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Auditory dysfunction in traumatic brain injury

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Abstract—Effective communication is essential for successful rehabilitation, especially in patients with traumatic brain injury (TBI). The authors examined the prevalence and characteristics of auditory dysfunction in patients with TBI who were admitted to a Department of Veterans Affairs TBI inpatient unit before and after the onset of Operation Iraqi Freedom (OIF). In order to delineate the characteristics of the auditory manifestations of patients who had sustained blast-related (BR) TBI, we reviewed the medical records of 252 patients with TBI and categorized them according to admission date, either before (Group I, $n = 102$) or after (Group II, $n = 150$) the onset of OIF. We subdivided Group II into non-blast-related (NBR) and BR TBI; no subjects in Group I had BR TBI. We found that admissions for TBI have increased 47% since the onset of OIF. In Group I, 28% of patients with TBI complained of hearing loss and 11% reported tinnitus. In Group II-NBR ($n = 108$), 44% complained of hearing loss and 18% reported tinnitus. In Group II-BR ($n = 42$), 62% complained of hearing loss and 38% reported tinnitus. Sensorineural loss was the most prevalent type of hearing loss in Group II-BR patients. In light of the high prevalence of hearing loss and tinnitus in this growing population of returning soldiers, we need to develop and implement strategies for diagnosis and management of these conditions.

Key words: auditory dysfunction, blast-related injury, hearing loss, non-blast-related injury, OIF, rehabilitation, sensorineural hearing loss, TBI, tinnitus, traumatic brain injury.

INTRODUCTION

Traumatic brain injury (TBI) is a leading cause of death and disability in the United States, with an estimated incidence of 1.4 million persons each year [1–2]. Because of the sudden and violent nature of the injury, TBI may cause concurrent trauma to the auditory pathway. Common causes of TBI include motor vehicle accidents, assaults, falls, gunshot wounds, and blasts [3]. Blast-related (BR) injury is caused by explosives that emit overpressurization shock waves or "blast waves" [4]. The term "primary blast injury" refers to direct injuries sustained from blast waves, while flying debris from a blast can also lead to trauma and secondary blast injuries [5]. The proximity and intensity of blast waves influence the magnitude of the injury. Because blast waves affect both gas and fluid filled structures (such as the

Abbreviations: BR = blast-related, CBT = cognitive-behavioral therapy, NBR = non-blast-related, OIF = Operation Iraqi Freedom, TBI = traumatic brain injury, THI = Tinnitus Handicap Inventory, TISI = Tinnitus Impact Screening Interview, VA = Department of Veterans Affairs.

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middle and inner ear), they can be destructive to the auditory system [4,6–7].

Since the start of Operation Iraqi Freedom (OIF) on March 20, 2003, and the continuation of Operation Enduring Freedom as part of the global war on terror, a large number of soldiers have sustained BR injuries [8–9]. Although recent advances in body armor technology and battlefield medicine allow people to survive exposure to powerful explosive devices, the destructive force of blast waves still affects various organs [2,10]. With BR injury, hearing loss often occurs [11–15]. Tinnitus is another common, but often underreported, auditory dysfunction that manifests immediately after blast exposure [16–19].

In this study, we sought to explore the characteristics of auditory dysfunction in patients with BR TBI and determine which type of hearing loss is most prevalent in this population. We also examined the differences in the number of new admissions to a Department of Veterans Affairs (VA) inpatient TBI unit for both BR and non-blast-related (NBR) TBI before and after the onset of OIF.

SUBJECTS AND METHODOLOGY

Participants

We reviewed the medical records of patients with TBI who were admitted to an inpatient rehabilitation unit of a university-affiliated VA medical center from December 1999 to July 2006. Patients were categorized according to their initial admission dates to the TBI rehabilitation unit. Only new admissions to the rehabilitation unit were reviewed; patients who were readmitted to the rehabilitation unit were excluded. Group I consisted of patients with TBI who were admitted between December 1, 1999, and March 31, 2003 (40-month period before patients began returning from OIF). Group II consisted of patients with TBI who were admitted between April 1, 2003, and July 31, 2006 (40-month period after patients began returning from OIF). Group II was further divided into two subgroups, namely NBR and BR TBI; no patients in Group I had a BR injury. The BR group consisted of patients who were admitted to the inpatient rehabilitation unit for their BR TBI. The NBR injury group included all patients with TBI who sustained their injury from a non-blast injury (e.g., motor vehicle accident, assault, fall).

Instrumentation

The local VA audiology service conducted immittance and pure tone audiometric evaluations and obtained air- and bone-conduction audiometric thresholds to quantify the hearing function at different frequencies [20]. Clinically certified audiologists conducted the audiological examinations in a sound-treated booth using a Grason-Stadler GSI-61 clinical audiometer (VIASYS Healthcare, Inc, Conshohocken, Pennsylvania). Immittance audiometry was used to determine the integrity of the tympanic membrane and the middle ear/ossicular system. Audiologists used the QT1 Quick Tymp Tympanometer (American Electromedics Corp, Amherst, New Hampshire) to perform the immittance testing.

Data Collection

Clinical data pertaining to the nature of the injury, demographics, and auditory dysfunction were obtained from extensive reviews of electronic medical records. The local institutional review board approved this protocol before data collection. A retrospective chart review was performed on all new admissions between December 1, 1999, and July 31, 2006.

RESULTS

Of the 252 patients with TBI whose medical records were reviewed, 233 (92%) were male and 19 (8%) were female. The mean age was 33.5 years (range 18–75). Details of the two groups of patients with TBI (I and II) and the three subgroups (I-NBR, II-NBR, II-BR) are presented in **Figure 1**. Group I (**Figure 1**, upper-left corner) consisted of 102 patients with TBI (93 males, 9 females, mean age 36.3, range 18–75) admitted from December 1, 1999, to March 31, 2003. Group II (**Figure 1**, upper-right corner) consisted of 150 patients with TBI (140 males, 10 females, mean age 31.6, range 19–73) admitted from April 1, 2003, to July 31, 2006. Sex did not significantly differ between the two groups (p = 0.51). However, patients in Group II were significantly younger than those in Group I (p = 0.01). Within Group I, the percentage of patients with TBI who reported hearing loss was 28 percent compared with a significantly higher 49 percent in Group II (p = 0.001). Tinnitus was reported by only 11 percent of the patients in Group I; a significantly higher proportion of patients in Group II (23%) reported tinnitus (p = 0.006).

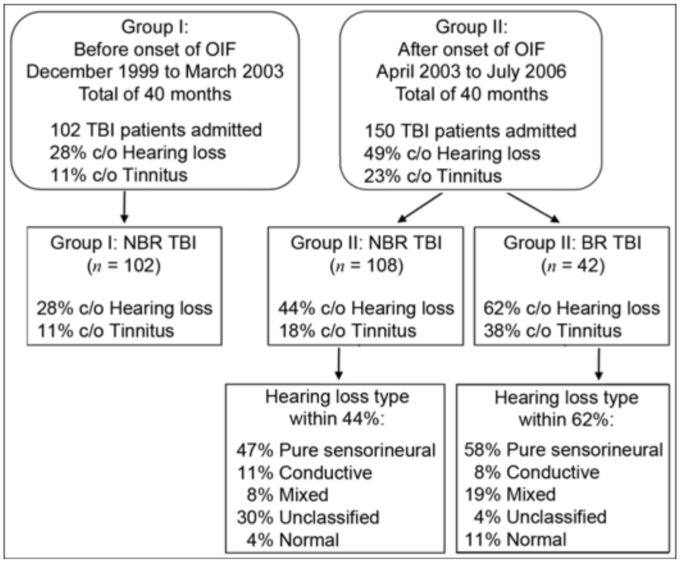

Figure 1.
Distribution of auditory complaints and types of hearing loss among patients admitted with traumatic brain injury (TBI). No patients in Group I had blast-related (BR) injuries. OIF = Operation Iraqi Freedom, c/o = complained of, NBR = non-blast-related.

Since no patients in Group I had BR TBI, we analyzed data for Group II. In Group II-NBR, 44 percent of patients (mean age 33.1) reported hearing loss, while in Group II-BR, 62 percent of patients reported hearing loss (significant difference, $p = 0.04$). The percentages of patients who reported tinnitus in Group II-NBR and II-BR were 18 and 38 percent, respectively (significant difference, $p = 0.007$).

Unfortunately, not all the patients in Group II-NBR who initially complained of hearing loss received complete audiological evaluations before they were discharged; these patients (30%) were given a diagnosis of unclassified hearing loss. In Group II-BR, only 4 percent of patients who initially complained of hearing loss did not receive an audiological evaluation before discharge; these patients (4%) were also given a diagnosis of unclassified hearing loss. Of those who received complete audiological evaluations in Group II-NBR, the types of hearing loss were distributed as follows: 47 percent pure sensorineural, 11 percent conductive, 8 percent mixed, and 4 percent normal (**Figure 1**). Of the patients who received an audiological evaluation in Group II-BR, the types of hearing loss were distributed as follows: 58 percent pure sensorineural, 8 percent conductive, 19 percent mixed, and 11 percent normal (**Figure 1**).

Although one would expect blast waves to cause tympanic membrane rupture and ossicular disruption (thus resulting in conductive hearing loss), available audiology reports showed that pure sensorineural loss was the most prevalent type of hearing loss in patients with BR TBI. A total of 15 patients were diagnosed with pure sensorineural hearing loss in Group II-BR. Some of them had written audiology reports from another hospital, but the actual audiograms could not be retrieved. Thus, only 11 of the 15 had complete audiograms that we could use to create a composite audiogram. **Figure 2** presents the mean hearing thresholds for those 11 patients with pure sensorineural hearing loss. In Group II-NBR, a total of 22 patients had sensorineural hearing loss and only 19 had complete audiograms that were retrievable. Patients with sensorineural hearing loss in Group II-NBR showed a similar composite audiometric pattern (**Figure 2**) but had ~10 dB better hearing sensitivity than their counterparts in Group II-BR.

DISCUSSION

Observing the 40-month trend before and after the onset of the OIF combat operation, we found a significant increase in the number of patients with TBI who were admitted to a VA inpatient rehabilitation unit (from 102

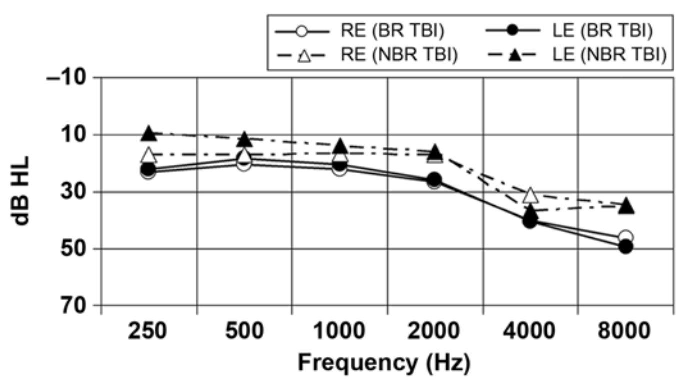

Figure 2.
Composite audiograms indicating mean hearing thresholds (dB hearing level [HL]) for patients with blast-related (BR) traumatic brain injury (TBI) (solid lines, $n = 11$) and non-blast-related (NBR) TBI (dashed lines, $n = 19$) in Group II (admitted from April 2003 to July 2006) with sensorineural hearing loss. Open shapes represent right ear (RE) and filled shapes represent left ear (LE). Audiogram taken from American National Standards Institute (ANSI). Maximum permissible ambient noise levels for audiometric test rooms. ANSI S3.1-1991. New York: ANSI; 1991.

to 150 patients, a 47% increase) and an associated increase in the number of patients with BR TBI (from 0 to 42 patients). Unfortunately, because of the urgent circumstances surrounding the injury and the memory deficits of patients with TBI, information pertaining to their blast exposure history (such as the number of blasts that the patients were exposed to and the proximity of the explosions) was unavailable. Nevertheless, we found a noticeable increase in the percentage of patients with hearing loss and tinnitus after the onset of OIF.

Hearing Loss in Blast-Related Traumatic Brain Injury

In our sample of patients with BR TBI, 58 percent of those who complained of hearing loss were diagnosed with pure sensorineural loss. Previous studies in the area of BR injuries also indicate a high prevalence of sensorineural hearing loss [21–23]. While patients in Group II-NBR had non-blast injuries, it is reasonable to assume that the majority of them had been subjected to gunshot noises and multiple blasts (during their training or combat exposure) that did not result in externally apparent injuries. This assumption may explain the similarity in the audiograms and the better overall hearing sensitivities between these patients and their counterparts in Group II-BR. As illustrated in **Figure 2**, composite audiograms of these patients resembled the ones of the victims of the Oklahoma City bombing in 1995 [23]. Interestingly, the "4 kHz dip" typically seen in noise-induced hearing loss was not prominent in this group of patients.

We also noted that the 11 percent of patients in Group II-BR and the 4 percent of patients in Group II-NBR who complained of hearing loss had normal peripheral hearing sensitivity. Although these patients' self-reports of "hearing loss" could possibly be caused by impairment in the central auditory pathway, we do not have sufficient data from this study to substantiate this hypothesis. The prevalence of central auditory processing disorders in this population should be explored. Unfortunately, arousal, attention, and comprehension deficits in the acute phase of TBI render complete audiological evaluations impractical [24–25]. We hope that with proper instrumentation and early identification, auditory dysfunction in patients with TBI may be fully evaluated and appropriate interventions implemented in a timely manner [17–18].

Tinnitus in Blast-Related Traumatic Brain Injury

Data from this study reveal that 38 percent of the patients with BR TBI reported tinnitus. As these patients gradually attain the ability to perform basic life functions, the persistent presence of tinnitus can become problematic. Tinnitus is already commonly reported by veterans because of the hazardous noise levels in so many military settings [26]. An estimated 3 to 4 million veterans have tinnitus, with up to 1 million of them requiring some degree of clinical intervention [27]. Audiologists routinely assess hearing loss and the potential need for amplification using standardized assessment tools. The clinical management of tinnitus, however, does not adhere to any standards, and audiologists generally have not received adequate tinnitus management training [28]. A very brief outline of proposed clinical services for patients with TBI who complain of tinnitus is provided here. Detailed guidelines for audiologists to clinically manage tinnitus are available elsewhere [28–29].

Patients with TBI who complain of tinnitus should undergo a tinnitus screening interview, a self-administered tinnitus questionnaire, tinnitus loudness and pitch matching, and an assessment of tinnitus maskability, in addition to the audiological examination. The Tinnitus Impact Screening Interview (TISI) is a tool that rapidly assesses the severity of a patient's tinnitus [30]. In its present form, the TISI involves only eight questions and can usually be completed in about 15 minutes. Patients should also complete the self-administered Tinnitus Handicap Inventory (THI), which provides a 0 to 100 index score [31–32]. Once patients complete the THI, they are placed into one of four ranges of self-perceived handicap: 0 to 16 (no handicap), 18 to 36 (mild handicap), 38 to 56 (moderate handicap), and 58 to 100 (severe handicap). Measuring tinnitus loudness, pitch, and maskability is important for documenting the psychoacoustic characteristics of tinnitus and generally helpful in counseling patients. These measures can be obtained in about 10 minutes with a clinical audiometer [29,33].

Approximately 80 percent of individuals who experience tinnitus do not require any intervention for their tinnitus, while the tinnitus is "clinically significant" for the remaining 20 percent [34–35]. Further, those whose tinnitus is clinically significant have different levels of need [36]. Tinnitus intervention should therefore be administered at different levels, depending on the level of need [37]. Education and self-care are the essential tools for most patients to successfully manage their tinnitus. Various types of therapy are available for this purpose [28,38–39]. Currently, the most common forms of tinnitus treatment include cognitive-behavioral therapy

(CBT) [40], Neuromonics Tinnitus Treatment [41], tinnitus masking [42–43], and tinnitus retraining therapy [35, 44]. An approach specific to audiologists (audiological tinnitus management) has recently been described in detail [28–29]. All of these methods, except for CBT, include a combination of educational counseling and some specific use of sound. CBT is a psychological form of treatment that includes cognitive restructuring, attention control, imagery training, and relaxation training. A summary of various tinnitus treatment methods is available in a recent book [45].

Tympanic Membrane Perforation in Blast-Related Traumatic Brain Injury

A recent report by a group of military physicians showed a high incidence of tympanic membrane perforation (35.2%) in blast-injury survivors [46]. After demonstrating an association between barotraumatic tympanic membrane rupture and loss of consciousness, the authors suggested that "physicians who are treating blast survivors with tympanic membrane perforation need to have a high index of suspicion for concomitant neurologic injury" [4]. Intrigued by this article, we proceeded to review the data pertinent to tympanic membrane rupture in our patient sample. Because of the retrospective nature of this study, much of the original data from the military treatment facilities were unavailable. Through the VA electronic medical records, we found that tympanic membrane perforation was present in only 6 of the 42 patients (14%) in Group II-BR. A confounding factor was that one of the patients in Group II-BR sustained his BR injury in a previous combat operation. He and his family learned about the VA's TBI inpatient program through various channels and sought help for his multiple impairments. Although this patient with TBI was an exception from the point of chronology, his auditory manifestations were very similar to those of his younger counterparts. If we removed this particular patient with intact eardrums from the analysis, the prevalence of tympanic membrane rupture in Group II-BR would only change from 14 percent (6/42) to 15 percent (6/41). Also, since all these patients (most of whom had severe TBI) were stabilized in a military medical facility where they received excellent care before being transferred to the VA, some of the less severe tympanic membrane perforations may have healed during the long hospitalization course. Nonetheless, in light of this intuitive correlation, we feel that physicians should closely examine the eardrums not only as a part of the initial intake process but also during follow-up at TBI inpatient rehabilitation facilities.

CONCLUSIONS

Hearing loss and tinnitus are highly prevalent in this growing population of returning soldiers who have BR TBI. Thus, we need to develop and implement strategies for diagnosis and management of auditory dysfunction in this population.

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