Airbag Deployment Study - Otologic Injuries Secondary to Airbag Deployment
Otologic Injuries Secondary to Airbag Deployment

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ABSTRACT

Airbags are clearly successful at mitigating injury severity during a motor vehicle accident (MVA). Deployment unfortunately has introduced new injury-causing mechanisms. A retrospective review of 20 patients who sustained otologic injuries resulting from airbag inflation was conducted. The most common complaints were hearing loss in 17 (85%), and tinnitus in 17 (85%). Objective hearing loss was documented in 21 of 24 (88%) subjectively affected ears; this included unilateral and bilateral sensorineural, unilateral conductive, and mixed hearing losses. Ten patients (50%) experienced disequilibrium. Four subjects (20%) had a tympanic membrane (TM) perforation; each required surgical closure. Ear orientation toward the airbag was found to be associated with hearing loss ($p = .027$), aural fullness ($p = .039$), and TM perforation ($p = .0004$). A wide variety of airbag-induced otologic injuries occur and may have long-term sequelae. It is important for health care personnel to be aware of these potential problems.

INTRODUCTION

Federal regulations required that airbags be installed in all passenger cars, vans, pickup trucks and utility vehicles as of September 1, 1998.1 Airbags clearly are successful at decreasing injury severity during a MVA.2,3 Based o n all types of crashes, they decrease fatalities by 21-22% for unbelted drivers, and by 9-16% for drivers wearing seatbelts.4-6

Airbag deployment unfortunately has introduced a new spectrum of injuries; numerous reports of injury patterns exist.5,7-17 The majority are relatively minor, and usually consist of erythema, abrasions, and contusions to the face, anterior neck, or upper chest.5,16 More serious harm is rare, but there are accounts of life-threatening trauma in the literature.9,10,16 Damage to the eye,7 cervical spine,8,9,16 facial nerve,17 temporomandibular joint,11 facial skeleton,7,8 and upper airway injury15 are of particular importance to the practicing otolaryngologist. Recent reports have documented a total of 13 people with otologic symptoms of hearing loss, tinnitus and / or disequilibrium.13,14,18-22

A number of patients with unusual otologic findings after airbag deployment were recently encountered in our practice. Many of these problems are yet to be described in the literature. The purpose of the present study is to retrospectively review these patients, as well as to discuss all relevant literature.

MATERIALS AND METHODS

Patients with otologic complaints after airbag deployment between April 1995 and April 1998 were retrospectively studied. Twenty airbag subjects were extracted from a total of 109 charts of MVA patients. Eighty-nine patients were excluded due to lack of airbag deployment. A retrospective chart review was conducted; a telephone questionnaire was performed to acquire any missing subjective data.

Each patient underwent a complete neuro-otologic examination. Testing was not standardized given the retrospective nature of this study. Pure tone and speech audiometry was performed post-accident and periodically after initial evaluation in nearly all subjects. Hearing tests completed less than one year before the MVA were retrieved for comparison purposes when possible. Post-accident audiometric testing was divided into two groups based on early (less than one month) and late (more than one month) after the MVA. A four-frequency (0.5, 1, 2, and 3 kHz) pure tone average (PTA) was calculated in standard fashion for each audiogram.

A number of statistical methods were utilized for data analysis. The Fisher's Exact test was used for independence between categorical variables. Differences between groups were tested using the Mann-Whitney Test. The Paired T-Test was used for comparison of audiometric PTA scores. Both affected ears (i.e., with bilateral involvement) were included in calculations for certain variables when appropriate. Driver inboard (right)

ears were considered as oriented towards a deploying passenger side airbag when overall head positioning was straight ahead.

RESULTS

Subject demographic and accident information is outlined in Table 1. There were 11 females and 9 males with a mean age of 48 years (range 7 to 75). Nearly all individuals were driving the car, and the driver side airbag deployed in all accidents studied. Passenger-side airbag deployment occurred in 9 of 20 (45%). All patients were wearing seatbelts, though case 4 (a child) was improperly restrained at time of impact. Follow-up averaged 18 months (range 4 to 40).

A wide variety of automobiles were involved. All vehicles sustained a frontal or near-frontal impact. Average speed of impact was 42 (range of 5 to 80) miles per hour. No patient sustained a skull-base fracture, or significant closed head injury.

History of previous otologic problems prior to the MVA was obtained; results are listed in Table 2. Three patients underwent surgery previously for chronic ear disease. Each of these subjects had been doing well before the accident with no evidence for active disease or perforation. Mild pre-existing subjective hearing loss was described in 9 of 20 (45%), infrequent tinnitus in 3 (15%), and mild intermittent disequilibrium in 1 (5%). No subjective complaint was felt to be bothersome just prior to the MVA.

New onset hearing loss in 17 (85%) and non-pulsatile tinnitus in 17 (85%) were the most common symptoms after airbag deployment. These occurred together on a statistically significant basis ($p < .0001$ by Fisher's Exact Test). Of the 17 with subjective hearing loss, it was unilateral in 10 (59%), bilateral in 7 (41%), and persistent in 13 (76%). Tinnitus was unilateral in 11 (65%), bilateral or non-localized in 6 (35%), and persistent in 9 (53%). Other common complaints in our 20 patients included: disequilibrium in 10 (50%), and aural fullness in 6 (30%). Disequilibrium was temporary in 6 of 10 (60%), persistent in 4 (40%), and delayed in 1 (10%). Aural fullness was associated with occupant head position towards the airbag ($p = .039$ by Fisher's Exact Test).

Objective hearing loss (drop of at least 10 dB at two frequencies) was documented in 21 of 24 (88%) subjectively affected ears. Of ears with objective hearing loss, the type was sensorineural in 17 (81%), conductive in 2 (10%), and mixed in 2 (10%). High frequencies (> 4 kHz) were most commonly affected, followed by middle (2-4 kHz) and low frequencies (< 2 kHz).

Seven subjects underwent a hearing test prior to the MVA. The audiometric configuration grossly changed (i.e., from normal to flat, or from flat to sloping) in 5 of 9 ears (56%) that had hearing objectively documented before the MVA. The PTA increased significantly after airbag deployment in these 9 ears by 10 dB both within the first month as well as one month after the accident. This average change was statistically significant for the early ($p < .001$ by Paired T-Test), and late ($p = .002$ by Paired T-Test) time periods. Of all tested variables, increased age ($p = .028$ by Mann-Whitney Test), and head position toward the airbag ($p = .027$ by Fisher's Exact Test) were statistically related to hearing loss. No significant difference was found between post-MVA hearing levels based on time from the MVA ($p = .804$ by Paired T-Test).

Of the 10 patients with dizziness, 4 (40%) had caloric weakness, 2 (20%) were diagnosed with benign paroxysmal positional vertigo (BPPV), and 2 (20%) developed endolymphatic hydrops. Two subjects (20%) had non-specific disequilibrium. Patients with BPPV were treated with a particle-repositioning maneuver. One subject with hydrops presented 2 months after the MVA in a delayed fashion. Medical therapy was effective in controlling hydrops symptoms. Four of the 10 (40%) with dizziness have chronic symptoms resistant to medical and vestibular therapy.

Three of 20 (15%) described chronic otalgia. TMJ dysfunction was diagnosed in each, and was bilateral in one. No subject appeared to have this condition before airbag deployment. Pain has been mitigated with conservative treatment alone.

Unilateral TM perforations were documented in 4 patients (20%). Two had mixed and two had conductive hearing losses. Three had the affected ear directly oriented toward the deploying airbag in front. The other was a driver who had the right TM perforated after being exposed to dual airbag inflation, despite a neutral head position. Ear orientation was the only statistically significant related variable for TM perforation ($p = .0004$ by Fisher's Exact Test). Each patient required a tympanoplasty, and showed hearing improvement postoperatively.

DISCUSSION

A new assortment of injuries has been documented since the introduction of automobile airbags.5,7-17 There are only 7 reports13,14,18-22 of otologic injury due to airbag deployment. These describe hearing loss, tinnitus, and / or disequilibrium. The potential risk to the ear from airbag restraint devices appears to be quite low.19

Temporary or permanent threshold shift (TS) in hearing has been reported.13,14,18-22 This study provides documentation of an additional 21 ears that were found to have objective hearing loss after airbag inflation. Most demonstrated a sensorineural hearing loss, but a conductive or mixed loss was noted in all ears with TM perforation. Case 13 had a mixed hearing loss related to previous chronic otitis media. As reported previously,23,24 traumatic TM perforation did not appear to protect the inner ear. This is suggested by a sensorineural component in two TM perforation subjects. Sensorineural hearing losses were commonly documented in the mid- and high-frequency range in earlier reports.13,14,19,20,22 Other airbag studies have shown 6 kHz to be the most common frequency showing a temporary TS in human volunteers,25 and in cats.26 Nearly all subjects with sensorineural hearing loss in this study had involvement of both the mid- and high-frequencies. These results are consistent with blast studies demonstrating no single typical audiometric configuration.23,24

Our subjects with sensorineural loss generally showed no change in hearing levels after the initial post-MVA audiogram. This is in contrast to the belief that airbags are more likely to produce a temporary TS.25-27 Increased age was a statistically significant variable associated with hearing loss in our study. Factors such as overall health, smoking, and microvascular disease may predispose to hearing loss.28 Individual responses to noise, and pre-existing hearing loss may also affect hearing results in airbag studies.19,25

Tinnitus was frequently noted in this study. As previously described in the literature,23-25,29 tinnitus tends to parallel sensorineural hearing loss. There are only a few known airbag patients with persistent tinnitus.13,14,18,19,22 This report documents an additional nine with chronic subjective tinnitus. Less than half of those in our study reporting tinnitus noted its resolution.

Specific dizziness syndromes in our study resolved with non-surgical therapy. No perilymphatic fistula was diagnosed in this report, but can occur after minor head injury.12,30 None of our patients experienced a significant head injury, though it is possible that drivers of vehicles sustaining a left-frontal impact may have struck the A-pillar between the windshield and driver’s side window. Stapes displacement with an intense pressure pulse might cause inner ear damage, including fistula formation or intralabyrinthine membrane rupture.19

Less common otologic complaints in this series included aural fullness and otalgia. The fullness sensation resolved in all affected individuals and was usually associated with a TM perforation. Otalgia was always due to TMJ dysfunction. This is consistent with prior documentation of airbag deployment being associated with TMJ damage.11 No alternate source of ear pain was discovered.

Airbag-induced TM perforations have not been reported by other authors. The threshold for perforation of a normal TM is thought to be about 180 dB sound pressure level, but can be as low as 160 dB with pre-existing otologic disease.12,31 Case 1 had undergone prior tympanoplasty; this may have lowered the threshold. None of the four perforation subjects demonstrated spontaneous healing. This is in contrast to the combat setting where resolution rates vary from 81-91%.29 Larger perforations, those posteriorly located, and those which fail to show healing within a few weeks have a significantly lower rate of closure.12,23,24,29 All perforations in our study were associated with these negative factors.

Our study suggests that ear positioning towards the airbag was an important factor with regards to hearing loss, aural fullness, and TM perforation. A feline study confirmed increased acoustic trauma associated with ear orientation toward the airbag. This held true for the right (inboard) ear of animals in the driver’s seat which were exposed directly toward the passenger side airbag.32 An ear facing a blast experiences a TM pressure which is approximately double that of an ear not facing the blast.31 Some clinical cases with hearing loss were associated with the head turned toward the airbag as well.13,14,18-22 Ear orientation thus may be important with regards to acoustic damage.

Those with a TM perforation in our study had the ear oriented to the inflating airbag directly in front (cases 1, 4, 19), or the passenger side airbag (case 18). The angle of incidence appeared to be important. Air trapping within the external auditory canal from airbag "slap" may also help to explain our observations. Based on results of this study, implementation of lateral (side) airbags in new vehicles may increase the chance of TM perforation and other otologic injuries.

Additional factors thought to be important with respect to TM perforation are vehicle interior size and geometry, occupant location, and number of airbags deployed. Engineering studies have documented an effect of vehicle size and window status on the pressure pulse associated with automobile airbag deployment.33 A smaller effective interior volume and closed windows are expected to augment the potential for acoustic trauma. This does not, however, take into account the protective effect of the low-frequency component inflation noise. This component has actually been found to reduce the effectiveness of the high frequency component in producing TS in human volunteers,27 and may modulate the flow of energy into the cochlea.34 Surprisingly, having the windows open might be less protective based on mathematical modeling.32 No subject with a perforation had the windows open, and none were in compact cars. Interior geometry variation is also known to have an effect on the pressure environment, and may contribute to otologic injury.35

Deployment of multiple airbags logically increases noise production. Though most perforation subjects were driving, it has been shown that a passenger TM receives increased sound pressure when both airbags inflate.33 Dual airbags did deploy in two TM perforation subjects; inflation of multiple airbags may have increased the overall pressure wave. Formation of a TM perforation therefore may be multifactorial, with many conditions playing a role.

Car size or type did not prove to be statistically significant for any specific otologic injury in this report. The majority of vehicles were American products; this likely reflects our patient population from the state of Michigan rather than increased danger associated with airbags from U.S. automakers. There is no reason to believe that American airbag restraint systems are not as safe as those produced by foreign car manufacturers.

There are a few limitations to this study. The small number of subjects from a select patient population may not be representative of all people who sustain airbag-induced otologic injury. Many of the variables studied are subjective, and thus difficult to quantify.

The reason that such a high percentage of our subjects had permanent or severe otologic damage may again be related to the nature of our referral population. It is thought that most MVA patients fail to report minor or temporary symptoms such as mild hearing loss or tinnitus. Since studies25,27 have demonstrated recovery of pre-exposure hearing levels within a few hours of airbag deployment, it is possible that most individuals are not bothered by transient symptoms. Hearing loss above the speech frequency range may not be immediately apparent or bothersome.13 We tended to see only those with persistent complaints who were eventually referred by local physicians.

The relative incidence of all otologic injuries secondary to an MVA is unknown. Airbags may actually be protective for some injury categories. This report is the first to document certain airbag-associated otologic problems. Unilateral TM perforations, unilateral conductive and mixed hearing loss, bilateral sensorineural hearing loss, and vertigo due to BPPV or endolymphatic hydrops have not been attributed to airbags previously. It should be noted, however, that many patterns of hearing loss have been reported after an MVA without airbag inflation.36 Furthermore, BPPV and other vestibular abnormalities have been seen following various types of head injury; again unrelated to airbag deployment.36 It is therefore difficult to establish a direct cause-and-effect relationship between airbags and some of the pathology encountered in this study.

CONCLUSIONS

A wide variety of airbag-induced otologic injuries occur and may have long-term sequelae. These include temporary or permanent hearing loss, tinnitus, disequilibrium, and otalgia. Four TM perforations were documented, and each required surgical intervention. Ear orientation was found to be a statistically significant variable associated with hearing loss, aural fullness, and TM perforation. Based on results of this study, implementation of new lateral (side) airbags may increase the chance of these injuries as deployment conditions change.

It is important for health care personnel to be cognizant of these potential injuries since airbags are now ubiquitous. Recognition of injury patterns is a logical step toward airbag design modification. Refinements may reduce both the incidence and severity of this new injury spectrum.

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