Cross-Sectional Vestibular Nerve Analysis in Vestibular Neuritis

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Objectives: We examined the association between the size and cross-sectional area of the superior vestibular nerve as measured on constructive interference in steady-state (CISS) parasagittal magnetic resonance imaging (MRI) and the vestibular nerve function as measured by electronystagmography.

Methods: The retrospective observational cohort study took place at an academic tertiary referral center. Twenty-six patients who met established clinical and electronystagmographic criteria for vestibular neuritis and who underwent parasagittal CISS MRI were identified. Two blinded investigators measured vestibular nerve height and width bilaterally at the level of the fundus of the internal auditory canal and calculated the cross-sectional nerve areas. The inter-rater reliability and agreement were analyzed. Symptom duration, age, and gender were also examined.

Results: A statistically significant decrease was observed in both vestibular nerve cross-sectional area and height as compared to the contralateral vestibular nerve. A non-statistically significant trend was observed for a relative decreased cross-sectional nerve area with increased age, as well as a decrease in nerve area with an increase in symptom duration.

Conclusions: Decreases in both vestibular nerve cross-sectional area and height are observed in patients with unilateral vestibular neuritis as measured on parasagittal CISS MRI.

Key Words: magnetic resonance imaging, vestibular nerve, vestibular neuritis.

INTRODUCTION

Vestibular neuritis is a common cause of peripheral vestibular vertigo. Patients typically present with the complaint of a single acute-onset attack of vertigo, associated with nausea and/or vomiting, postural instability, and horizontal nystagmus, that lasts approximately 7 to 10 days. The hearing is preserved, and the remainder of the neurologic examination findings are nonfocal. The symptoms improve spontaneously, although some patients retain residual disequilibrium. The majority of cases are of a single occurrence, but a small percentage of patients (fewer than 5%) will experience recurrent symptoms, a complex commonly referred to as benign recurrent vertigo.

The pathogenesis of vestibular neuritis is believed to be viral, immunologic, vascular, or idiopathic. The viral cause is thought to be most common, secondary to herpes virus, followed by varicella zoster or an unknown virus. The diagnosis is typically made by clinical history and physical examination in accordance with 4 established criteria for vestibular neuritis: 1) acute or subacute onset; 2) horizontal spontaneous nystagmus with a fast-phase component toward the unaffected ear; 3) hyporesponsive bithermal caloric test results in the affected ear (with greater than 25% asymmetry between the sides, as measured with Jongkees’s formula); and 4) perceived displacement of verticility with the eyes rotated toward the affected ear without vertical divergence of one eye above the other. The differential diagnosis of vertigo is quite large, but commonly includes vestibular neuritis, labyrinthitis, retrocochlear lesion, Meniere’s disease, migraine-associated vertigo, transient ischemic attack, and infarction or hemorrhage of either the inner ear or the brain stem.

Additional modalities such as audiometry, magnetic resonance imaging (MRI), and vestibular evoked myogenic potential testing may provide a useful adjunctive role in diagnosis. Magnetic resonance imaging of the internal auditory canal with gadolinium enhancement may assist in the assessment of potential retrocochlear lesions, brain stem hemorrhage or infarct, and nerve or cochlear inflammation. Occasionally, MRI may demonstrate vestibular nerve or labyrinthine enhancement. Parasagittal MRI has been demonstrated previously as a means to accurately and reliably measure structures within the internal auditory canal, specifically the cochlear nerve. Additional studies have utilized MRI to examine cochlear nerve size in deaf patients. We have found no reports of studies that utilized MRI to quantify vestibular nerve size.

Baloh et al described histologic findings to sug-
gest an inflammatory process within the vestibular ganglion, specifically, reduced synaptic density in the vestibular nucleus, hair cell loss, and epithelialization of the utricular maculae and semicircular canal cristae. In addition, a histologic temporal bone analysis by Gianoli et al.\(^\text{13}\) cited anatomic differences between the bony channels of the superior and inferior vestibular nerves.

Taking these histologic findings into consideration along with previous studies that utilized MRI to analyze cochlear nerve size, we aimed to measure vestibular nerve dimensions and cross-sectional area in patients with unilateral vestibular neuritis. We hypothesized a reduction in the cross-sectional area of the affected superior vestibular nerve in patients with unilateral vestibular neuritis as measured on parasagittal MRI.

MATERIALS AND METHODS

University of Miami Institutional Review Board approval was obtained. Current Procedural Terminology coding was used to identify patients who had undergone vestibular testing and bithermal caloric testing at the Miami Ear Institute between January 2007 and August 2010 for the complaint of vertigo. This patient data list was then narrowed to only those who also underwent high-resolution 3-dimensional (3-D) constructive interference steady-state (CISS) sequence parasagittal MRI of the internal auditory canals (IACs) at the University of Miami within 1 month of vestibular testing. The total number of patients was 68.

All patients included met the following inclusion criteria: 1) previously established clinical examination criteria for vestibular neuritis (acute or subacute vertigo, horizontal spontaneous nystagmus with a fast-phase rotational component toward the unaffected ear, and perceived displacement of verticity with the eyes rotated toward the affected ear without vertical divergence of one eye above the other);\(^\text{6,7}\) 2) a vestibular function analysis by electronystagmography (ENG; Balanceback Intuitive VNG, Kettering, Ohio) and bithermal caloric test results demonstrating asymmetric hyporesponsive caloric irrigation of the affected ear by at least 25%; 3) a duration of symptoms at the time of presentation of 2 months or longer; 4) parasagittal CISS MRI of the internal auditory canals (read by radiology personnel as within normal limits, with no evidence of enhancement or a lesion) within 1 month of vestibular testing; and 5) 18 years of age or greater. The total number of patients who met the above criteria was 26.

The exclusion criteria were 1) a retrocochlear lesion, infarct, or intracranial hemorrhage on MRI; 2) bilateral vestibulopathy on ENG; 3) a nerve unable to be adequately visualized on MRI for recording of complete measurements; 4) incomplete caloric data; 5) a reduced vestibular response (RVR) of less than 25%; 6) a previous history of vertigo (ie, diagnosis of Meniere’s disease or previous episode of vestibular neuritis); and 7) new or progressive auditory dysfunction demonstrated by audiograms to accompany vestibular symptoms.

Twenty-six patients met all criteria for further analysis. For each patient, one superior vestibular nerve was designated from ENG data as affected, and the contralateral, unaffected superior vestibular nerve was termed the internal control nerve. During database review, 7 patients were found to have unilateral acoustic neuroma on MRI and also to have undergone vestibular studies. The 7 patient MRIs with acoustic neuromas were utilized for their contralateral unaffected superior vestibular nerves to serve as an external control.

The MRI scans were performed on a Siemens Sonata scanner (Siemens AG, Munich, Germany) via an 8-channel head coil with a magnetic field strength of 1.5 T. Gradient echo T2 3-D (CISS) sequences were obtained and reconstructed to create a parasagittal plane perpendicular to the IAC. The time of repetition was 8.58 ms, the time of echo was 4.28 ms, and 2 averages were taken. The slice thickness was 0.7 mm, and 52 slices were obtained. The matrix size was 256 \(\times\) 256 pixels and was reconstructed to 512 \(\times\) 512 pixels. The field of view was 170 mm. Measurements were obtained on the Centricity Picture Archiving and Communication System (General Electric, Fairfield, Connecticut) with 0.1-mm electronic calipers.

Two independent blinded investigators measured both the superior-inferior and anterior-posterior dimensions of both the superior and inferior vestibular nerves at the level of the fundus of the IAC for 8 of the 26 MRI scans (Fig 1). Standardization of measurements at the level of the fundus was achieved as follows: after scrolling from medial to lateral, we identified the first MRI slice that possessed visible hyperintense cerebrospinal fluid (CSF) between the superior and inferior vestibular nerves, and measurements were then obtained from the next-most-lateral (0.7 mm) slice. An Altman plot was used to assess the inter-rater reliability and agreement with views of the region of the fundus. After reliability was determined, the original single blinded investigator measured the remaining 18 MRI slices.

The nerve cross-sectional area was then calculated from the measurement \([\frac{(H/2)(W/2)}{\pi}]\). Data
were imported into JMP version 8.0.1 software (SAS Institute Inc, Cary, North Carolina) for statistical analysis. Wilcoxon rank sums were utilized for correlation of the vestibular nerve area to the ENG caloric data. Other demographic and clinical variables were included and examined: age, gender, and symptom duration. A p value of 0.05 or less was considered statistically significant.

RESULTS

Twenty-six of the 68 patients (38%) met both clinical and ENG inclusion criteria for vestibular neuritis (RVR range, 25% to 100%). The mean age of the group was 54 years (range, 39 to 69 years). The gender distribution included 8 men (30.7%) and 18 women (69.3%). The average symptom duration was 311 days (range, 60 to 1,500 days; 95% confidence interval, 161 to 461 days).

An Altman plot was performed to analyze the inter-rater reliability for measurements of the height of the affected superior vestibular nerve (Fig 2). The mean difference between the measurements made by the independent blinded investigators was 0.023 mm (95% confidence interval, −0.1400 to 0.1861). Data demonstrate that observer 2 tended to give lower measurements (mean of 0.02 mm). Nevertheless, limits of agreement are small enough that we can be confident that investigators were in agreement for clinical purposes.

A minor trend was observed between the area of the affected superior vestibular nerve and the RVR, in which a smaller nerve area tended to be associated with an increased RVR, although this trend did not reach statistical significance (p = 0.78). When we attempted to correlate the area of the affected superior vestibular nerve with age, a non–statistically significant trend (p = 0.64) was noted toward a smaller nerve area with increased age. A non–statistically significant trend was also observed toward a decreased area of the superior vestibular nerve with an increased duration of symptoms (p = 0.52). No statistically significant difference was observed be-

### COMPARISON OF AFFECTED AND CONTROL VESTIBULAR NERVES IN TERMS OF DIMENSIONS AND CROSS-SECTIONAL AREA

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<th>Affected Nerve</th>
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<td>Superior vestibular nerve</td>
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<td>Height (mm)</td>
<td>0.88 ± 0.20</td>
<td>0.99 ± 0.28</td>
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<td>Width (mm)</td>
<td>0.85 ± 0.14</td>
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<td>Area (mm²)</td>
<td>0.60 ± 0.19</td>
<td>0.71 ± 0.25</td>
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<td>Inferior vestibular nerve</td>
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<td>Height (mm)</td>
<td>0.85 ± 0.20</td>
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<td>Area (mm²)</td>
<td>0.56 ± 0.21</td>
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between gender and superior vestibular nerve area.

DISCUSSION

Vestibular neuritis is a common cause of peripheral vestibular vertigo. It is commonly diagnosed through a combination of established clinical and ENG criteria, although adjunctive diagnostic techniques such as audiometry and MRI may be utilized to rule out other diagnoses such as labyrinthitis, retrocerebellar lesions, and vascular insults.\(^\text{1,6,7}\) Although various causes have been described for vestibular neuritis, limited reports have directly addressed radiographic findings of the vestibular nerve in this disease process.

Conflicting reports exist with regard to whether radiographically visualized changes such as enhancement are present on MRI, particularly in the acute phase.\(^\text{3,14}\) The use of a high field strength (3 T) and high-dose gadolinium–penetic acid may improve diagnostic specificity.\(^\text{14}\) Currently, there is no commonly used objective system for the measurement of vestibular nerve enhancement. Previous studies that examined traditional MRI for both non-dizzy and dizzy patients concluded that routine MRI alone is unlikely to reveal the cause of dizziness, as structural abnormalities are common in both groups.\(^\text{15}\)

Within the University of Miami's Department of Otologylogy Ear Institute, CISS protocol MRI is used routinely for assessing retrocerebellar disease. Use of CISS for neuro-otologic purposes was first noted in the literature in 1993, specifically for imaging the inner ear and cerebellopontine angle.\(^\text{16}\) The CISS protocol is a T2-weighted rephasing 3-D gradient echo sequence that is advantageous because of its high signal level and spatial resolution. Flow compensation and a homogeneous signal intensity distribution provide excellent contrast between CSF and neural tissue. This study demonstrates that parasagittal CISS MRI is a suitable technique for accurately measuring structures within the IAC.

This is the first investigation, to our knowledge, to utilize imaging studies to quantify vestibular nerve dimensions and to demonstrate a statistically significant difference in both height and cross-sectional area in the superior vestibular nerve in patients with unilateral vestibular hypofunction. With regard to reproducibility, inter-rater reliability analysis found vestibular nerve measurements to be quite accurate, with a mean difference between clinical investigators of 0.02 mm — likely of no clinical significance.

This investigation demonstrates a statistically significant reduction in both height and cross-sectional area of the affected superior vestibular nerve. Previously described histologic findings of Baloh et al\(^\text{12}\) demonstrated decreased vestibular nerve synaptic density in patients with vestibular neuritis. Additional histologic studies have established that the bony channel of the superior vestibular nerve is both 7 times longer than the inferior channel and possesses more bony spicules — findings that may predispose the superior vestibular nerve to more ischemia and entrapment.\(^\text{13}\) Our findings suggest that the radiographic correlate to previously described histologic findings may be manifested as a decreased cross-sectional nerve area on MRI. A non–statistically significant trend that accompanies a decreased vestibular nerve area includes an increase in symptom duration. These findings may also suggest further atrophic changes in nerve density that translate to a reduction in area.

One limitation of this investigation relates to software measurement limitation to increments of 0.1 mm, which may result in rounding error. The investigator's ability to measure nerve dimensions also is limited by the quality of the MRI picture. Higher-resolution MRI accompanied by future software upgrades will allow for both improved accuracy and precision of measurements. Motion artifact, as well as the inherent variability of nerve position in terms of proximity to the IAC wall and adjacent nerves, may limit the accuracy of measurements. Infrequently, we were unable to visualize CSF between the superior and inferior vestibular nerves, or immediately between the nerve and the IAC wall. In this situation, the investigator deemed the nerve unmeasurable on MRI (because the nerve borders were unable to be visualized), and the scan was not a candidate for the study.

As anatomic data are usually not available, an objective radiographic means of nerve analysis may be of use in the future to further identify the culprit nerve in conjunction with history and clinical correlation. Occasionally, clinical findings may imply a misleading anatomic location, such as a labyrinthine lesion manifesting as vestibular neuritis, or partial sparing of both the inferior and superior vestibular nerves.\(^\text{17-19}\) This study suggests that cross-sectional analysis of the superior vestibular nerve may be readily measured on parasagittal MRI and may possibly play an adjunctive role in the diagnosis of unilateral vestibular hypofunction, although it is obviously not a substitute for clinical judgment.

This study focused on superior vestibular nerve dimensions because the patients’ clinical diagnosis of vestibular neuritis was largely supported by weakness on caloric testing (which reflected activity of the horizontal semicircular canal, innervated by the superior vestibular nerve). Future directions for
expansion of this research will be to examine potential correlation between the area of the inferior vestibular nerve and vestibular evoked myogenic potentials. At this point in time, the relationship between vestibular nerve dimensions on MRI and symptom resolution is unknown. Future investigations will be directed at this question, in addition to the relationship to vestibular decompensation (recurrence of symptoms after successful compensation). Last, although novel findings are presented within this pilot study, confirmation with a larger, preferably prospective, investigation is warranted.

**REFERENCES**


