Asymmetric hearing loss stratification and vestibular Schwannoma risk: a meta-analysis

https://hdl.handle.net/2144/16052

Boston University
ASYMMETRIC HEARING LOSS STRATIFICATION
AND VESTIBULAR SCHWANNOMA RISK:
A META-ANALYSIS

by

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B.A., University of Rochester, 2011

Submitted in partial fulfillment of the
requirements for the degree of
Master of Science
2015
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ACKNOWLEDGMENTS

I would like to thank Dr. Grundfast for the original idea of completing my thesis on the topic of MRI scans for asymmetric sensorineural hearing loss. His continued mentorship throughout this project’s completion was essential for its success. I would also like to thank Dr. Devaiah both for his guidance, and for allowing me to use the original data from our meta-analysis for this project. The contribution of Parth Shah, MS4 BUSM, was crucial in gathering and organizing the original data for this meta-analysis. Finally, I would like to thank my advisor, Dr. Symes, who introduced me to Dr. Grundfast and has continually supported my pursuit of a career in medicine.
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ABSTRACT

Introduction
Asymmetrical sensorineural hearing loss [ASNHL] is a common otological complaint. Vestibular schwannoma [VS] is a rare, benign tumor that commonly presents with ASNHL. Magnetic resonance imaging [MRI] is the gold standard in diagnosing VS, but is an expensive imaging modality. Therefore, this meta-analysis evaluates the diagnostic yield of MRI scans in patients with ASNHL to rule out VS.

Methods
A systematic review was performed using a keyword search on the PubMed Database. We excluded articles based on: Non-English, case reports, wrong diagnostic test, solely pediatric subjects, inadequate/unnecessary data, repeated studies, and unclear presenting symptoms. The demographics, definition of ASNHL, and the number and results of MRIs were collected. Positive MRIs were grouped based on differences in interaural hearing loss.

Results
5,783 MRIs on subjects with ASNHL were collected from fourteen studies. 296 MRI
scans (5.1%) were positive for VS. 170 positive scans were grouped. In Group A (10+ dB) 11.2% had VS; in Group B (15+ dB at ≥2 frequencies or 20+ dB at 1 frequency) 6.5% had VS, Group C (20+ dB) yielded 5.1% with VS, and Group D (30+ dB) had 0.7% yield of positive VS.

Conclusion

MRI scans to rule out VS in patients with ASNHL has an extremely low diagnostic yield when assessing subjects on the basis of ASNHL. The degree of ASNHL does not correlate with increased odds of VS diagnosis. Overall, the risk of VS diagnosis in patients with any degree of ASNHL is low.
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<tr>
<td>CN</td>
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<td>MRI</td>
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<td>NF2</td>
<td>Neurofibromatosis Type 2</td>
<td></td>
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<tr>
<td>PTA</td>
<td>Pure Tone Average</td>
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<td>SD</td>
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<td>SNHL</td>
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<tr>
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INTRODUCTION

Hearing loss is a common problem that impacts the lives of all individuals at some point in their lives. For many, it is short-lived phenomenon, resulting of a change in altitude or an acute infectious process. However, chronic bilateral or unilateral hearing loss is also a widespread problem affecting 16.1% individuals aged 20–69 in the United States and in a greater proportion after reaching the fifth decade of life.\(^1\) Research shows that earing impairment is an independent negative predictor of both socioeconomic status\(^2\) and cognitive ability,\(^3\) which makes determining its etiology and potential for treatment an important issue in medicine today. This study will primarily focus on the cause of a particular type of hearing loss, known as asymmetrical sensorineural hearing loss [ASNHL]. Although there are several potential causes of ASNHL, it is also well established that progressive ASNHL in the mid-high frequencies may be associated with a retrocochlear pathology known as a vestibular schwannoma [VS].\(^4,5\) Although benign, this tumor can have severe consequences if left untreated.\(^6,8\) In order to better appreciate the nuance of VS diagnosis, one must first understand how we hear and the different types of hearing loss.

How we Hear & Conductive and Sensorineural Hearing Loss

Hearing loss is classified as one of three types: conductive hearing loss [CHL], sensorineural hearing loss [SNHL], or mixed hearing loss [MHL].\(^9\) These classifications are determined by the anatomical position of the pathological process that is causing the hearing deficit.\(^10\) In a normal hearing individual, environmental sound is transmitted from
the external ear along the external auditory canal to the tympanic membrane. The sound wave then transfers to the middle ear, traveling from the medial aspect of the tympanic membrane to the oval window through three bones. First, the sound wave travels through the malleus, which is attached to the medial aspect of the tympanic membrane; second, it moves through the incus, which acts as a bridge connecting the malleus to the third bone, the stapes, which is connected to the oval window via the stapes footplate. The purpose of these three bony ossicles is to amplify the sound energy transferred from the environment to the fluid filled inner ear. The middle ear space also contains the proximal Eustachian tube which functions to equalize the pressure between the environment and the middle ear space.

Individuals with conductive hearing loss are unable to appreciate noise in the environment due to an interruption of the noise signal prior to reaching the fluid of the inner ear (Figure 1). Many pathological processes can result in this decrease in the transmission of environmental sound waves to the inner ear. Common examples of conductive hearing loss include: otitis media, otosclerosis, cholesteatoma, perforation of the tympanic membrane, and cerumen impaction. Each of these examples interrupts the mechanical function of the external or middle ear structures and by definition result in conductive hearing loss.
Figure 1. Anatomy of Ear
The three main structures of the ear include: the external ear, the middle ear, and the inner ear. The external ear begins with the external ear structure and extends to the tympanic membrane through the external auditory canal. The middle ear consists of the medial aspect of the tympanic membrane, three bony ossicles (malleus, incus, and stapes), and the proximal Eustachian tube. The inner ear includes the semicircular canals, the cochlea, organ of Corti, and the vestibulocochlear nerve [CN VIII].

(Figure Taken from Bagai et al., 2006)

Sensorineural hearing loss is due to a pathological process that interrupts the noise signal after it reaches the inner ear space and before it reaches the brain for interpretation. The inner ear space includes the cochlea, the semicircular canals, and the vestibulocochlear nerve (Cranial Nerve [CN] VIII). In normal hearing individuals, the stapes footplate vibrates over the oval window causing displacement of the perilymph fluid of the cochlea which is sensed by the endolymph of the organ of Corti. The organ of Corti then converts this mechanical pressure signal into an action potential that is
transmitted along the cochlear nerve of CN VIII to the brain (Figure 1).\textsuperscript{9,11} CN VIII also contains the vestibular nerve which carries information regarding balance from the semicircular canals.\textsuperscript{11}

Mixed hearing loss is hearing loss due to a combination of conductive and sensorineural elements interfering with the noise signal transmission.\textsuperscript{9}

\textit{Tuning Fork Tests}

The presentation of bilateral or unilateral subjective hearing loss can be of conductive or sensorineural origin. To classify the hearing impairment as conductive or sensorineural, the clinician can use a tuning fork in clinic. Using a 512-Hertz [Hz] tuning fork, clinicians can evaluate individuals’ hearing with the Weber test and Rinne’s test.\textsuperscript{9,10} In the Weber test, a vibrating tuning fork is placed at the vertex of the forehead and the patient is asked at which ear the sound is heard loudest. A normal hearing individual will perceive the sound in both ears equally, while in an individual with unilateral conductive hearing loss, the sound will lateralize to the problem ear. If the individual has a sensorineural hearing loss, the Weber test will lateralize to the normal hearing ear.\textsuperscript{9,10,12}

The Rinne test is an examination of air conduction hearing. In this two-step evaluation the U-shaped portion of the vibrating tuning fork is placed near the external auditory canal, and then the base of the vibrating tuning fork is placed on the mastoid tip. The patient is then asked to discern which was louder, the air conduction with the tuning fork outside the external auditory canal or the bone conduction with the base of the tuning fork on the mastoid tip. A normal hearing individual will hear air conduction greater than bone conduction. If the bone conduction of sound is louder than the air
conduction, then there is thought to be a conductive hearing loss in that ear.\(^9,10,12\)

Although the Weber and Rinne tests have a high sensitivity for evaluating the type of hearing loss,\(^12\) a formal audiologic evaluation is indicated in individuals with subjective hearing loss without an obvious etiology, such as the finding of cerumen impaction or a perforated tympanic membrane, on physical examination.\(^12,13\)

The Audiologic Evaluation

A formal audiologic examination consists of pure-tone audiometry [PTA], speech audiometry, and impedance audiometry. Pure-tone audiometry will allow the clinician to determine the type of hearing loss and the level of the hearing impairment.\(^10\) PTA evaluates both air conduction of sound and also bone conduction of sound through headphones and a bone oscillator at the mastoid bone respectively. The patient is placed in a soundproof room and tones are delivered to each ear separately at frequencies ranging from 250 to 8000 Hz and at varying intensities ranging from 10–120 decibels [dB].\(^12\) The intensity (y-axis) at which the patient can distinguish each tone frequency (x-axis) 50% of the time is considered the threshold for hearing and is plotted on an audiogram (Figure 2).\(^12,13\) The bone conduction test stimulates the cochlea directly through the mastoid bone and thus, measures noise conduction from the inner ear to the brain.\(^10\) The air conduction test examines the patient’s ability to recognize pure tones through the air from the external auditory canal to the brain.\(^10\) The difference between these two measurements is known as the air-bone gap,\(^10,12\) and a conductive hearing loss can be diagnosed when the bone conduction is normal and there is an increase in threshold of dB in air conduction, as in Figure 2. Hearing loss is categorized based on the
following threshold ranges: mild 26–40dB, moderate 41–55dB, moderately severe 56–70dB, severe 71–90dB, and profound >90dB.9,12,14–17

**Figure 2. Conductive Hearing Loss**

Showing a mild conductive hearing loss in the left ear. There are normal bone conduction bilaterally and the right air conduction threshold is the same as the right bone conduction threshold.

(Figure Taken from Staffel, 2011)10

An audiogram of an individual with sensorineural hearing loss will not show the air-bone gap as previously discussed. Rather these patients’ audiograms show the same thresholds (>25db) for air conduction and bone conduction bilaterally, as shown in Figure 3. The high rate of noise-induced hearing loss and age-related hearing loss, also called
presbycusis$^{15}$ in the general population make symmetrical SNHL the most common type of hearing loss$^{15}$. As previously mentioned, a unilateral or asymmetric sensorineural hearing loss [ASNHL] may also present on an audiogram, which may indicate a retrocochlear neoplasm, the most common being a vestibular schwannoma$^{4,18,19}$.

**Figure 3. Sensorineural Hearing Loss**
This audiogram shows symmetrical sensorineural hearing loss with an increase in bone and air conduction thresholds at 4000 Hz. This increase at 4000 Hz is known as the “noise notch” and indicates that hearing loss is secondary to noise exposure.

(Figure Taken from Staffel. 2011)$^{10}$
In addition to the PTA assessment, speech audiometry is also a component of the formal audiologic assessment. This examination evaluates speech reception, recognition, and understanding.20

**Speech Audiometry**

The speech reception threshold [SRT] measures the threshold (dB) level at which a patient can correctly repeat 50% of spondee words, which are two-syllable words that place equal emphasis on each syllable.15,21 The SRT is compared with the patient’s corresponding PTA values at frequencies of 500, 1000, and 2000Hz.21 The speech recognition score [SRS] or word recognition score [WRS] presents patients with 50 monosyllabic words at an intensity level within their detectable range of hearing relative to the SRT or PTA thresholds.21-23 The WRS of an individual with normal hearing is expected to be >90% when the individual is presented with words 30dB higher than their SRT.21 The SRS is often judged excellent to good in patients with conductive hearing loss when the presentation intensity is adequate to reach the cochlea. However, patients with SNHL will generally show reduced performance when the threshold level is increased beyond that which is needed for maximum WRS. This is known as the “rollover” effect, and it is especially evident when testing individuals with SNHL of retrocochlear etiology versus an individual with SNHL of cochlear etiology.13,20,21,24,25

**Tympanometry**

Tympanometry is an additional component of the formal audiologic examination, which primarily evaluates the functional efficiency of the middle ear.26 This provides the
clinician with additional information to assist in distinguishing conductive versus sensorineural hearing loss. Tympanometry measures the change in eardrum compliance that results from a static pure tone signal at variable negative and positive pressures (-300 to +200 decapascal [daPa]). The resultant compliance curve, known as a tympanogram, will be normal (compliance peak between −150 and +50 daPa) in a patient with only SNHL, whereas hearing loss of conductive etiology will result in curves characteristic of an external or middle ear pathologic process.

While the formal audiologic evaluation outlined above is a useful tool when distinguishing conductive hearing loss from sensorineural hearing loss, the results can often lead to additional questions about a patient’s hearing. A particularly challenging situation for clinicians is the presence of ASNHL on an audiogram. As previously mentioned, ASNHL has long been known as the most common presenting symptom for a rare retrocochlear neoplasm called a vestibular schwannoma. Although rare, a recent survey found that 94% of clinicians always or frequently order an MRI to rule out VS in patients with ASNHL – many citing medicolegal concerns. This is a reasonable concern in light of a recently published retrospective analysis of a decade’s worth of medical malpractice in otolaryngology, which showed, “failure to diagnose,” was the most common legal allegation brought against otolaryngologists. More importantly, missed diagnosis of vestibular schwannoma can lead to an increased likelihood of deafness, facial weakness, and cranial nerve injury at the time of treatment, which will, by any measure, significantly affect an individual’s quality of life.
**Vestibular Schwannoma**

Vestibular schwannoma, also called an acoustic neuroma, is a rare benign neoplasm thought to arise from the Schwann-glial junction\(^{33}\) of the vestibular portion of CN VIII (Figure 1).\(^ {34}\) Virchow called this tumor a neuroma based on the macroscopic similarities of the tumor to axonal structures.\(^{35}\) However, in 1942 Murray and Stout\(^ {33}\) identified the tumor’s origin in Schwann cells histologically, and a more recent investigation found these tumors to predominantly arise from the vestibular portion of CN VIII,\(^ {34,36}\) despite their well known impact on hearing prior to this discovery.\(^ {8}\)

Equipped with new knowledge, Eldridge\(^ {37}\) and colleagues led a Neurosurgical consensus meeting in 1992 which served to officially adopt the term, *vestibular schwannoma* for what was previously described as an acoustic neuroma. However, even today, the two terms are commonly used interchangeably.\(^ {37}\)

VS is the most common retrocochlear neoplasm in the cerebellopontine angle [CPA],\(^ {18,19,38}\) and its location can result in a substantial impact on morbidity and potentially mortality despite its non-metastatic character.\(^ {39}\) In the pre-imaging era of the early 20\(^{th}\) century, these tumors were often diagnosed on post-mortem examination in conjunction with clinical symptoms that included cerebellar dysfunction, blindness, cranial nerve dysfunction, anosmia, hydrocephalus, and papilledema.\(^ {8,18}\) In the seminal work by Cushing in 1917, the presentation of unilateral hearing loss was first noted as the primary presenting symptom of patients with VS.\(^ {8}\) Cushing also describes the inability of studying this pathology at an early stage due to the lack of diagnostic equipment available. He explained, “by the time they have come under observation the [tumor]
growth had enlarged sufficiently to deform the cerebellum.\textsuperscript{8} The size of the tumor at this late stage ultimately led to death through the brainstem compression that reduced the respiratory drive.\textsuperscript{8} This late-stage clinical presentation has become less prevalent with technological advances in diagnostic equipment over the past four decades.\textsuperscript{40}

The majority of patients with VS today present with [ASNHL]\textsuperscript{29} despite the origin of neoplasm on the vestibular portion of CN VIII.\textsuperscript{34,36} This may seem paradoxical as the vestibular portion of CN VIII carries balance information;\textsuperscript{11} however, the lack of balance disturbance is explained by the tumor’s slow growth. The theory is that the gradual growth of VS within the intracanalicular space allows the contralateral vestibular apparatus and central nervous system to compensate for the diminishing input of vestibular information from the affected ear.\textsuperscript{40} Moreover, the fibers that carry the high frequency signal are located near the surface of the cochlear nerve.\textsuperscript{41} Due to the proximity of the vestibular and cochlear nerves, the tumor growth on the vestibular nerve sheath interrupts these signals by mass effect and creates a progressive ASNHL often at the middle to high frequencies.\textsuperscript{42}

\textit{Age and Incidence of Vestibular Schwannoma}

The mean age range for sporadic unilateral VS diagnosis is 53–58\textsuperscript{43,44} years, while those with autosomal dominant neurofibromatosis type 2 [NF2] often present with bilateral VSs in childhood.\textsuperscript{45} The remainder of this article will focus on VS in its unilateral and sporadic form. The incidence of VS has been steadily increasing from 3.4 per million in 1976\textsuperscript{46} to 11–19 per million in 2008.\textsuperscript{43,46} The increasing incidence is explained by the steady improvement of imaging modalities that have shifted practice
from the acoustic brainstem response [ABR] and computed tomography [CT], which were popular in the 1970s, to magnetic resonance imaging [MRI] with gadolinium-enhancement, which in the late 1980s became the gold standard for diagnosing vestibular schwannomas. Unsurprisingly, as the imaging modalities have improved, the average tumor size at diagnosis has been steadily declining with a Danish longitudinal study reporting an average tumor size of 30mm in 1979 compared with 10mm in 2008.

Diagnostic Modalities

The ability to diagnose VS at an early stage underwent a series of transformations beginning with the development of the acoustic brainstem response [ABR] introduced in 1970 by Jewett et al. This non-invasive exam uses scalp electrodes and a click-stimulus administered in the external auditory canal to track the evoked electrical potentials along the auditory nerve fibers from CN VIII as they leave the cochlea and travel to the brain. The recorded pathway is visualized as five waveforms, each with anatomical correlates as seen in Figure 4. An interruption of the evoked signal at any point along the pathway would result in a latency in the most prominent wave V when compared with the contralateral waveform. In 1977, Selters compared the evoked potentials from each ear using the most prominent wave V in patients with VS and found an interaural latency in wave V above 0.4 milliseconds was able to identify VS with 94% sensitivity. Increased sensitivity was achieved through lowering the threshold of an abnormal result to an interaural latency of >0.2 milliseconds; however, this was achieved at the cost of a high rate of false positives.
Figure 4. The ABR and Anatomical Correlates
The ABR (upper-left) shows the prominent waveforms I-V (waves VI and VII are often indistinguishable in clinical practice). The click-stimulus (lower-left) is administered into the external auditory canal crossed the conductive portion of the ear and reaches the cochlea, where the organ of Corti generated action potentials that are sent to the brain. The anatomical correlates to the ABR waveforms (Right): Wave I: Distal portion of CN VIII; Wave II: Proximal portion of CN VIII; Wave III: Cochlear nucleus; Wave IV: Superior olivary complex; Wave V: Lateral lemniscus or inferior colliculus \(^{54}\) (Figure taken from Vogel and Arias, 2015) \(^{57}\)

In the 1970s physicians also used CT scans with air cisternography or carbon dioxide cisternography to rule out CPA tumors; however, tumors less than 15mm were often missed or unreliably diagnosed in the form of false-positives. \(^{18,58,59}\) As the 1980s progressed, the availability of the MRI increased, and was shown to be a more effective imaging modality than the CT scan in ruling out VS. \(^{18,39,60}\) However, the ABR remained a common diagnostic procedure into the early 1990s. \(^{18}\)
In the late 1980s, MRI with gadolinium enhancement became the new gold standard for the diagnosing of vestibular schwannomas. This technique has the ability to detect tumors as small as 4mm without false positive results and thus, it was used as a control to measure the ability of the ABR exam to detect VS. In a prospective study, Gordon et al. described a 100% sensitivity for ABR to diagnose VS in tumors >2cm in diameter and a 69% sensitivity to detect tumors <1cm. Similar proportional decrease in sensitivity with decreasing tumor size was found in several other studies comparing ABR to MRI in the 1990s and into the twenty-first century.

Despite the high sensitivity of ABR in detecting VS >2cm in diameter being further corroborated in more recent studies, the majority of clinicians no longer utilize ABR to rule out VS. The primary reason for this change is the 100% sensitivity and the almost 0% false positive of MRI for tumors as small as 4mm. In addition, a Danish study analyzing 2200 VS patients over the last four decades has shown a decreasing trend in tumor size at diagnosis to below 20mm and thus, out of the most sensitive range for detection using ABR.

Asymmetric Sensorineural Hearing Loss

As previously mentioned, ASNHL is the most common presenting symptom in individuals with diagnosed VS, and the MRI with gadolinium enhancement is the most sensitive imaging modality for detecting these tumors. However, there is little agreement in the literature regarding what threshold of asymmetry constitutes the diagnosis of ASNHL. Saliba et al. report variability in the reported definition of ASNHL, which can be seen in Table 1.
Table 1. Variability in the reported definition of ASNHL$^{18,42,69-72}$

<table>
<thead>
<tr>
<th>Asymmetries</th>
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<td>$\geq 15$ dB at 3,000 Hz (Rule 3,000)</td>
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</tr>
<tr>
<td>$\geq 20$ dB at any single frequency between 0.5 and 4 kHz</td>
<td>Department of Health</td>
</tr>
<tr>
<td>$\geq 20$ dB at two neighboring frequencies</td>
<td>Sunderland</td>
</tr>
<tr>
<td>$\geq 15$ dB between the average of 0.5, 1, 2 and 3 kHz</td>
<td>AAO-HNS</td>
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<td>$\geq 15$ dB between the average of 0.5 and 8 kHz</td>
<td>Oxford</td>
</tr>
<tr>
<td>$\geq 15$ dB between the average of 1 and 8 kHz</td>
<td>Seattle</td>
</tr>
<tr>
<td>$\geq 15$ dB at any single frequency between 0.5 and 4 kHz</td>
<td>Nashville</td>
</tr>
<tr>
<td>$\geq 10$ dB at two or more frequencies; OR $\geq 15$ dB at any single frequency</td>
<td>AMCLASS</td>
</tr>
<tr>
<td>$\geq 15$ dB at two or more frequencies; OR $\geq 15%$ difference between speech discrimination</td>
<td>Cueva</td>
</tr>
</tbody>
</table>

AAO-HNS: American Academy of Otolaryngology Head and Neck Surgery
AMCLASS: Audiogram Classification system
OR: Odds Ratio
SNHL: Sensorineural hearing loss

(Table Amended from Saliba et al., 2011$^{73}$)

Summary

In the current era of health care reform and defensive medicine, ordering MRI
scans to rule out VS in patients with ASNHL remains common despite the low yield of
abnormalities on these expensive imaging studies.$^{30}$ This fact has inspired many studies
to evaluate the burden of investigating patients with ASNHL.$^{62,67,74-77}$ The impetus to
reduce the number of MRI scans to rule out VS due to the low yield is countered by a lack of consensus in the literature regarding the degree of ASNHL, if any, that is predictive for VS diagnosis. Therefore, this study aims to address this issue by conducting a systematic review of the current literature involving patients with ASNHL who have had an MRI scan with the hope of establishing the predictive value of ASNHL for VS.
SPECIFIC AIMS

The objective of this study is to determine the diagnostic yield of MRI scans used in patients with ASNHL to rule out vestibular schwannoma. Specifically,

1. Data regarding patients with ASNHL who have undergone MRI will be gathered via a systematic review of the current literature. Patients with ASNHL who were evaluated on MRI with and without VS diagnosis will be included in the analysis.

2. Data regarding the degree of difference in interaural hearing loss in patients with ASNHL who underwent MRI scan with and without the diagnosis of vestibular schwannoma will be examined.

3. Statistical analysis regarding the predictive yield of ASNHL for VS diagnosis on MRI scan as well as the association, if any, between the degree of ASNHL and VS will be determined.

These studies will demonstrate the diagnostic yield of ASNHL for VS diagnosis on MRI as well as determine the risk, if any, between the degree of asymmetry in ASHNL and VS diagnosis. We hope this study will shed light on the low overall predictive value of ASNHL for VS.
METHODS

Search Strategy

A systematic review of published articles using an electronic keyword search in the PubMed Database was conducted. Five separate keyword searches were performed using the following search terms in October 2014:

- “Asymmetric sensorineural hearing loss”
- “Asymmetrical sensorineural hearing loss and MRI”
- “Asymmetric hearing loss and acoustic neuroma”
- “Asymmetric hearing loss and vestibular schwannoma”
- “Asymmetric hearing loss and MRI”

An additional strategy used to ensure that we gathered all available data involved the examination of references used in the publications that were relevant to our final analysis. These two search methods yielded a total of 695 articles. We initially excluded 353 articles because their study population did not include patients with asymmetric sensorineural hearing loss. A summary of this comprehensive, systematic review is organized into a flowchart as seen in Figure 5.
Rationale for Exclusion

We further applied our exclusion criteria by eliminating review articles and case reports were excluded due to their lack of original patient data and anecdotal nature respectively. Articles that reported data on ASNHL patients who were evaluated for VS with diagnostic modalities other than MRI were excluded in the, “Wrong diagnostic test,” cohort. Solely pediatric studies were largely thought to contain information regarding patients with NF2 and not unilateral sporadic VS and therefore were excluded. When two publications performed the same analysis on an overlapping patient population, the older article was excluded from the final analysis. Our final refinement of the publications.
excluded articles that did not clearly separate the number of patients with progressive ASNHL versus sudden ASNHL and without a clear definition of the term, “sudden.”

**Recorded Variables**

The data extraction from each of these articles included: demographic data regarding the population studied, definition of ASNHL used to select patients in study population, and number and results of MRI scans for ASNHL. In addition, information regarding the degree of asymmetry in VS patients was grouped when available.

**Statistical Analysis**

The diagnostic yield of VS on MRI scans for patients with ASNHL was assessed by comparing the number of MRI scans performed versus the number of positive scans. The MRI scans that were positive for VS were then stratified into four groups:

- **Group A** included studies that evaluated patients with interaural asymmetry in hearing of 10 dB or more
- **Group B** contained patients who received an MRI due to an interaural difference of 15dB at two frequencies *or* 20dB at one frequency
- **Group C** underwent a MRI scan due to an interaural asymmetry of 20dB or greater
- **Group D** contained patients who had an MRI scan to rule out vestibular schwannoma if their interaural asymmetry was 30dB or greater

The variables chosen for this stratification are based on the definitions of ASNHL within the papers that were analyzed. Those articles without definitions of ASNHL were not
included in the stratified analysis.

Using the pooled data, an odds ratio was calculated between the four groups. We classified the dependent variable as the outcome of the MRI scan and the independent variable as the definition ASNHL used as inclusion criteria for the MRI scan. This allowed us to assess the odds of having a positive scan based on the screening method in one group versus another. If two groups being compared had an odds ratio that included the integer value of 1.0 within the 95% Confidence Interval then these two groups were deemed to have a statistically insignificant difference.

In addition to an odds ratio, we also examined these four groups using a chi-squared trend analysis, which allowed us to better understand the association between the degree of asymmetry and positive MRI scans for vestibular schwannoma.
RESULTS

The search strategy outlined in Figure 5 resulted in fourteen studies that met our search criteria and were included in our analysis. Table 2 highlights these fourteen articles and the data extracted from them, which included: the definition of ASNHL used in each study, the number of MRI scans performed for ASNHL, and the number of positive scans for VS. Demographic data was scarce, but pooling available data showed a varied cohort of 48% males and 52% females who had an age range of 15-70 years.

Table 2. Articles Included in Meta-Analysis

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Title</th>
<th>Definition of ASNHL</th>
<th>MRI Scans</th>
<th>+ VS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suzuki et al.(^79)</td>
<td>Prevalence of Acoustic Neuroma Associated With Each Configuration of Pure Tone Audiogram in Patients With Asymmetric Sensorineural Hearing Loss</td>
<td>≥15dB at any frequency (500Hz - 4,000Hz) AND left and right air conductance do not intersect within this range</td>
<td>500</td>
<td>13</td>
</tr>
<tr>
<td>Urben et al.(^80)</td>
<td>Asymmetric Sensorineural Hearing Loss in a Community-Based Population</td>
<td>≥10dB at two frequencies OR ≥15dB at 1 frequency</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>Saliba et al.(^73)</td>
<td>Rule 3,000: a more reliable precursor to perceive vestibular schwannoma on MRI in screened asymmetric sensorineural hearing loss.</td>
<td>≥10dB at one or more frequencies OR ≥15% asymmetry in WRS</td>
<td>212</td>
<td>84</td>
</tr>
<tr>
<td>Obholzer et al.(^51) (2004)</td>
<td>Magnetic Resonance Imaging Screening for Vestibular Schwannoma: Analysis of Published Protocols</td>
<td>≥15dB with the better hearing ear mean PTA ≤30 dB OR ≥ 20dB with better hearing ear mean PTA &gt;30 dB</td>
<td>392</td>
<td>32</td>
</tr>
<tr>
<td>Authors</td>
<td>Study Title</td>
<td>Criteria</td>
<td>Patients</td>
<td>Other</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td>----------</td>
<td>-------</td>
</tr>
<tr>
<td>Newton et al. 81</td>
<td>Magnetic Resonance Imaging Screening in Acoustic Neuroma</td>
<td>≥15 dB average over all frequencies OR ≥15 dB at two adjacent frequencies in unilateral hearing loss OR ≥20 dB in bilateral asymmetric hearing loss</td>
<td>132</td>
<td>2</td>
</tr>
<tr>
<td>Dawes and Jeannon, 69</td>
<td>Audit of Regional Screening Guidelines for Vestibular Schwannoma</td>
<td>≥20 dB or greater at two adjacent frequencies.</td>
<td>195</td>
<td>10</td>
</tr>
<tr>
<td>Wilson et al. 82</td>
<td>Cost Analysis of Asymmetric Sensorineural Hearing Loss Investigations</td>
<td>≥30 dB over three contiguous frequencies</td>
<td>137</td>
<td>1</td>
</tr>
<tr>
<td>Mahrous et al. 83</td>
<td>Positive findings on MRI in patients with asymmetrical SNHL</td>
<td>Not written</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>Baker et al. 84</td>
<td>Should patients with asymmetrical noise-induced hearing loss be screened for vestibular schwannomas?</td>
<td>Not written</td>
<td>304</td>
<td>6</td>
</tr>
<tr>
<td>Kwan et al. 85</td>
<td>Screening for Vestibular Schwannoma by Magnetic Resonance Imaging: Analysis of 1821 Patients</td>
<td>Not written</td>
<td>1,821</td>
<td>54</td>
</tr>
<tr>
<td>Ravi and Wells 86</td>
<td>A cost effective screening protocol for vestibular schwannoma in the late 90s</td>
<td>Not written</td>
<td>89</td>
<td>2</td>
</tr>
<tr>
<td>Carrier and Arriaga 74</td>
<td>Cost-effective evaluation of asymmetric sensorineural hearing loss with focused magnetic resonance imaging</td>
<td>Not written</td>
<td>485</td>
<td>7</td>
</tr>
<tr>
<td>Daniels et al. 87</td>
<td>Causes of Unilateral Sensorineural Hearing Loss Screened by High-Resolution Fast Spin Echo Magnetic Resonance Imaging: Review of 1,070 Consecutive Cases</td>
<td>Not written</td>
<td>1,070</td>
<td>56</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>5,783</strong></td>
<td><strong>296</strong></td>
</tr>
</tbody>
</table>

+VS: Positive MRI scans for vestibular schwannoma

 dB: decibels

 PTA: Pure Tone Average

 WRS: Word Recognition Score
Overall, we were able to gather 5,783 MRI scans performed to rule out vestibular schwannoma due to the presence of ASNHL. 296 MRI scans were positive for VS, which represents a diagnostic yield of 5.1% (Table 3).

Table 3. Diagnostic Yield of MRI Scans for ASNHL

<table>
<thead>
<tr>
<th>Total MRI Scans</th>
<th>+VS</th>
<th>% Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,783</td>
<td>296</td>
<td>5.1</td>
</tr>
</tbody>
</table>

+VS: Positive MRI scans for vestibular schwannoma

Eight of the fourteen studies included in our final analysis contained the definition of ASNHL that was used to include patients in the study. By stratifying these articles into Groups (A-D) based on their minimum level of interaural asymmetry, we were able to calculate the diagnostic yield of investigating different levels of ASNHL. The stratified groups, the associated minimal level of interaural hearing loss criteria, and diagnostic yield is of each is summarized in Table 4.

Table 4. Degree of ASNHL and Diagnostic Yield of MRI Scans

<table>
<thead>
<tr>
<th>Group</th>
<th>Interaural Asymmetry</th>
<th>MRI Scans</th>
<th>+VS</th>
<th>% Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td>10+ dB</td>
<td>1,058</td>
<td>125</td>
<td>11.2</td>
</tr>
<tr>
<td>Group B</td>
<td>15+ dB at ≥2 Frequencies or 20+ dB at 1 Frequency</td>
<td>524</td>
<td>34</td>
<td>6.5</td>
</tr>
<tr>
<td>Group C</td>
<td>20+ dB</td>
<td>195</td>
<td>10</td>
<td>5.1</td>
</tr>
<tr>
<td>Group D</td>
<td>30+ dB</td>
<td>137</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1,914</td>
<td>170</td>
<td></td>
</tr>
</tbody>
</table>

+VS: Positive MRI scans for vestibular schwannoma
Group A included studies that used a 10+ dB difference in interaural hearing loss to include patients for further investigation. 11.2% of the 1,058 MRIs performed for this level of ASNHL were positive for VS. Group B pooled data from studies that used a combination of either 15+ dB difference at two or more adjacent frequencies or 20+ dB difference at any of the test frequencies. 524 MRIs were completed in Group B and 6.5% of those were positive for VS. Group C studies used a 20+ dB difference and had 5.1% of their 195 MRIs positive for VS. Finally, Group D included studies with the strict criteria of including subjects with a 30+ dB of interaural hearing, and 0.7% of the 137 subjects were positive for VS.

The odds ratio of Group A versus Group B was 1.93 (95% CI 1.30 – 2.86), Group A versus Group C was 2.48 (95% CI 1.28 – 4.81), and Group A versus Group D was 18.22 (95% CI 2.53 – 131). Therefore, Group A showed statistically significant odds of vestibular schwannoma on MRI when compared with any other Group. The odds ratio between Group B and Group D was 9.44 (95% CI 1.28 – 69.57) and thus an individual in Group B showed a 9-fold increase in odds of VS on MRI scan than a member of Group D. Those groupings with an odds ratio that contained the integer 1.0 between in their confidence interval were deemed to have an insignificant difference in odds. Those grouping and odds ratios were as follows: Group B versus Group C with odds ratio of 1.28 (95% CI 0.62 – 2.65); Group C versus Group D had an odds ratio of 7.35 (95% CI 0.93 – 58.12). The odds ratios between stratified groups are shown below in Table 5.
Table 5. Odds Ratios between Stratified Groups

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Odds Ratio</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A vs. Group B</td>
<td>1.93</td>
<td>1.3 – 2.86</td>
</tr>
<tr>
<td>Group A vs. Group C</td>
<td>2.48</td>
<td>1.28 – 4.81</td>
</tr>
<tr>
<td>Group A vs. Group D</td>
<td>18.22</td>
<td>2.53 – 131</td>
</tr>
<tr>
<td>Group B vs. Group C</td>
<td>1.22</td>
<td>0.62 – 2.65</td>
</tr>
<tr>
<td>Group B vs. Group D</td>
<td>9.44</td>
<td>1.28 – 69.57</td>
</tr>
<tr>
<td>Group C vs. Group D</td>
<td>7.35</td>
<td>0.93 – 58.12</td>
</tr>
</tbody>
</table>

The overall odds ratios above show that investigating individuals with a lower degree of asymmetry in hearing loss results in greater odds of positive VS on MRI scan. Therefore, our study does not support a positive correlation between VS diagnosis on MRI and the degree of ASNHL.
DISCUSSION

By compiling data from fourteen studies, this meta-analysis of 5,783 MRI scans for ASNHL to rule out VS is the largest of its kind. The number of patients with ASNHL who were evaluated with MRI was high, while the number of patients with MRI scans positive for VS was low. The overall diagnostic yield of 5.1% of MRI scans is consistent with previous studies investigating this topic. The range of positive VS diagnosis on MRI in the fourteen articles we analyzed ranged from Wilson et al. at 0.7% to Saliba et al. at 39%. Wilson et al. arguably had the strictest criteria of ASNHL as they only included patients with an interaural difference in hearing loss of 30dB or greater over three contiguous frequencies. By contrast, Saliba et al. who included patients with an interaural asymmetry of 10dB at one or more frequencies was arguably the least restrictive criteria for ASNHL. It must also be noted that Saliba et al. mention in their methods that they received an undisclosed portion of their data from a, “referred tertiary care center,” and thus, they likely had a high proportion of patients that were suspicious for VS within their cohort. In fact, the second highest rate of VS diagnosis on MRI in patients with ASNHL came from Urben et al. at 11.7%. Urben and colleagues also had a lenient threshold for asymmetry requiring interaural difference of 10dB or greater at 2 frequencies or greater than 15dB at one frequency. Studies with reduced thresholds of asymmetry in ASNHL that yielded a relatively higher number of VS patients are consistent with the results from our stratified sample.

The odds ratios between the stratified Groups support the findings that a lower degree of interaural asymmetry does not correlate odds of VS diagnosis on MRI scan.
Group A subjects had the smallest amount of interaural difference in hearing loss, and had 18-fold greater odds being diagnosed with VS compared with those who were in Group D (30+ dB interaural difference). Although the 30+ dB hearing group was made up of 137 subjects from one study, Wilson et al.\textsuperscript{82} this cohort was thought to be large enough to provide an adequate basis for comparison. Moreover, the odds ratio findings are consistent with epidemiological trends, which show the improvement of hearing in patients diagnosed with VS over the past three decades.

From 1976 to 2008, the percentage of individuals with PTA better than 30dB at the time of diagnosis increased from 9% to 23% at the time of VS diagnosis.\textsuperscript{35} Other recent studies offer more support, suggesting that more than half of VS patients are considered to have good hearing at diagnosis.\textsuperscript{35,\textasciitilde{}88,\textasciitilde{}93} These trends are consistent with our stratification findings from the eight articles with available definitions of ASNHL (Table 3). Our results showed increased odds of VS diagnosis when the definition of ASNHL for subjects to be assessed with MRI was a relatively lower degree of asymmetry in interaural hearing loss. On the other hand, this finding is surprising as articles analyzing patients with VS describe hearing deterioration in the affected ear regardless of the tumor’s growth, stasis, or shrinkage.\textsuperscript{89,\textasciitilde{}94} Thus, one would assume that patients with previously undiagnosed VS will have worsening asymmetry; however, our data does not support this. Unilateral hearing loss is the most common presenting symptom in patients with VS, but it is also common in non-VS patients. Therefore, ASNHL on an audiogram alone should be coupled with other factors when determining the potential suspicion of vestibular schwannoma.\textsuperscript{35}
This study provides evidence that a lower degree of asymmetry in ASNHL had a higher diagnostic yield (11.2%) than the mean yield (5.1%); however, 11.2% of all MRI scans for ASNHL to rule out VS remains extremely low. Therefore, our results provide evidence that screening patients for MRI scans using ASNHL is insufficient for diagnosis and is an inefficient use of valuable resources. As previously mentioned, a 2011 survey of neurotologists found that 94% of respondents always or frequently ordered MRIs in patients with ASNHL with 40% citing medicolegal concerns as one of the motivating factors for their decision.\(^3\) While MRI is clearly the gold standard in ruling out vestibular schwannoma, clinicians have an ethical responsibility to prevent undue burden on their patients and the healthcare system by ordering unnecessary MRIs. Therefore, providers have an obligation to understand other factors when considering an MRI scan. Below, we consider additional elements of a patient’s profile that may increase a clinician’s suspicion for VS.

Additional Factors for VS Suspicion

An additional factor that may make clinicians more or less suspicious of a vestibular schwannoma is a patient’s age. Over three decades, a Danish group has reported a steady increase in age at the time of VS diagnosis from age 49 in 1976 to 58 in 2011.\(^5,35,95\) Furthermore, the proportion of patients in the 60–70 year age group has grown from 15% to 29% over those three decades while the proportion of those 70 years and older has also grown to a lesser extent.\(^35,46\)

While age is an important factor for the clinician to consider, the presence, laterality, and character of tinnitus is another important variable. Like hearing loss,
tinnitus is a widespread problem, affecting 50 million individuals in the United States. According to some estimates, as many as 95% of patients with vestibular schwannoma will have tinnitus ipsilateral to their worse hearing ear. However, only 1–2% of ASNHL patients presenting with or without tinnitus in their worse hearing ear will be diagnosed with VS. Therefore, in addition to the ipsilateral nature of the tinnitus, the clinician must also assess character of the tinnitus. Retrospective studies evaluating tinnitus in patients with vestibular schwannoma have found it to be predominantly high-pitched and persistent over a period of greater than six months. Therefore, there should be increased suspicion for VS when asymmetrical hearing loss is coupled with high-pitched, ipsilateral tinnitus. Another interesting reason for the importance of tinnitus, as a presenting characteristic of VS, is the association between tinnitus at diagnosis and tumor growth. Agrawal et al. analyzed 180 patients with VS and found tinnitus at the time of diagnosis to increase the odds of tumor growth three-fold when growth was defined as ≥1mm/year.

An additional factor that should be considered is the word recognition score [WRS]. Many articles have reported the association of a WRS that is worse than expected compared to the PTA hearing loss in patients with VS. The previously mentioned phenomenon known as, “Rollover,” where a patient’s WRS decreases with increased intensity [dB], has been a frequently cited component of a VS patient’s presentation. Because WRS is a part of the formal audiological assessment, this score should be a part of neurotologists’ clinical evaluation for suspicion of VS prior to MRI. After diagnosis with VS, the WRS can also be helpful in determining treatment
options. A recent study has shown the WRS at diagnosis to be predictive in hearing preservation in a study of 932 patients with VS who were treated with observation.\textsuperscript{95} Figure 6 shows the average \%WRS (y-axis) over a period of observation (x-axis) for individuals with different speech discrimination [SD] at presentation.

WRS: Word Recognition Score  
SD: Speech Discrimination

\begin{figure}[h]  
\centering  
\includegraphics[width=0.8\textwidth]{figure6.png}  
\caption{SD at Diagnosis Predictive for Long-Term Hearing}  
This figure shows that preservation of word recognition score is a function of speech discrimination at diagnosis.  
(Figure Taken from Stangerup et al., 2010)\textsuperscript{95}
\end{figure}

Asymmetric sensorineural hearing loss in VS patients normally occurs progressively over a period of months to years. However, 2.7\%–10.2\% of patients with VS will present with sudden onset (hours - days) of ASNHL.\textsuperscript{101-106} While sudden ASNHL
is not common in VS patients, current American Academy of Head and Neck Surgery guidelines recommend that sudden hearing loss with an asymmetry of $\geq 10$ dB at two or more frequencies or a 10% decrease in WRS warrants further evaluation of retrocochlear pathology. Because sudden onset of ASNHL is rare in VS patients, we did not include MRI scans analyzing patients with this symptom in our analysis. These studies were excluded due to the varied definition of the term, “sudden,” which consisted of hours, days, and weeks. Although rare, when a patient’s sudden onset of ASNHL is followed by a progressive asymmetric hearing loss or a worsening asymmetric WRS, this patient should be evaluated to rule out retrocochlear pathology.

Although VS usually presents on the vestibular nerve, vestibular symptoms like dizziness and disequilibrium do not occur with the same frequency as ASNHL. However, several studies have reported a high proportion of VS patients have at least one episode of disequilibrium in their history. Thus, positive history of dizziness or disequilibrium should also increase a clinicians’ suspicion for VS.

Finally, there is currently a controversy in the literature regarding the association of noise exposure and vestibular schwannoma. One of the articles included in this analysis, Baker et al., analyzed a cohort of military personnel with noise-induced ASNHL and compared them against a civilian population. Interestingly, they found that 152 MRI scans for ASNHL in the noise–exposed military cohort contained 4 positive scans for VS while 152 MRI scans of civilian cohort without noise-induced ASNHL contained 2 positive scans. These results accurately reflect the current debate in the literature regarding the association of noise exposure and VS. In 2006, Edwards et al.
analyzed 146 patients with VS and 564 controls and found significantly increased odds of a history of any noise exposure in VS patients. While in 2014, Fisher et al. analyzed 451 VS patients with 710 matched controls and found an association between VS and noise exposure during leisure activities, but no association between VS and occupational noise exposure. Although there is certainly a legitimate argument regarding recall bias in the VS population in these studies, the variable outcomes in the current literature make this factor’s association with VS nonspecific. Therefore, if a patient with ASNHL has a history of noise exposure, a clinician can not immediately rule out VS.

Although ASNHL is the most common symptom in patients presenting with VS, this asymmetry must be considered within the context of the patients’ overall presentation. Other symptoms and factors like: tinnitus, WRS, timing of onset, dizziness, and a history of noise exposure, should be evaluated prior to ordering an MRI scan. Other important factors in addition to ASNHL are summarized in Table 6.

**Table 6. Information that can influence level of suspicion for diagnosis of VS**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Increases Suspicion</th>
<th>Decreases Suspicion</th>
<th>Other Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient Age</td>
<td>Age 30-70 years*</td>
<td>Age greater &gt;70 years*</td>
<td></td>
</tr>
<tr>
<td>Tinnitus Laterality and Character</td>
<td>Ipsilateral to the worse hearing ear + High pitch, Persistent ≥ 6 months*</td>
<td>Bilateral or contralateral to the worse hearing ear + Medium or low pitch, intermittent, pulsatile</td>
<td></td>
</tr>
<tr>
<td>Word Recognition Score</td>
<td>Worse than expected in comparison to PTA and SRT*</td>
<td>Congruent with PTA and SRT*</td>
<td>Recent literature suggests improved PTA and WRS at VS diagnosis; however, the incongruity between the two remains</td>
</tr>
</tbody>
</table>
### Table

<table>
<thead>
<tr>
<th>Timing of onset of ASNHL</th>
<th>Sudden onset followed by progressive hearing loss of $\geq 10$ dB at 2 or more frequencies or $\geq 10%$ reduction in WRS$^{107}$</th>
<th>Rapid onset then return of normal hearing</th>
<th>2.7% to 10.2% VS patients present with sudden hearing loss$^{79,101,102,104-106}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dizziness, disequilibrium</td>
<td>Positive history and abnormal vestibular testing$^{7,108,109}$</td>
<td>No complaints and No abnormality with vestibular testing</td>
<td></td>
</tr>
<tr>
<td>History of noise exposure</td>
<td>No significant noise exposure</td>
<td>Significant noise exposure with recollection that noise was closest to the worse hearing ear</td>
<td>Positive and negative correlations between a history of noise exposure and VS have been reported$^{110-113,117}$</td>
</tr>
</tbody>
</table>

PTA: Pure Tone Average  
SRT: Speech Reception Threshold  
WRS: Word Recognition Score

* Table prepared in collaboration with Dr. Kenneth M. Grundfast, Professor and Chairman, Department of Otolaryngology, Boston Medical Center, Boston, MA
Study Limitations

The primary limitation of this study is the lack of primary data, which is an inherent characteristic of any meta-analysis. Our data was collected to assess our primary outcome in discovering the diagnostic yield of VS using MRI scans to evaluate patients with asymmetric sensorineural hearing loss. However, 43% (6 of 14) did not contain the definition of ASNHL the investigators used to include subject within their trial. Although there is no consensus in the literature regarding ASNHL, the paucity of this criterion within these six articles did not allow for stratification of all 296 positive MRI scans. In addition, three articles that were to be included in our analysis did not adequately differentiate the subjects with sudden ASNHL from those with progressive ASNHL. Therefore, these studies were not included in our analysis.

Another area of interest that we were not able to investigate due to a lack of data was the lack of data regarding the degree of asymmetry in each VS patient at the time of diagnosis. With our stratification groups, we were able to assume that we were capturing broad degree of asymmetry with more lenient inclusion criteria and vice-a-versa; however, there was not enough information regarding the actual interaural asymmetry of VS patients for an analysis. Therefore, we can only comment on the ASNHL used in the criteria for screening with MRI rather than the ASNHL of individual patients.

An additional limitation is the lack of demographic data we were able to include in our analysis. Although we assumed that our subjects would be between the third and seventh decades of life, many articles did not present data regarding patient age. This
variable would have been especially interesting to compare with Stangerup et al. as they report an average age of 58 years in their data set.\textsuperscript{35}
Conclusion
Our analysis of 5,783 MRI scans showed a 5.1% mean positive yield of vestibular schwannoma diagnosis in patients being evaluated due to their asymmetric sensorineural hearing loss. We also show that increased interaural asymmetry does not increase the odds of vestibular schwannoma diagnosis. We hope these findings will provide evidence that asymmetric sensorineural hearing loss should not be the only factor considered when determining whether a patient should have a MRI scan to rule out vestibular schwannoma.
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Boston University School of Graduate Medical Sciences
M.S. in Medical Science Candidate, Class of 2015

Undergraduate
09/2007 - 05/2011
University of Rochester
B.A. Biology, Health and Society – Distinction

TEACHING EXPERIENCE:

Tutor, Human Physiology, Boston University School of Medicine, Boston, MA 09/2014 - Present

Tutor, Biochemistry, Boston University School of Medicine, Boston, MA 09/2014 - Present

Tutor, Science Buddies, Rochester, NY 09/2010 - 05/2011

Workshop Leader, Principles of Biology, University of Rochester 2008 - 2010


PROFESSIONAL MEMBERSHIPS

Outcomes Research Consortium 2009 - Present

The American Society of Anesthesiologists 2010 - 2013

RESEARCH EXPERIENCE:

09/2014 – Present
Master’s Thesis, Department of Otolaryngology, Boston Medical Center, Boston, MA
Mentor: Kenneth Grundfast, MD; Anand Devaiah, MD
Description: Asymmetric hearing loss stratification and vestibular schwannoma risk: a meta-analysis
Research Coordinator, Department of Outcomes Research, Cleveland Clinic Foundation, Cleveland, OH
Mentor: Daniel I. Sessler, MD
Outcomes Research Mentors: Andrea Kurz, MD, Alparslan Turan, MD, and Brian Hesler, MD
Description: Multiple prospective and retrospective projects. Briefly, these include:

Data acquisition, analysis, and manuscript preparation for a registry analysis of intraoperative allergic reactions. Published in Anesthesiology

Patient recruitment, data acquisition for ENIGMA-II, a prospective randomized controlled trial analyzing effects of intraoperative nitrous oxide on post-operative cardiac morbidity. Published in The Lancet

Patient recruitment, data acquisition for VISION, an observational trial in non-cardiac surgical patients analyzing post-operative hemodynamic changes and myocardial events. Published in Anesthesiology

12/2010 - 5/2011
Undergraduate Biochemistry Independent Study, Department of Biochemistry, University of Rochester, Rochester, NY
Mentor: Anthony Olek, PhD
Description: Design, data acquisition, pre-lab, post-lab, and quiz preparation for students to assess the antioxidant efficacy of biological materials.

6/2010 - 8/2010
Student Research, Department of Outcomes Research, Cleveland Clinic, Cleveland, OH
Mentor: Daniel I Sessler, MD
Description: Design, data acquisition, analysis and manuscript preparation of a randomized controlled trial investigating underbody warming mattress versus forced air warming during open abdominal surgery; published in Anesthesia & Analgesia

Student Research: Department of Anesthesia, University College of London Hospital, London, UK
Mentor: Robert Stephens, MD
Description: Design and implementation of an anesthesiologist interview project for medical student information about a career in anesthesia (http://www.ucl.ac.uk/anaesthesia/careers)
Recruited and interviewed patients about their experience with anesthesia as part of the Patient Information Project (http://www.ucl.ac.uk/anaesthesia/patients/experiences)
Supervised data collection at UCLH for UK-wide audit on prediction of post-operative morbidity

Student Research, Department of Outcomes Research, Cleveland Clinic, Cleveland, OH
Mentor: John Doyle, MD
Description: Design, data acquisition, analysis and manuscript preparation of a randomized controlled trial comparing GlideScope versus fiberoptic scope for elective intubation in obese patients; Published in the British Journal of Anaesthesia
PUBLICATIONS:

**Peer-Reviewed Articles**


**Supplemental Authorship**
