective hearing loss	57%	68%	57%	.179
Tinnitus	80%	86%	87%	.363
Pressure	80%	86%	87%	.363
Hyperacusis	32%	36%	33%	.586
Vertigo	4%	5%	3%	.752

Hyperbaric oxygen therapy (HBOT), tinnitus functional index (TFI), p-values calculated with Wilcoxon signed-rank test and Chi-Square test.

Table 2. Population parameters, before and after treatment, in total population and in both subgroups.

	Total population (n=43)			Steroids + HBOT (n=21)			Steroids only (n=22)		
	Pre	post	p-value	Pre	post	p-value	Pre	post	p-value
TFI	31 ± 22	22 ± 21	.005	40 ± 23	24 ± 23	.005	25 ± 18	18 ± 18	.082
VAS loudness	30 ± 32	15 ± 20	.001	39 ± 39	13 ± 20	.006	23 ± 24	17 ± 21	.253
SNHL	44%	23%	.001	62%	43%	.078	27%	5%	.001
PTA	8.6 ± 10.0	5.9 ± 8.0	.172	10.2 ± 13.8	7.7 ± 11.9	.823	7.7 ± 6.7	4.7 ± 3.8	.078
Tinnitus	81%	23%	.000	86%	38%	.001	77%	9%	.000
Pressure	81%	14%	.000	86%	14%	.000	77%	14%	.000
Subjective HL	65%	23%	.000	71%	38%	.030	59%	9%	.000
Hyperacusis	35%	9%	.004	38%	10%	.030	32%	9%	.062
At least 1 symptom	100%	49%	.000	100%	62%	.001	100%	36%	.000

HBOT: hyperbaric oxygen therapy, TFI: tinnitus functional index total value, VAS loudness: visual analogue scale for tinnitus loudness, SNHL: sensorineural hearing loss, PTA: pure-tone average, HL: hearing loss, p-values calculated with Wilcoxon signed-rank test and Chi-Square test.