Asymmetric Hearing Loss Prompting MRI Referral in a Military Population: Redefining Audiometric Criteria

Anthony M. Tolisano, MD1, Ricardo M. Burgos, MD2, Michael B. Lustik, MS3, Lex A. Mitchell, MD2, and Philip D. Littlefield, MD1

No sponsorships or competing interests have been disclosed for this article.

Abstract

Objective. To reevaluate asymmetric sensorineural hearing loss (ASNHL) criteria used to justify magnetic resonance imaging (MRI) in the evaluation of retrocochlear tumors in a military population.

Study Design. Retrospective case-control study.

Setting. Tertiary care military medical center.

Subjects and Methods. Patients with military service and a history of ASNHL prompting referral for MRI, with or without retrocochlear tumors, were compared between 2005 and 2016. Predictor variables included pure tone ASNHL, speech audiometry, and a history of noise exposure. Logistic regression models for hearing asymmetries were performed, and receiver operator curves were used to calculate sensitivity and specificity.

Results. Thirty-eight retrocochlear tumors were identified. The MRI diagnosis rate for patients with ASNHL was 0.85%. Patients with tumors were slightly older (42 vs 37 years, \(P = 0.021\)) and had less noise exposure (47% vs 85%, \(P < .001\)). A sensitivity of 0.83 and a specificity of 0.58 were calculated for asymmetries \(\geq 10\) dB at 2000 Hz without adjusting for noise exposure. Instituting this imaging threshold would have reduced the number of MRI scans by half while missing 16% of tumors.

Conclusion. The tumor diagnosis rate among those undergoing MRI for ASNHL is low in the military population, likely because service-related noise exposure commonly causes ASNHL. Optimal MRI referral criteria should conserve resources while balancing the risks of over- and underdiagnosis. For those with a history of military service, an asymmetry \(\geq 10\) dB at 2000 Hz among patients meeting current ASNHL referral criteria is most predictive of a retrocochlear tumor.

Keywords

asymmetric hearing loss, retrocochlear tumor, magnetic resonance imaging, sensitivity, specificity

Received August 27, 2017; revised November 28, 2017; accepted January 10, 2018.

All branches of the US military screen for occupational hearing loss, but the army is the only branch that requires annual screening audiograms for all active duty members regardless of noise exposure risk (Department of the Army pamphlet 40-501; January 8, 2015). The intent is early identification of noise-induced hearing loss (NIHL). One consequence is the identification of asymmetric sensorineural hearing loss (ASNHL), which prompts referral to an otolaryngologist to rule out retrocochlear lesions such as vestibular schwannoma (VS).

Up to 90% of retrocochlear lesions are VS, and they most commonly present with ASNHL.1,2 ASNHL mandates further workup since a delayed diagnosis of VS can have serious consequences. Whereas audiograms are typically ordered for those who have symptoms of hearing loss or tinnitus, our practice has changed so that the audiogram is now screening a largely asymptomatic population.

Magnetic resonance imaging (MRI) of the internal auditory canals (IACs) is the current gold standard for confirmation of retrocochlear tumors, with virtually 100% sensitivity and specificity for treatable retrocochlear lesions.3 The MRI protocol at our institution consists of noncontrast axial
fluid-attenuated inversion recovery through the brain, followed by axial 3-dimensional T2* gradient recalled echo through the IACs. This identifies lesions as small as 2 mm, and abnormal scans are subsequently confirmed with gadolinium contrast.

There is no consensus regarding hearing asymmetry criteria to justify MRI referral. We have used the “rule of 3000” for 5 years: pure tone asymmetry ≥15 dB at 3000 Hz or speech discrimination asymmetry >10%. Others commonly use an asymmetry ≥15 dB at any 2 consecutive frequencies.

In civilian practice, 2% to 8% of MRI of the IACs for ASNHL reveals tumors. We suspect that ASNHL is less likely to identify tumors in our patients because of the high prevalence of NIHL in the military. NIHL is frequently asymmetric despite the axiom that both ears are equally affected by noise. Nevertheless, the medical-legal precedent is to further evaluate asymmetries even if there is a history of NIHL. The high prevalence of ASNHL in the military may cause a high false-positive rate when the current asymmetry criteria for MRI are applied. We therefore hypothesize that asymmetry criteria can be optimized for the military by analyzing lower audiometric frequencies less affected by noise.

Materials and Methods
This study was approved by our Institutional Review Board (Tripler Army Medical Center 16R47). This retrospective case-control study compares patients with ASNHL with retrocochlear lesions (tumor group) with those having negative MRI of the IACs (control group) at a tertiary military medical center. The tumor group was created by reviewing MRI of the IACs in the past 11 years with retrocochlear lesions. The control group was created by surveying MRI of the IACs over the past 3 years and selecting negative cases; the first 5 qualifying MRI scans were for ASNHL. Six retrocochlear tumors were identified, 20) and superior semicircular canal dehiscence (n = 16). There were incidental findings in 76 (11%), most commonly mastoid effusions (n = 20) and superior semicircular canal dehiscence (n = 16). Four retrocochlear tumors were found on the side opposite of hearing asymmetry. These were also considered incidental, since the finding was equivalent to having no asymmetry on the affected side.

Demographics and History of Noise Exposure
Between 2005 and 2016, 38 patients with retrocochlear masses met inclusion and exclusion criteria. Patients were considered asymptomatic if they were identified exclusively by screening audiograms. No patients presented with facial weakness or numbness. Almost all were male, and there was no sex difference between the control and tumor groups (male: 97% vs 95%, respectively; P = .352). Patients with tumors were slightly older (median: 38 vs 37 years; P = .038; see Table 1).
Patients without a tumor had a history of noise exposure 85% of the time, as opposed to 47% of those with a tumor \( (P < .001; \text{ Figure 1}) \). This relationship held true for impulse noise exposure (64% vs 37%, \( P = .008 \)) and continuous noise exposure (36% vs 13%, \( P = .019 \)). Twenty-five patients (14%) of the control group had combined (impulse and continuous) noise exposure versus 1 in the tumor group.

Hearing asymmetry on the left was more common in the control group than in the tumor group (70% vs 50%, \( P = .032 \)). Similarly, a left-side noise notch was more common in the control group (37.2% vs 13.9%, \( P = .006 \)). No difference in right-side noise notch was found (25.0% vs 19.4%, \( P = .530 \)). When included in a model with level of asymmetry and history of noise exposure, neither side of asymmetry nor presence of left noise notch was significant.

### Table 1. Demographics and History of Noise Exposure.

<table>
<thead>
<tr>
<th></th>
<th>Group 1 (Control)</th>
<th>Group 2 (Tumor)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>5 of 180</td>
<td>2 of 38</td>
<td>.352</td>
</tr>
<tr>
<td>Age, y</td>
<td>180</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>20-29</td>
<td>66</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>30-39</td>
<td>37</td>
<td>13</td>
<td>34</td>
</tr>
<tr>
<td>40-49</td>
<td>48</td>
<td>7</td>
<td>18</td>
</tr>
<tr>
<td>50-70</td>
<td>29</td>
<td>11</td>
<td>29</td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>37 (12)</td>
<td>42 (14)</td>
<td>.021</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>37 (26-46)</td>
<td>38 (31-55)</td>
<td>.038</td>
</tr>
<tr>
<td>Noise exposure</td>
<td>167</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>No or unknown</td>
<td>25</td>
<td>15</td>
<td>53</td>
</tr>
<tr>
<td>Any</td>
<td>142</td>
<td>14</td>
<td>.47</td>
</tr>
<tr>
<td>Impulse</td>
<td>107</td>
<td>11</td>
<td>.37</td>
</tr>
<tr>
<td>Continuous</td>
<td>60</td>
<td>4</td>
<td>.13</td>
</tr>
</tbody>
</table>

Abbreviation: IQR, interquartile range.

### Tumor Characteristics and Management

Twenty tumors were on the right side and 18 on the left. Mean intrameatal tumor measurements were 5.4 mm (anterior-posterior) \( \times \) 6.7 mm (transverse). Twenty tumors extended beyond the meatus, and the mean extrameatal segment measured 15.1 mm. Fundal involvement was definitively noted in 12 cases and approximated the fundus in 5 (Table 2).

The most common diagnosis was VS (n = 33), as ascertained from MRI characteristics and surgical confirmation when available. There were no malignancies. Of 38 patients, 37 had known treatment plans. Eleven were observed with serial MRI scans and did not require intervention. Fifteen had surgery, and 11 were treated with stereotactic radiation.

There were 3 cases of delay in diagnosis \( >6 \) months (mean, 43 months), defined as a delay between the first identification of hearing asymmetry and the diagnostic MRI. These cases were included in the analysis even though it is possible that the tumor characteristics had changed since the audiograms. The average tumor measured 9.2 mm \( \times \) 10.3 mm (intrameatal portion), and each extended extrameatally for an average of 14.8 mm.

### Role of Hearing Conservation Audiograms

A total of 25,768 hearing conservation audiograms were completed at our institution between January 2013 and December 2015, in accordance with the requirement to screen all soldiers for hearing loss regardless of presence or absence of hearing loss symptoms. Identification of asymptomatic ASNHL on a routine hearing conservation test was similar between tumor cases and controls (42% vs 53%, \( P = .285 \)). Nearly half (44%) of all tumors were identified because of an asymmetry on routine hearing conservation tests. No difference in tumor size was found between those identified on hearing conservation and those with symptomatic hearing loss. Moreover, active management by

---

**Figure 1.** Noise exposure history. \( *P < .05 \).
surgery or radiation was similar when tumors were identified by a hearing conservation test or due to symptomatic hearing loss (63% vs 75%, \( P = .483 \)).

### Hearing Loss and Asymmetries

All 216 formal audiograms prompting MRI referral had asymmetries ≥10 dB in at least 1 frequency. Of these, 128 (59%) had ≥15-dB asymmetry at 3000 Hz. When combined with ≥15-dB asymmetry at any 2 adjacent frequencies, 95% of audiograms met 1 of these 2 criteria.

The distribution of asymmetries for frequencies ≥3 kHz for the tumor group was not significantly different than that for the control group (Table 3). However, asymmetries <3 kHz and SRT were significant (Figure 2). C-scores from ROC curves were highest for 1- and 2-kHz asymmetries of ≥10 dB, and they were lower for frequencies ≥3 kHz (Figure 3). C-scores for SRT were similarly high. Eight tumor cases had WRS asymmetries >8%, but obvious pure tone asymmetries were also seen in each, so WRS was not examined further.

The models favored sensitivity over specificity, since the consequence of missing a tumor is greater than the consequence of an unnecessary MRI (Table 4). Without adjusting for noise exposure, an asymmetry ≥10 dB at 2 kHz provided a sensitivity of 0.83 and a specificity of 0.58 (C-score = 0.78). A C-score of 1.0 means 100% sensitivity and specificity, while a C-score of 0.5 is indicative of chance. An SRT ≥10 dB also performed well (sensitivity, 0.89; specificity, 0.68; C-score, 0.85). Meanwhile, an asymmetry ≥15 dB at 3 kHz was more useful in this non-noise exposed group (sensitivity, 0.97; specificity, 0.35; C-score, 0.83).

### Discussion

The US Army recently mandated annual hearing conservation audiograms for all active duty service members regardless of noise exposure risk. This compelled us to reassess our hearing asymmetry criteria for MRI of the IACs. The intention of this policy is to identify occupational NIHL, but there are inevitably referrals for ASNHL. While the audiogram was already a de facto screening test for retrocochlear lesions, it typically is ordered when a patient describes an otologic symptom. In the military, it has now become a true screening test for a group that is largely asymptomatic.

There are numerous studies regarding the audiologic criteria for ordering MRI,\(^4,6,9\) but there are no published clinical practice guidelines. In these studies, a ≥15-dB asymmetry at 3 kHz (rule of 3000) was determined to be the best criteria,
but this had a lower diagnostic value in our population. The 2011 Saliba study produced a sensitivity of 0.73 and a specificity of 0.76. Although we had a similar sensitivity of 0.78, we had a much lower specificity of 0.46. We attribute this differential to the fact that (1) these studies did not evaluate highly noise-exposed populations and (2) NIHL in the military is up to 4 times as prevalent as it is matched civilian populations.

In a 2016 study, Pena and associates evaluated the VS detection rate in a group of US veterans. They recognized that ASNHL in a population with substantial noise exposure would change the sensitivity and specificity of audiograms, and they proposed stricter asymmetry criteria, 45 dB at 3 kHz, which resulted in a sensitivity of 0.33 and a specificity of 0.82. We calculated similar numbers (sensitivity, 0.36; specificity, 0.89) under these criteria in our study groups. Of course, stricter criteria risk missing tumors that are concealed by NIHL. Rather than increased stringency, it would be better to optimize criteria in a way that separates the audiometric characteristics of retrocochlear lesions and NIHL.

NIHL often has a noise-notch pattern, where hearing loss is greater at 4 and 6 kHz than at 8 kHz. However, those without excess noise exposure can have noise notches, and noise notches are frequently asymmetric. Wilson and McArdle reviewed 539,932 audiograms from the Department of Veterans Affairs and found that 10% had only right- or left-sided notches. Our strategy for refining asymmetry criteria was to direct attention away from frequencies altered by noise, knowing that tumors tend to affect a broad distribution of frequencies.

We were surprised to find that SRT performed similarly to the best pure tone criteria. SRT is a basic hearing test, but previous work did not utilize SRT in this context. Our pure tone data offer 1 explanation, since they favor low frequencies, and the SRT has long been estimated with low-frequency thresholds. This finding deserves further study for reproducibility. Meanwhile, we were unimpressed by the WRS, because most patients with tumors had normal WRS results and those who did not also met pure tone threshold asymmetry criteria. There is an obvious ceiling effect. In comparison, SRT rarely has constraints on either side of the threshold value.

It remains to be seen if the army’s aggressive hearing surveillance will result in increased VS diagnoses, but in the last 11 years, 42% of tumors at our institution were identified via hearing screening and not because of symptoms. Meanwhile, there were no significant differences in tumor size or treatment between these groups.

Implementation of our proposed criteria (10 dB at 2000 Hz, without adjusting for noise exposure) would have missed only 6 of 38 tumors (16%). In comparison, 8 tumors would have been missed had we used the rule of 3000. Importantly, 100 of the 180 MRI scans in the control group would not have been ordered.

Because the army screens for hearing loss annually, the risk of a missed tumor is less consequential than it is in civilian populations, since the majority of those missed on first pass would ultimately progress to the point of MRI referral in subsequent years. Meanwhile, with unusual exceptions, vestibular schwannomas are benign slow-growing tumors. A third of those identified
in this study are followed by serial MRI scans. We believe that a false-negative rate of 16%, as would be the case if our MRI referral criteria were implemented, is reasonable and mirrors risks accepted in the head and neck literature.24 Note also that 5% of VSs present without hearing loss, so even the most liberal asymmetry criteria will miss tumors.25 Any estimate of a false-negative rate for asymmetric hearing loss must be considered in addition to this. Of course, the decision to order MRI is less difficult with other concerning symptoms, such as facial nerve dysfunction, facial numbness, vertigo, or imbalance.

Our data are skewed by a necessary selection bias: all subjects in the control group already met some form of asymmetry criteria, as two-thirds had ≥15-dB asymmetry at 3000 Hz. For now, it is best to treat our findings as a conditional probability. If there is ≥15-dB asymmetry at 3000 Hz or ≥15-dB asymmetry at any 2 adjacent frequencies, then look for a ≥10-dB asymmetry at 2000 Hz. This study could be followed by a prospective study that includes subjects with low-frequency asymmetries without meeting the criteria for ≥15-dB asymmetry at 3000 Hz. This would further simplify the criteria but would require (temporarily) ordering even more MRI scans than we do now. It would also be useful to look at all our hearing conservation audiograms to see if there are many asymmetries that do not fit into the inclusion criteria used in this study.

Limitations to this study include the fact that data were analyzed retrospectively from a single institution. However, because care is delivered to military personnel in an essentially closed system with internal referrals, nearly all the important clinical information is able to be captured. We intend to expand this analysis to additional military medical centers for further validation. While our patient population is typical of the Military Health System (MHS), these data are not generalizable outside the MHS. However, the MHS is one of the largest integrated health systems in the United States. We are aware that the records that we reviewed contain additional data with potential diagnostic utility (ie, handedness, cumulative rifle use, total combat experience), but additional qualifiers risk overfitting the data. We believe that it is best to start with simple criteria that are easily applied in the clinic.

**Conclusion**

There is a high incidence of ASNHL in the military. While our local practice patterns are in line with various published MRI criteria for ASNHL, we had an exceptionally low diagnostic MRI rate. For pure tones, we found that among patients with active military service regardless of noise exposure, a 2-kHz ≥10 dB produced the best combination of sensitivity (0.83) and specificity (0.58) for patients already meeting standard asymmetry referral criteria. Asymmetries <3 kHz were more useful than asymmetries at ≥3 kHz. We also found that an SRT ≥10 dB performed well, although this has never been reported. Using these criteria in our population would decrease MRI referrals by half without unreasonably increasing the risk of missed diagnoses.

It is too loud in the military, so look at 2000.

**Author Contributions**

Anthony M. Tolisano, conception, acquisition/analysis/interpretation of data, manuscript drafting and revision, final approval, accountability; Ricardo M. Burgos, conception, acquisition of data, manuscript revision, final approval, accountability; Michael B. Lustik, analysis/interpretation of data, manuscript revision, final approval, accountability; Lex A. Mitchell, analysis/interpretation of data, manuscript revision, final approval, accountability; Philip D. Littlefield, conception, acquisition/analysis/interpretation of data, manuscript drafting and revision, final approval, accountability.

**Disclosures**

Competing interests: None.
Sponsorships: None.
Funding source: None.

**References**


