Associations of Video Head Impulse Test and Caloric Testing among Patients with Vestibular Schwannoma

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Abstract

Objective. To determine relationships between caloric testing (CT) and video head impulse testing (vHIT) among patients with unilateral vestibular schwannoma (VS). To describe the distribution of CT and vHIT measurements and assess associations with tumor size and self-perceived handicapping effects.

Study Design. Retrospective review.

Setting. Tertiary referral hospital.

Subjects and Methods. Subjects were adults with presumed unilateral VS between 2014 and 2017. Interventions were CT and vHIT. Primary outcomes were vHIT value (abnormal <0.8) and CT value (abnormal >25%). Secondary outcomes were tumor size and Dizziness Handicap Inventory scores.

Results. Fifty-one individuals had complete data for CT and vHIT. The odds of abnormal gain increases by 2.18 for every 10% increase in unilateral weakness on CT (range, 1.44-3.34; P < .001). A significant negative correlation between CT and gain exists (r = −0.64, P < .001). Odds of observing saccades increased by 2.68 for every 10% increase in unilateral weakness (range, 1.48-4.85; P = .001). This association was larger in magnitude for overt than covert saccades (odds ratios, 2.48 and 1.59, respectively). Tumor size was significantly associated with an increase in caloric weakness (β = 0.135, P < .001). With every 10-mm increase of tumor size, odds of abnormal gain on vHIT increased 4.13 (range, 1.46-11.66; P = .007). Mean Dizziness Handicap Inventory score was 19.7 (r = 22), without association to caloric weakness, gain, or tumor size.

Conclusion. CT and vHIT both effectively assess vestibular function for patients with VS and correlate to tumor size. These findings are important as vHIT has a lower overall cost, improved patient tolerance, and demonstrated reliability.

Keywords

vestibular schwannoma, caloric test, head impulse test

The incidence of vestibular schwannomas (VSs) was recently cited at approximately 23 per million population per year.1 Unilateral VS typically affects individuals in the sixth decade, and sexes are represented equally.2 Although VSs arise from the superior and inferior vestibular nerves,3 patients frequently present with tinnitus and progressive unilateral hearing loss.2 The lack of disabling vertigo may be due to the slow growth of VS, allowing for adaptation via central compensation mechanisms.4 Patients undergoing surgical resection experience a sudden change in the unilateral vestibular input from the affected side, resulting in complete loss of function. This sudden change and lack of immediate compensation result in vertigo, with subsequent imbalance and disequilibrium.5

Workup includes audiometric testing as well as imaging. These inform the patient’s treatment strategy and help dictate the surgical approach. Vestibular testing aids in the assessment of residual vestibular function, providing useful data for these patients. It may be useful information to counsel the patient on predicted postoperative dizziness. Caloric testing (CT) and the video head impulse test (vHIT) have both demonstrated usefulness in diagnosing and assessing peripheral vestibular dysfunction. These tests evaluate the vestibular system in different frequency ranges and may therefore provide complementary information.6

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CT has long been the gold standard method of demonstrating unilateral vestibular function via irrigation of warm (44°C) and/or cold (30°C) water.7 The left and right lateral semicircular canals are tested separately, equivalent to a low-frequency rotation stimulus between 0.002 and 0.004 Hz.8 Semicircular canals respond efficiently to angular movements at 1 to 6 Hz, making this stimulus nonphysiologic.5 Factors such as room lighting, anatomy, medications, and mental tasking can affect a patient’s response. Patients also habituate with repeated testing and report associated vertigo as discomforting.5

While the head impulse test has been used for decades,10 the advent of vHIT has increased sensitivity and specificity in detecting vestibular impairment. Specifically, one advantage of vHIT is detection of covert saccades, which occur during head movement.11 Canals are tested at frequencies of 3 to 5 Hz, within physiologic ranges. Because vHIT tracks the eye movement during and after head movement, it provides an objective assessment. Gain, the ratio of eye velocity to head velocity, is one analysis parameter. Another is the presence of corrective saccades, which are interpreted as a sign of peripheral vestibular hypofunction.

CT and vHIT have been studied extensively for peripheral vestibular disorders to compare their ability to diagnose and screen for conditions such as vestibular neuritis, Ménière’s disease, and gentamicin toxicity.7 Although head impulse testing approaches a specificity of 91%,8 sensitivity remains low, making it a poor screening test. Few studies specifically compared CT and vHIT in the setting of VS. The objective of this study was to determine the relationship between CT and vHIT among patients with unilateral VS. Additionally, we describe the distribution of CT and vHIT measurements and assess their association with tumor size and self-perceived handicapping effects.

**Methods**

This study was approved by the Duke University Institutional Review Board (Pro00083282).

**Patients**

We selected adult patients (>18 years old) with presumed unilateral VS at our institution between 2014 and 2017. They were identified through the Duke Enterprise Data Unified Content Explorer via diagnosis codes 225.1 and D33.3. Inclusion requirements were data for vestibular testing from CT and vHIT of the horizontal semicircular canals. Exclusion criteria were bilateral schwannomas or previous radiation or surgery. Tumor size was measured by the largest dimension in an axial plane, as reported by a neuroradiologist, and was not assigned to a particular grading scale. Patients underwent surgery, radiation, or observation; therefore, only a presumed diagnosis of VS could be made.

**Vestibular Testing**

Vestibular testing, including videonystagmography and vHIT, was performed and analyzed by 1 of 2 audiologists. All testing occurred prior to any treatment, such as surgery or radiation.

**Videonystagmography**

Videonystagmography was performed with equipment manufactured by Neuro-Kinetics Inc (Pittsburgh, Pennsylvania; Vest 7.5.2 and iPortal 5.1). Eye-specific calibration is obtained with patient seated 1.5 m from the wall. The oculomotor portion included evaluation of smooth pursuit, random paradigm horizontal saccades, horizontal optokinetics, as well as measures of spontaneous (vision denied) and horizontal gaze nystagmus. Patients were screened for nystagmus in dynamic and static positions with the Dix–Hallpike and head roll tests. Binaural bithermal water caloric irrigations were performed with the patient positioned in a reclining chair at 30° to orient the semicircular canals vertically. The ear canals were irrigated with the Aqua Stim (Micromedical Technologies, Chatham, Illinois) at 44°C and 30°C (right ear first, warm first) for 30 seconds with a flow rate of 500 mL/min. Patients were mentally tasked during calorics and measures of spontaneous nystagmus. Clinical decision making was based on Jongkee’s formula, and >25% asymmetry was considered significant. We applied a monothermal warm cutoff of 10% asymmetry such that if the warm irrigations were symmetric and there were no other abnormal findings, such as spontaneous nystagmus, cool irrigations were not completed.12 If a patient had no response to conventional temperatures in one ear, a syringe of ice water was perfused by turning the patient’s head away from the test ear during irrigation and returning the head to the center position after 30 seconds. A single instillation of fluid to fill the EAC was performed (approximately 1-3 mL).

**Video Head Impulse Testing**

vHIT was performed with Eye See Cam 1.1.1 with OtoAccess 1.4 (Interacoustics, Middelfart, Denmark). Results were collected with the right eye unless eye movement, visual acuity, or eye dominance dictated moving the camera to the left eye. Standard calibration and head calibration were performed per the manufacturer’s protocol. Horizontal head impulse was performed about the yaw axis with hands placed on top of the patient’s head or at the patient’s neck near the jaw line. Contact with goggles or strap was avoided to minimize unintended camera movement. Minimum and maximum head velocity filters were set at 150° and 310° per second, respectively. We collected ≥10 head impulses per ear; however, postcollection analysis resulted in deletion of noisy tracings. The examiner analyzed all gain measurements, with ultimate clinical decision making focused on regression gain and/or instantaneous gain at 60 milliseconds. Gain <0.80 was considered abnormal. The clinician actively assessed the presence of corrective saccades during the head impulse and analyzed the traces for the presence of covert and/or overt corrective saccades after results were collected. The presence of corrective saccades were determined by the examiner and interpreted to reflect...
the presence of peripheral vestibular asymmetry. To account for possible examiner bias from knowledge of the patient’s clinical history (eg, diagnosis and laterality of VS), months to years after data collection the audiologists were blinded to patients’ histories and asked to reanalyze the traces. This was done independently as well as together to reach a consensus regarding the presence or absence of corrective saccades.

**Statistical Analysis**

Distribution and frequencies are presented as counts and percentages for categorical variables and as means and standard deviations or medians and interquartile ranges for continuous variables. Differences between groups were assessed with the Wilcoxon rank sum test for continuous variables and the chi-square test for categorical variables. Spearman’s rank correlation was calculated to measure the correlation between continuous variables.

Separate logistic regression models were fit to estimate the odds ratio (95% CI) of percentage unilateral caloric weakness and 2 vHIT measurements (saccade type and gain). Saccade measurements included overt saccades, covert saccades, and any saccades. Gain was treated as categorical (0.8 and ≥0.8). All logistic regression models were adjusted for age (continuous, linear) and treated percentage unilateral weakness as continuous (linear) and categorical (by quartile).

Separate linear regression models were fit to estimate the association of tumor size and Dizziness Handicap Inventory (DHI) with percentage unilateral weakness. All models were adjusted for age (continuous) and treated percentage unilateral weakness as continuous (linear).

**Results**

Patient characteristics are outlined in Table 1. Of the 56 patients originally screened, 5 were missing at least 1 vHIT measure and were excluded. Fifty-one patients were included, with a mean SD age of 56 ± 14.4 years. We observed a near-even split between male and female patients (45.1% male) as well as tumor laterality (51% right sided). The mean tumor size was 12.2 ± 7.0 mm.

**CT and vHIT Saccades**

The mean observed caloric weakness across all patients was 43.5% ± 32.7%. Saccades were observed in 22 (43.1%) patients, with 20 (39.2%) having overt saccades and 9 (17.6%) having covert saccades. There were significant associations between overt and covert saccades and unilateral weakness, with a larger association for overt saccades. With every 10% increase in unilateral weakness, the odds of a patient having an overt saccade increased by a factor of 2.48 (95% CI, 1.45-4.25; \(P = .001\)), and the odds of a patient having a covert saccade increased by a factor of 1.59 (95% CI, 1.16-2.18; \(P = .004\)), as estimated from...
fitting a logistic regression model treating unilateral weakness as a continuous measure. Figure 1 presents the relationship between the predicted odds ratio of saccades and unilateral weakness, with 25% unilateral weakness as a reference.

Figure 1. Relationship of unilateral weakness and estimated odds ratio (OR) of saccades, with 25% unilateral weakness as the reference. Gray shading indicates the respective 95% confidence intervals for each group of saccades.

Of the 51 patients, 16 (31.4%) had a gain <0.8 on at least the ipsilesional side. An additional 3 (5.9%) showed decreased gain on the contralesional side. As seen with saccades, there was a significant association between increasing caloric weakness and the presence of decreased gain (<0.8). With every 10% increase in unilateral weakness, the odds of a patient having decreased gain increased by a factor of 2.18 (95% CI, 1.42-3.34; \( P < .001 \)). Gain was also analyzed as a continuous variable, and Figure 2 illustrates the linear relationship between decreased gain and increased caloric weakness for the ipsilesional and contralesional sides. Spearman’s rank correlations for ipsilesional gain and contralesional gain to caloric weakness were –0.64 and –0.51, respectively (\( P < .001 \)).

CT, Tumor Size, and DHI

Patients’ caloric weakness was significantly associated with tumor size. After adjustment for age, with every 1% increase in caloric weakness, one can expect a 0.135-mm increase in tumor size (\( P < .001 \)). Caloric weakness was also assessed as a categorical variable in quartiles (Figure 3). There was no association between unilateral weakness and patients’ self-perceived scores on the DHI (\( P = 0.95 \)).

vHIT and Tumor Size

A significant association was shown for the presence of either overt or covert saccades and for overt alone. With an increase of 10 mm in tumor size, the odds ratio of any saccade was 3.55 (95% CI, 1.31-9.59; \( P = .013 \)). For that same increase in size, the odds ratio for overt saccades was 3.89 (95% CI, 1.41-10.71; \( P < .01 \)). There was no statistically significant relationship with covert saccades (\( P = .08 \)). With a cutoff of 0.8 for gain, for every 10-mm increase in tumor size, the odds ratio of decreased ipsilesional gain (<0.8) was 4.13 (95% CI, 1.46-11.66; \( P = .007 \)). There was a similarly significant association for decreased contralesional gain (\( P = .03 \)). Figure 4 presents the relationship of ipsilesional gain and tumor size with gain as a continuous variable.

Figure 2. The relationship between gain and unilateral weakness.

Figure 3. Relationship of tumor size with caloric weakness by quartile: Q1, 0%-11%; Q2, 12%-35%; Q3, 36%-69%; Q4, 70%-100%.

Figure 4. Relationship between ipsilesional gain and tumor size.
Discussion

In this retrospective study, we did not seek to determine the screening ability for either CT or vHIT, as performed in prior studies. Although other researchers examined the relationships between the vestibular tests among patients with VS, we believe that this study provides unique contributions to current knowledge.

In regard to CT, 32 (63%) patients had abnormal findings of >25% unilateral weakness. Analyzing caloric weakness as a continuous variable, we demonstrated a significant relationship between the degree of weakness and tumor size (β = 0.135, P < .001). As mentioned, CT evaluates the vestibulo-ocular reflex (VOR) in a low-frequency range, which may explain why there have been discrepancies in vHIT-CT associations in prior studies. Because the value of caloric asymmetry is thought to be unaffected by central compensation, the asymmetry is likely to remain more stable. It also allows for isolation of the side being tested (left vs right) and for localization of a peripheral lesion. In terms of clinical utility, Batuecas-Caletrio et al found that the degree of caloric weakness influences the time frame of recovery among patients undergoing VS surgery. They evaluated 24 patients and found significant relationships between CT and improvements of the subjective visual vertical (SVV). The SVV tests the ability of patients to judge whether an object is oriented vertically. Those with greater caloric weakness had quicker normalization of the SVV after surgery, and improvements in SVV correlated to DHI improvements. We did not evaluate the DHI over time (assessed only at first vestibular assessment), as our institution collects subjective data via Penn Acoustic Neuroma Quality of Life scores. Regardless, this study does add to the existing literature regarding the utility of CT in the workup and assessment of patients with VS. Specifically, associations of caloric weakness with tumor size may guide the initial counseling to patients prior to imaging studies, providing further support for postoperative outcomes as they relate to preoperative testing.

The vHIT has been validated against the scleral search coil method for measurement of VOR, and it is easier to perform and better tolerated by patients. Its utility as a screening test may be poor, but its performance does not preclude follow-up testing with calorics when it is normal. Additionally, there were no instances of abnormal vHIT with normal CT. To our knowledge, only one prior study demonstrated an association with vHIT and tumor size, and it did so measuring gain asymmetry. In that study of 50 patients, the authors did not find any associations between gain and calorics. In contrast, our study found significant associations between caloric weakness and gain as well as saccades. The evaluation of caloric weakness and saccades showed a larger association with overt saccades. Several studies stated that the presence of covert saccades suggests that vestibular dysfunction has been compensated and “eyead coordination anticipates movements in the real-life situation.” Because caloric weakness was associated with overt and not covert saccades, this may reflect that greater caloric weakness is associated with less preoperative compensation. The association between caloric weakness and decreased gain was significant for the ipsilesional side (P < .001) and approached significance for the contralesional side (P = .1). This likely corresponds to the decreased inhibition of the VOR from the affected side during testing of the non- VS side. Turning the head horizontally to the contralateral side results in excitation of that semicircular canal. Simultaneously, the ipsilesional side would be inhibited. The nonzero baseline firing rate of vestibular afferent neurons allows for paired canal to encode rotational acceleration.

In our study, the vHIT gain and the presence of saccades were associated with tumor size. Only the relationship of overt saccades to tumor size was statistically significant, however. Again, this may be due to the lack of compensatory refixation saccades during head movements among patients with larger tumors, much like what was seen among those with greater caloric weakness. After adjustment for age and laterality, gain was also found to be negatively associated with tumor size. This study and that from Batuecas-Caletrio et al are the only ones to show an association between tumor size and VOR gain. We evaluated tumor size as a continuous variable rather than assigning tumor grade, which may have helped to reveal this relationship.

From the standpoint of CT and vHIT, this study provides agreement with prior studies in the relationship of caloric weakness and vHIT with tumor size. Given that our study has contradictions to prior work (relationship of vHIT gain and CT, no relationship with DHI), it may serve as additional data for meta-analysis. The majority of studies examining vestibular testing with VS have <50 patients. However, the statistical significance in this study, even with 51 patients, suggests that these relationships reflect true associations. Clearly, more work is required to establish the exact relationship of these tests with objective and subjective results. In doing so, clinicians may better counsel patients in regard to postoperative expectations as they relate to disequilibrium as well as overall quality of life.

Limitations

There are several limitations of the current study. It is retrospective, and several patients were excluded due to the lack of complete data in caloric or head impulse testing. Incomplete data for all patients stemmed from differing practice patterns from the 2 locations where patients were evaluated, which has been corrected for future collection. Tumor measurements were also based on diameter in the axial plane, and volumetric analysis was not performed. At the time of initial testing, vestibular examiners may have known the diagnosis and affected sides of patients, which introduces bias into their assessment. To account for this, the vHIT traces were reanalyzed months to years after initial clinical assessment with examiners blinded to laterality, and there was no difference in their interpretations.
**Future Studies**

To date, only a few studies have demonstrated a consistent relationship between preoperative vestibular testing and self-perceived handicapping effects as measured by the DHI. These differences in postoperative DHI between groups disappear anywhere from 3 to 6 months after surgery. The DHI was developed to evaluate the self-perceived handicapping effects imposed by vestibular system disease and is not specific for VS. The Penn Acoustic Neuroma Quality of Life survey, however, may serve as a means to detect relationships between testing and outcomes following treatment with surgery, radiation, or observation.

**Conclusion**

In this study, calorics and head impulse testing effectively assessed vestibular function for patients with VS. They demonstrated significant associations with each other, as well as individually with tumor size. Patients tolerate vHIT far better than CT, and vHIT may be a better test to obtain data for counseling patients with VS about possible postoperative dizziness. While this study did not find a relationship between CT or vHIT and subjective symptoms at the time of vestibular testing, future studies will help determine if such a correlation exists with posttreatment quality-of-life surveys.

**Author Contributions**

C. Scott Brown, substantial contributions to conception of the work, acquisition and analysis of data, drafting the work and critically revising it, final approval of version to be published, agree to be accountable for all aspects of the work; Sarah B. Peskoe, acquisition, analysis, and interpretation of data, drafting the work and critically revising it, final approval of version to be published, agree to be accountable for all aspects of the work; Thomas Risoli Jr, acquisition, analysis, and interpretation of data, drafting the work and critically revising it, final approval of version to be published, agree to be accountable for all aspects of the work; Douglas B. Garrison, acquisition, analysis, and interpretation of data, drafting the work and critically revising it, final approval of version to be published, agree to be accountable for all aspects of the work; David M. Kaylie, substantial contributions to conception of the work, acquisition and analysis of data, drafting the work and critically revising it, final approval of version to be published, agree to be accountable for all aspects of the work.

**Disclosures**

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