



Audiological characteristics of the contralateral ear in patients with unilateral physical non-explosive ear trauma

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ABSTRACT

Objectives: To document the frequency of occurrence and types of symptoms experienced in the contralateral ear in patients with unilateral physical non-explosive (UPN) ear trauma and to compare the audiometric and tympanometric parameters between asymptomatic and symptomatic contralateral ears. **Design:** Prospective analytical clinical study Setting: Specialized (Ear, Nose, and Throat) clinic of a tertiary health institution. Participants: Patients with UPN ear trauma who presented within the first week of the incident. Main outcome measures: Otologic symptoms in the contralateral ear in UPN ear trauma

Results: Eighteen out of 53 patients (34.0%) experienced symptoms in the contralateral ear. The symptoms were tinnitus in 77.8% (14/18), hearing loss in 66.7% (12/18), and ear blockage in 27.8% (5/18). There was hearing loss in 38/53 (71.7%) of contralateral ears. Hearing loss type and PTAV at the low frequencies were not significantly different ($p=0.142$), but other audiometric parameters were significantly different between asymptomatic and symptomatic contralateral ears ($p<0.05$ in all). Type C tympanogram was more prominent in the symptomatic contralateral ear. There was a statistically-significant difference in the type of tympanogram between the two categories of patients ($p=0.018$). There was no difference in acoustic reflex between the two categories of patients ($p=0.095$).

Conclusions: The contralateral ear may be affected in up to one-third of patients with UPN ear trauma, and experience otologic symptoms similar to those of the traumatized ears. Audiologic and audiometric parameters were abnormal in most of the contralateral ears. The two ears must be assessed thoroughly in cases of UPN ear trauma.

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1. Introduction

The ear is a delicate structure that is mostly encased within the skull and can be vulnerable in trauma through different mechanisms. The pinna can be involved in simple blunt trauma, bruised or damaged from physical contact blows, or friction with a hard surface, lacerated or can be avulsed (da Lilly-Tariah and Somefun, 2007). Excessive pressure is by far the most common mechanism of trauma to the tympanic membrane (Mitchell, 2003). Middle ear injury producing dislocation of the ossicles, or injury to adjacent inner ear structures or both occurs in up to one-third of patients

with severe head trauma (Ort et al., 2004).

Non-explosive blast injury of the ear refers to the otological trauma caused by a blow to the ear that seals the external auditory meatus. It results in a sudden increase in air pressure within the ear canal that strikes the tympanic membrane (Berger et al., 1994). Non-explosive injuries are physical ear injuries often resulting from slaps, although other causes may include punches, hitting the ear with a hard object, direct rupture or perforation of the tympanic membrane. The consequences of such injuries include audiologic, otologic and vestibular malfunctions. These manifest as earaches, hearing loss, tinnitus, otorrhoea, vertigo or other forms of imbalance. The symptoms are usually localized to the traumatized ear and can be bilateral in cases involving the two ears. We previously studied traumatic injuries to the ears with particular emphases on the traumatic rupture of the tympanic membranes and described the characteristics, causes and consequences of these (Sogebi et al., 2018).

In the course of that previous study, we encountered patients

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with unilateral physical contact ear trauma who also had otologic symptoms in the apparently normal non-traumatized contralateral ear. We wondered if these could be similar to the contralateral ear effect previously described in temporal bone lesions. Bocca et al. (1954) had realized after testing patients with temporal lobe lesions limited to one hemisphere, that the ear contralateral to the involved hemisphere was the one that usually demonstrated the deficit on their central auditory tests, and tagged the phenomenon the contralateral ear effect. Occurrence of symptoms in the apparently normal non-traumatized ear in some of our patients may have medico-legal implications especially in cases of trauma from assault.

These complaints of patients served as the impetus for this study, to clarify if the contralateral ear was also injured in cases of unilateral physical non-explosive ear trauma. Thus the study aims to document the frequency of occurrence and the types of symptoms experienced in the contralateral ear in patients with unilateral physical non-explosive traumatic ear injuries. It also compares the audiometric and tympanometric profiles between the asymptomatic and symptomatic contralateral ear in traumatic ear injury. This will clarify if the contralateral ear also needs thorough evaluation when one ear is traumatized, and consider the possibility of compensation award for this reason.

2. Patients and methods

2.1. Ethical considerations

Study protocol was approved by Olabisi Onabanjo University Teaching Hospital, Health Research Ethics Committee (number OOUTH/HREC/149/2017). Informed consent was obtained from all the patients before the inclusion of their data in the study.

2.2. Study design

Prospective analytical clinical study.

2.3. Study setting

Specialized (Ear, Nose, and Throat) clinic of a tertiary health institution.

2.4. Study duration

January 2015 to July 2018.

2.5. Participants

Patients with unilateral physical non-explosive ear trauma (such as slaps, blows, assaults) who presented within the first week of the incident.

2.6. Exclusion criteria

Patients with otologic symptoms or hearing impairment pre-dating the ear trauma, previous ear diseases including cerumen impaction, otorrhoea, or evidence of tympanic membrane perforation from infection.

2.7. Data collection

Information obtained from the patients included age, sex, affected ear, mechanism and time of injury. Inquiries about otologic symptoms in both the traumatized and the contralateral (non-traumatized) ear were documented. For patients that had

symptoms in the contralateral ear, clarifications were made about duration between the experience of ear trauma and first notice of symptom in that ear.

Patients had otoscopic examination of the ears at first contact, and one week after this (second contact). On the second contact, further clarifications on symptoms (like an earache, fluctuating hearing loss, noise in the ear, or feeling of blockage) in the contralateral ear were made, otoscopy was done, a Pure Tone Audiometry (PTA) and tympanometry studies were performed on the patients. Pure tone audiometry and tympanometry (including acoustic reflex) were performed according to standard practice using diagnostic Amplivox 240 audiometer, and Amplivox otowave 102 tympanometer respectively. Pure tone audiometry measured air conduction at frequencies 0.25, 0.50, 1.0, 2.0, 4.0 and 8.0 kHz, and the bone conduction thresholds at 0.25, 0.50, 1.0, 2.0, and 4.0 kHz. The level of the hearing was classified based on the Pure Tone Average PTA_v, (the average of the air conduction hearing thresholds across the six frequencies measured) as follow; normal hearing 0–25.0 dBHL and mild hearing loss 25.1–40.0 dBHL.

Tympanometry was classified based on the graphical tympanometric tracings; Type A tympanogram peaks at the pressure zero i.e. where there is no differential in pressure between the external auditory canal and the middle ear cavity, thus there is maximum compliance of the tympanic membrane; this indicates normal middle ear functioning.

In type As tympanogram, the tympanic membrane is stiffer than normal, i.e. lower compliance in the presence of normal middle ear pressure; this is seen in otosclerosis. In type Ad tympanogram, the tympanic membrane has higher compliance in the presence of normal middle ear pressure; this is seen in ossicular chain discontinuity. In type B (flat) tympanogram there is no peak indicating immobility of the tympanic membrane; this is seen in middle ear effusion or perforated tympanic membrane. Type C tympanogram shows a peak in the negative pressure range which indicates eustachian tube dysfunction.

2.8. Data presentation and analysis

The data is presented in tabular form. Discrete variables were presented as proportions and continuous variables presented with measures of central tendency and dispersion. Patients were categorized into two groups based on the presence or absence of symptoms in the contralateral ear.

Comparative analyses were performed on the audiometric and tympanometric measures between the two categories of patients with Chi-square test for categorical variables and Students t-test for continuous variables using the SPSS version 20 (Il, USA). A p-value <0.05 was assumed statistically significant.

3. Results

Fifty three out of sixty one originally recruited patients had complete data of the ears for this study; data of eight patients were excluded comprising five who did not report for the second contact appointment thus audiological assessments were not done, while three other patients reported late more than one month after the initial contact, thus their data were excluded.

Descriptive statistics were performed by first checking for normality in data distribution using the Kolmogorov-Smirnov test (all the continuous variables had p values > 0.05).

Thirty-four of the 53 patients (64.2%) were males, (Male: Female = 1.8:1). The age of the patients ranged from 9 to 61 years, with over half (30/53) of the patients within the age bracket 21–40, mean age was 35.9 ± 12.5 years.

Eighteen of the patients (34.0%) experienced symptoms in the

Table 1
Clinical profile of the patients.

Parameter	Number (n)	Percentage (%)
Age range (years)		
≤20	5	9.4
21–40	30	56.6
41–60	17	32.1
≥61	1	1.9
Mean ± Standard deviation	35.9 ± 12.5	
Sex		
Male	34	64.2
Female	19	35.8
Contralateral ear		
Asymptomatic	35	66.0
Symptomatic	18	34.0
Otologic symptoms (in 18 symptomatic ears)		
Fluctuating hearing loss	12	66.7
Tinnitus	14	77.8
Ear blockage	5	27.8
Otalgia	3	16.7

contralateral ear, with multiple symptoms including tinnitus in 77.8% (14/18), fluctuating hearing loss in 66.7% (12/18), and ear blockage in 27.8% (5/18). Ear blockage is a feeling of obstruction in the ear and can be due to wax impaction in the external auditory canal, fluid accumulation in the middle ear cavity i.e. otitis media with effusion, or eustachian tube dysfunction, which were clarified in the patients by otoscopy and tympanometry. The symptoms in the contralateral ear commenced 1–5 (median = 3) days after the ear trauma. Forty-one (77.4%) of the patients had rupture or tear of the tympanic membrane in the traumatized ear while all the patients had intact tympanic membranes in the untraumatized contralateral ear. The detail of the clinical profile of the patients is seen in Table 1.

The output level accuracy of the audiometer was within 3 dB, the coefficient of variation for the air conduction threshold measurement was 18.3%, and that for the bone conduction measurement was 17.3%. Audiometric profile of the contralateral ears revealed that air conduction was normal at the low frequencies (0.25–1.0 kHz) in 30 (56.6%), and at the high frequencies (2.0–8.0 kHz) in 13 (28.3%) ears. Bone conduction thresholds were normal at the low frequencies in 36 (67.9%), and at the high frequencies in 18 (40.0%) of the patients. Comparisons between the audiometric parameters in relation to age (cut-off of 40 years) revealed that PTA_vs and Air- Bone Gaps (ABGs) were significantly higher in patients >40 years compared to those ≤40 years ($p < 0.001$ in both cases).

Pure tone audiometric assessment of the contralateral ears also revealed normal hearing (PTA_v ≤25.0 dB) in 15 (28.3%), and mild

Table 3
Comparative analyses of the tympanometric profile of the contralateral ear.

Parameter	Asymptomatic	Symptomatic	Chi -square value	p-value
Tympanogram type				
A	23 (65.7)	4 (22.2)		
B	7 (20.0)	4 (22.2)		
C	3 (8.6)	7 (38.9)		
As	1 (2.9)	2 (11.1)		
Ad	1 (2.9)	1 (5.6)	12.042	0.018
Acoustic reflex				
Present	16 (45.7)	4 (22.2)		
Absent	19 (54.3)	14 (77.8)	2.792	0.095

hearing loss (PTA_v 25.1–40.0 dB) in 38 (71.7%) ears; the types of hearing losses were sensorineural (PTA_v >25.0 dB for both air and bone conduction, ABG <10.0) in 24 (45.3%) or mixed (PTA_v >25.0 dB for both air and bone conduction, ABG >10.0) in 10 (18.9%) ears. Pure tone averages in all frequencies were 27.2 ± 5.0 dB, subdivided into low (0.25–1.0 kHz) 25.5 ± 4.8 dB, and high (2.0–8.0 kHz) frequencies 29.0 ± 6.4 dB.

The tympanometric measures revealed type A (normal) tympanograms in 27 (50.9%) ears, type B tympanogram in 11 (20.8%), and type C tympanogram was found in 10 (18.9%) ears. Acoustic reflex was absent in 33 (62.3%) of the ears.

Table 2 is the comparative analysis of the audiometric parameters of the contralateral ear in the two categories of patients. The hearing thresholds denoted as PTA_v were significantly different between the asymptomatic and the symptomatic ears ($p = 0.046$). The type of hearing loss and the average air-bone gaps were also significantly different between the ears ($p = 0.049$ and 0.001 respectively). The pure tone average at the low frequencies was not significantly different ($p = 0.142$) between asymptomatic and symptomatic ears.

In Table 3, type A (normal) and B (flat) tympanograms were proportionately more in the asymptomatic, while type C tympanogram was disproportionately more in the symptomatic contralateral ears. There was a statistically significant difference ($p = 0.018$) in the type of tympanogram between the two categories of patients. There was no difference ($p = 0.095$) in the presence of acoustic reflex between the two categories of patients.

4. Discussion

4.1. Key findings of the study

In unilateral physical non-explosive ear trauma, about one-third of contralateral ears had otologic symptoms. The symptoms in the

Table 2
Comparative analyses of the audiometric profile of the contralateral ear.

Parameter	Asymptomatic	Symptomatic	Statistics	p-value
Hearing level (in dB)				
Normal (1–25.0)	13 (37.1)	2 (11.1)		
Mild hearing loss (25.1–40.0)	22 (62.9)	16 (88.9)	*3.970	0.046
Type of hearing loss				
Conductive	1 (4.3)	3 (20.0)		
Sensorineural	18 (78.3)	6 (40.0)		
Mixed	4 (17.4)	6 (40.0)	*6.031	0.049
Pure tone average, PTA_v				
Low frequency (0.25–1.0 kHz)	24.8 ± 4.4	26.9 ± 5.4	1.492	0.142
High frequency (2.0–8.0 kHz)	27.0 ± 5.1	32.9 ± 7.0	3.497	0.001
All frequency (0.25–8.0 kHz)	25.9 ± 4.4	29.9 ± 5.0	2.946	0.005
Air-bone gap (ABG) in dB				
	5.4 ± 2.1	7.8 ± 2.4	3.613	0.001

Statistic is comparative statistical analyses performed using either Chi-square test (designated with *) or Student t-test.

contralateral were similar to those of the traumatized ears. Audiometric and tympanometric parameters were significantly worse in the symptomatic compared to the asymptomatic contralateral ears.

4.2. Strengths of the study

This study is a novel contribution to medical literature because it considered audiologic characteristics in the apparently normal ear in unilateral physical non-explosive ear trauma. The contralateral ear may be affected by trauma to one ear. Experience of symptoms in the contralateral ear may portend significant transmitted trauma. Audiologic and audiometric parameters were abnormal in most of the contralateral ears.

4.3. Comparisons with other studies

The finding that the majority of the contralateral ears assessed in this study had abnormalities in the audiometric parameters may be an indication of transmission of trauma to them. The audiometric assessment confirmed that less than a third (28%) of these ears had normal hearing thresholds, and the pure tone average in all frequencies was above the acceptable threshold limit of 25 dBHL.

Tympanometric parameters in our patients also manifested some abnormalities. In theory, expected effects of trauma may be ossicular chain discontinuity, manifesting as type Ad tympanogram (Lous et al., 2012). The tympanogram seen in this study suggested that the mechanism of action may not be by simple direct transmission of forces that could dislodge or disarticulate the ossicular chain. The possibility of more complex mechanisms initiated by the transmitted forces which may include distortions in the neural pathway was considered. Absent acoustic reflexes might also be part of the disruption in the neural pathway associated with this trauma.

The symptoms observed in the contralateral ears were comparable to those of the patients with traumatic tympanic membrane perforations (Sogebi et al., 2018), suggesting similar pathophysiology. There was also the possibility of a transient period of inactivity before manifestations of symptoms in the contralateral ear. This was the rationale for delaying the audiological assessments until the first week after initial contact with the patients. The study ascertained there was no pre-existing hearing impairment nor other otologic symptoms in the symptomatic contralateral ear among the patients. A study on animal models had reported that ears are more vulnerable to acoustic trauma following contralateral unilateral cochlear injury. This increased vulnerability may be due to damaged neural structures (Lim et al., 2014). The possibility of similar vulnerability of the contralateral ear from physical non-explosive ear trauma is a subject which needs to be further explored. There is also a need to ascertain if the hearing threshold shift is temporary or permanent as there is a lack of information regarding the intricate relation between temporary and permanent hearing threshold shifts (Rosenhall et al., 2019).

Pure tone audiometry remains one of the easiest means of clarifying hearing impairment, and the measures in this study confirmed mild sensorineural or mixed types of hearing losses, worse at the high frequencies in the contralateral ears. Other previous reports have confirmed typical sign of acoustic trauma on audiograms to be a high-frequency sensorineural hearing loss (SNHL) with varying dips which could be unilateral, bilateral or different on each side, depending on the mechanism of injury (Brusis, 2011; Orji and Agu, 2009). These dips were however not noted in our patients' audiograms.

Classical type of tinnitus observed in this study was similar to that previously observed in our general population, being short

term, discrete, intermittent, and non-pulsatile in nature (Sogebi, 2013). Cochlear-type tinnitus is suggested to result from aberrant activity generated before or at the cochlear nerve level. It is proposed that outer hair cells, through their role in regulating the endocochlear potential, can contribute to the enhancement of cochlear spontaneous activity (Noreña, 2015). Hair cell damage may also lead to considerable hyperactivity in the central auditory pathways, mediated by a reduction in inhibition, which may underlie some clinical symptoms like tinnitus. Homeostatic plasticity, the most discussed and acknowledged mechanism in recent years, is most likely responsible for excited central activity following cochlear damage (Zhao et al., 2016).

Audiometric results suggest less of the symptomatic contralateral ears had normal hearing compared with the asymptomatic ears, with evidence of significantly higher hearing thresholds in all frequencies, especially at the high tones. Abnormality of bone conduction in several adjacent high frequencies noted in traumatized ear (Berger et al., 1997) was however noted in the contralateral ears in our patients. The particular type of hearing impairment affecting the higher frequencies is acoustic trauma from noise. While environmental noise levels has been reported to be high in our local environment (Ologe et al., 2006), trauma may be an aggravating factor.

Abnormal tympanometric measures were also comparatively more in the symptomatic ear, which might be due to transmitted shearing force which can initiate a myriad of pathological processes in the middle ear. We could not ascertain if these abnormalities in the middle ear predated the traumatic episode to the contralateral ear, and remained as subclinical middle ear malfunctions (Sogebi et al., 2017), to be stimulated or aggravated by physical non-explosive trauma to the contralateral ear.

4.4. Limitations

The assumption that audiometric abnormalities discovered in the ears resulted from trauma to the contralateral ear could be wrong as there was no assessment performed before the episode of trauma to confirm or refute pre-existing hearing impairment in the patients. This uncertainty will invariably introduce some bias to the findings of the study. Another bias could be the statistically significant difference recorded between symptomatic and asymptomatic contralateral ears since hearing loss was one of the criteria used for the differentiation. The performance of PTA alone limited the assessment of disabling effects of trauma in the patients. Combining PTA and speech audiometry makes it possible to use the Clinical Outcome Score which reveals more about the disabling effect of the trauma than changes in audiometry. Unfortunately, the audiometer could not perform speech audiometry because the microphone and the software for that were not installed. The decline in hearing acuity with increasing age may also be a confounder to the results.

4.5. Clinical applicability of the study

A thorough clinical evaluation must be made of the two ears even in cases of unilateral ear trauma. Symptoms in a contralateral ear may connote significant transmission of trauma with derangement in audiometric and tympanometric parameters. These must be borne in mind especially when there is a possibility of compensation or litigation in unilateral physical non-explosive ear trauma.

5. Conclusions

The contralateral ear may be affected by trauma in up to one-

third of patients with unilateral physical non-explosive ear trauma, and experience otologic symptoms similar to those of the traumatized ears. Audiologic and audiometric parameters were abnormal in most of the contralateral ears. The two ears must be assessed thoroughly in cases of ear trauma even if only one ear is traumatized.

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Declaration of competing interest

The authors have no conflict of interest to declare.

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