The incidence of high-frequency hearing loss after microvascular decompression for trigeminal neuralgia, glossopharyngeal neuralgia, or geniculate neuralgia

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OBJECT The primary aim of this study was to evaluate the incidence and discuss the pathogenesis of high-frequency hearing loss (HFHL) after microvascular decompression (MVD) for trigeminal neuralgia (TGN), glossopharyngeal neuralgia (GPN), or geniculate neuralgia (GN).

METHODS The authors analyzed preoperative and postoperative audiogram data and brainstem auditory evoked potentials (BAEPs) from 93 patients with TGN, 6 patients with GPN, and 8 patients with GN who underwent MVD. Differences in pure tone audiometry > 10 dB at frequencies of 0.25, 0.5, 1, 2, 4, and 8 kHz were calculated preoperatively and postoperatively for both the ipsilateral and the contralateral sides. Intraoperative monitoring records were analyzed and compared with the incidence of HFHL, which was defined as a change in pure tone audiometry > 10 dB at frequencies of 4 and 8 kHz.

RESULTS The incidence of HFHL was 30.84% on the side ipsilateral to the surgery and 20.56% on the contralateral side. Of the 47 patients with HFHL, 20 had conductive hearing loss, and 2 experienced nonserviceable hearing loss after the surgery. The incidences of HFHL on the ipsilateral side at 4 and 8 kHz were 17.76% and 25.23%, respectively, and 8.41% and 15.89%, respectively, on the contralateral side. As the audiometric frequency increased, the number of patients with hearing loss increased. No significant postoperative difference was found between patients with and without HFHL in intraoperative BAEP waveforms. Sex, age, and affected side were not associated with an increase in the incidence of hearing loss.

CONCLUSIONS High-frequency hearing loss occurred after MVD for TGN, GPN, or GN, and the greatest incidence occurred on the ipsilateral side. This hearing loss may be a result of drill-induced noise and/or transient loss of cerebrospinal fluid during the course of the procedure. Changes in intraoperative BAEP waveforms were not useful in predicting HFHL after MVD. Repeated postoperative audiological examinations may be useful in assessing the prognosis of HFHL.

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KEY WORDS microvascular decompression; high-frequency hearing loss; trigeminal neuralgia; glossopharyngeal neuralgia; geniculate neuralgia; pure tone audiometry; auditory brainstem response; pain
TGN, GPN, or GN. Patients with significant HFHL (> 10 dB change in pure tone audiometry) have deficiencies in high-frequency components of speech, such as consonant sounds, and can have difficulties understanding speech in the presence of background noise. These deficiencies can have a negative impact on lifestyle because these patients may be unable to distinguish words that start and end with similar consonant sounds. Recognizing and understanding the incidence and pathogenesis of HFHL will be helpful in developing strategies to prevent it during MVD in particular and in craniotomies in general. The primary aim of this study was to evaluate the incidence and discuss the pathogenesis of HFHL after MVD for TGN, GPN, or GN.

Methods

Study Design

The study evaluated patients who underwent MVD for TGN, GPN, or GN at the University of Pittsburgh Medical Center between 2004 and 2012. The criteria for inclusion were as follows: 1) diagnosis of TGN, GPN, or GN and surgical treatment by MVD; 2) availability of preoperative and postoperative audiometry data; and 3) availability of intraoperative neurophysiological brainstem auditory evoked potential (BAEP) measurements. Patients with no preoperative or postoperative audiograms and without useful intraoperative monitoring data were excluded from the study. The study was approved by the institutional review board for retrospective review of data on human subjects at the University of Pittsburgh. The design of the study and the analysis of the data are intended to be similar to those used in a study published previously by many of the present paper’s authors.

Surgical Technique

The MVD was performed under general anesthesia. With the patients placed in the lateral decubitus position, surgeons performed a small retromastoid craniectomy. The compressing vessel was mobilized by dissection of the arachnoid bands that tethered the vessel, and a Teflon pledget was placed between the vessel and the nerve to attain adequate decompression. Decompression of cranial nerves V, IX, and X was accomplished by techniques such as sectioning of the nervus intermedius to treat TGN, GPN, and GN, respectively. During the surgery, BAEPs were recorded and closely monitored.

Pure Tone Audiometry

Pure tone audiometry can be used either for screening or for complete evaluation of hearing deficits. Preoperative and postoperative audiometry testing is a routine protocol at our institution. Audiometry testing was conducted before and after surgery at frequencies of 0.25, 0.5, 1, 2, 4, and 8 kHz in a quiet testing environment with low levels of background noise that were within American National Standards Institute requirements with standard equipment: a GSI 61 audiometer with TDH-BOP headphones (both from Grason-Stadler). The hearing threshold in pure tone audiometry was defined as the softest sound a patient could hear at each frequency for 50% of the series of ascending tones. Testing was done beginning with the ear in which the patient perceived he or she had better hearing. If the patient responded to a pure tone presented at a clearly audible level, a 10-dB-down, 5-dB-up pattern was employed by decreasing the tone by 10 dB until the patient no longer responded and then increasing the tone by 5 dB until the patient responded. This was the patient’s initial ascending response. To check for accuracy, the technician decreased the intensity of the tone by 10 dB 1 more time to check for no response and then increased the tone in 5-dB increments until the patient responded again to the signal. The dB level at which the patient responded consistently (minimum 2 out of 3 responses in ascending order), was recorded as the air conduction threshold. Then the same tests were performed on the patient’s other ear. After the surgery, postoperative audiograms were collected within 7 to 21 days.

The mean of the thresholds measured at 0.5, 1, and 2 kHz was defined as the pure tone average (PTA). High frequencies were defined as frequencies at 4 and 8 kHz, and HFHL was defined as a change in the pure tone audiometry of > 10 dB at these frequencies. The speech discrimination score (the phonetically balanced score) was represented as a percentage and was coupled with the PTA score to determine whether the patient had nonserviceable hearing loss according to the American Academy of Otolaryngology–Head and Neck Surgery classification system. According to this classification system, nonserviceable hearing loss is defined by Class C/D, which involves a PTA of > 50 dB and a speech discrimination score of < 50%. Preoperative and postoperative PTA and phonetically balanced data for both the ipsilateral and the contralateral ear were compared to determine whether a change in class occurred. The presence of conductive hearing loss was also indicated by calculation of an air-bone gap of > 10 dB at frequencies of 0.5, 1, or 2 kHz.

Intraoperative BAEP Monitoring

Stimulation and Recording

Parameters of the BAEP monitoring were set according to the recommended guidelines of the American Clinical Neurophysiology Society. Baseline BAEPs were obtained preoperatively in our diagnostic laboratory. During surgery, potentials were recorded continuously by stimulation of the ear ipsilateral to the affected side with alternating rarefaction and condensation clicks. A stimulus rate of 12 Hz was used for optimal resolution of the collected peaks. A click intensity of at least an 85-dB sound pressure level was implemented, and white noise at an intensity of a 65-dB sound pressure level was used to mask the activity in the contralateral ear. Five hundred and twelve trials were averaged over each 12-msec observation interval to obtain interpretable BAEP data. Three channels were used for recording. Channels 1 (Cz/A1) and 2 (Cz/A2) were formed between the vertex and the left and right ear mastoid, respectively. Channel 3 (Cz/Cv2) spanned from the vertex to cervical C2. Wave V (wV), the largest component of the BAEP waveform, was analyzed in real time during the procedure. Significant changes in wV were recorded and reported to the surgeon to monitor brainstem function, to detect ischemia, and to identify perturbations, which are indicators of hearing function.
Criteria for Significant Change

Two components of wV were monitored and compared with baseline responses during the course of the surgery: amplitude and latency. Significant changes in each variable were recorded and reported to the surgeon. A significant change in amplitude took place when wV decreased to 50% of its baseline value, and a significant change in latency occurred when wV shifted at least 0.5 msec away from the baseline. In addition, the specified differences in latency or amplitude were required to occur during at least 2 consecutive trials in order to be considered significant and to prevent technical issues from interfering with data collection. A combined remote and onsite model was used for physician interpretation at the University of Pittsburgh Medical Center.30

Analysis of Neurophysiological Parameters

Several aspects of the BAEP waveforms were recorded and analyzed periodically throughout the operation. The latency of Waves I, III, and V, the interpeak latency (IPL) between these waves (wI–III, wIII–V, and wI–V), and the amplitude of Waves III and V were all recorded at 5 specific points in the surgery. First, a baseline waveform was selected prior to the incision after positioning and intubation were completed. The next waveform was selected during the period when the surgeon was opening the dura. The third waveform was noted at the start of significant change, that is, when wV shifted either 0.5 msec away from the baseline or when the amplitude of wV decreased to 50% of its baseline value. A fourth waveform indicating maximum change was noted when wV was at its greatest latency. Lastly, the “on skin” or last epoch was recorded after the surgery was completed. The increase in latency was reported to the surgeon as the difference in milliseconds between the selected waveform and the baseline waveform. The change in amplitude was reported as a percentage of the baseline value (for example, if the baseline value was 1 and decreased by 0.2, then it was reported as 80% of the baseline).

Statistical Analysis

Intraoperative BAEP changes were compared with preoperative and postoperative audiometric data to determine whether BAEP data were useful predictors of HFHL. Patients were grouped into 2 categories depending on whether they had HFHL. A 2-tailed t-test was used to determine if there was significant statistical difference between patients with HFHL and without HFHL. A p value of < 0.05 was used to determine statistical significance.

### TABLE 1. Patient characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Present</th>
<th>Absent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ipsilat (n = 33)</td>
<td>Contralat (n = 22)</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>7:26</td>
<td>6:16</td>
</tr>
<tr>
<td>Side (lt/rt)</td>
<td>13:20</td>
<td>8:14</td>
</tr>
<tr>
<td>Age (yrs ± SD)</td>
<td>52.63 ± 11.91</td>
<td>55.70 ± 10.60</td>
</tr>
</tbody>
</table>
also noted that one-fifth of the patients experienced con-
ipsilateral HFHL after MVD for TGN, GPN, or GN. We
postoperative hearing loss
intraoperative BAEP changes and correlation with
and 2 (33.3%) of 6 patients with GPN had HFHL. The
difference in incidence rates of HFHL was not compared
because of the small sample sizes for patients with GPN
and GN compared with TGN.

Intraoperative BAEP Changes and Correlation With
Postoperative Hearing Loss
Statistical analysis of BAEP data revealed no signifi-
cant difference for the specified parameters between pa-
tients with and without HFHL (Table 4). The latency of
wV, the amplitude of wV, and the IPL between Waves I
and V were compared for the 2 categories at baseline and
the maximum change, but the p values calculated for each
category were not significant (p > 0.05). Stepwise logistic
regression analysis did not identify a significant intraop-
erative variable that increased the odds of HFHL (p = not
significant).

Discussion
Our present study shows that one-third of patients have
ipsilateral HFHL after MVD for TGN, GPN, or GN. We
also noted that one-fifth of the patients experienced con-
tralateral HFHL after MVD. HFHL after MVD is not well
known but has been previously reported in patients who
underwent MVD for HFS. This is the first study to dem-
onstrate the presence of HFHL immediately after MVD
for TGN, GPN, or GN. Ipsilateral sensorineural hearing
loss after MVD could be attributed to 1) stretching of
cranial nerve VIII during retraction of the cerebellum, 2)
manipulation of the labyrinthine artery and/or the anterior
inferior cerebellar artery, 3) direct trauma to the nerve by
instruments or nearby coagulation, and 4) new compres-
sion of the nerve by the prosthesis interposed between the
offending vessel and the affected nerve complex at the end
of surgery.23 Although drill-induced noise could aggravate
or contribute to sensorineural hearing loss by a mecha-
nism of acoustic trauma and reduced bone-conduction
thresholds,4,12,13,22 it could also contribute to ipsilateral and
contralateral HFHL. Our clinical practice includes some
patients who complain of hearing disturbance and some
who do not, which makes HFHL an incidental finding.
We hypothesize that the patients who do not complain do
not have the opportunity during their hospital stay to real-
ize their hearing change. Hence we plan to systematically
evaluate the short- and long-term clinical effects of these
hearing changes in patients by means of a postdischarge
quality-of-life survey.

Our results suggest that HFHL was present in patients
regardless of the presence of conductive or sensorineural
hearing loss. These conditions can mask HFHL during
evaluation of the auditory nerve using speech recognition
scores or pure tone tests. Noise levels ranging from 117
to 122 dB in the sound pressure level13 have been report-
ded from drilling in the cortical bone and mastoid cavity.
These sound levels are equivalent to those at an amplified
rock concert in front of speakers or a nearby airplane en-
gine. Our review of the literature indicated that exposure
to high-intensity noise damages the hair cells of the co-
chlear structures. At the subcellular level, the tip links of
a hair cell, which are thought to gate mechanoelectrical
transduction channels, are broken by high-intensity noise.
After acoustical overstimulation, broken tip links were
detected and resulted in reduced hair bundle stiffness,
disrupted mechanoelectrical transduction, and temporary
noise-induced hearing loss.3,18,35

Interestingly, our study also found a high incidence
of HFHL in the ear contralateral to the operative side,
which is similar to findings about MVD for treatment of
HFS. Postoperative contralateral hearing loss has been re-
ported in association with surgeries other than MVD, for
example, acoustic neuroma surgery. At least 12 instances
of contralateral hearing loss have been documented after
acoustic neuroma surgery.31 Drilling of the mastoid can
temporarily affect both the ipsilateral and contralateral
ears. This could be because hair cells that detect higher frequencies are damaged
first, followed by damage to hair cells that detect lower
frequencies.4 Some additional mechanisms, including
transient loss of cerebrospinal fluid, have been implicated
in HFHL.9,20 Similar results were also reported in asso-

<table>
<thead>
<tr>
<th>Audiometric Frequency (kHz)</th>
<th>Side Ipsilat to Op</th>
<th>Side Contralat to Op</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HL* No HL* % HL</td>
<td>HL* No HL* % HL</td>
</tr>
<tr>
<td>0.25</td>
<td>12 95 11.21</td>
<td>8 99 7.48</td>
</tr>
<tr>
<td>0.5</td>
<td>15 92 14.02</td>
<td>11 96 10.28</td>
</tr>
<tr>
<td>1</td>
<td>21 86 19.63</td>
<td>7 100 6.54</td>
</tr>
<tr>
<td>2</td>
<td>21 86 19.63</td>
<td>8 99 7.48</td>
</tr>
<tr>
<td>4</td>
<td>19 88 17.76</td>
<td>9 98 8.41</td>
</tr>
<tr>
<td>8</td>
<td>27 80 25.23</td>
<td>17 90 15.89</td>
</tr>
<tr>
<td>4 &amp;/or 8</td>
<td>33 74 30.84</td>
<td>22 85 20.56</td>
</tr>
</tbody>
</table>

HL = hearing loss.
* Values represent the number of patients.

### Table 3. Incidence of nonserviceable and conductive hearing loss

<table>
<thead>
<tr>
<th>Condition</th>
<th>Criteria</th>
<th>Affected Side</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGN (n = 93)</td>
<td>AAO-HNS Class C/D</td>
<td>Ipsilat</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contralat</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>CHL</td>
<td>Ipsilat</td>
<td>14</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contralat</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>GN (n = 8)</td>
<td>AAO-HNS Class C/D</td>
<td>Ipsilat</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contralat</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CHL</td>
<td>Ipsilat</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contralat</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>GPN (n = 6)</td>
<td>AAO-HNS Class C/D</td>
<td>Ipsilat</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contralat</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CHL</td>
<td>Ipsilat</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Contralat</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

AAO-HNS = American Academy of Otolaryngology–Head and Neck Surgery; CHL = conductive hearing loss.
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... association with elective craniotomy when audiograms were performed before and after the procedure. These studies found that drill-generated noise during craniotomy significantly affected high-frequency (4–6 kHz) but not low-frequency (0.25–2 kHz) hearing. As noted, the short outer hair cells of the high-frequency region have been found to be more vulnerable to sound stimulation than the taller receptor cells in the low-frequency area. During MVD for HFS, it is possible that the proximity of cranial nerve VII to the cochlear nerve may increase the stretching and compression of cranial nerve VIII and thereby increase the probability of HFHL. Interestingly, these surgeries involve cranial nerves that are anatomically farther from the auditory nerve, yet the results are consistent both ipsilaterally and contralaterally. This evidence may indicate that HFHL is the result of a pathological process more complex than simple “nerve stretching.”

The change in latency or decrease in the wV amplitude...
of BAEPs has been reported to be a predictor of hearing loss.\textsuperscript{11,16,29} In the study reported here, no significant difference was found between the groups with and without HFHL during any stage of MVD for any other BAEP waveform latency or amplitude measurements, including Waves I, III, and V and interpeak latencies. HFHL probably was not secondary to stretching of the auditory nerve during MVD but likely was induced by high-intensity drilling noise during craniotomy early in the procedure.\textsuperscript{34} Studies performed on hair cells in animal models have reported evidence of reestablished signal transduction upon regeneration of the tip links of hair cells in cultured explants 6 hours after the stimulus,\textsuperscript{35} or in vivo after 24–120 hours.\textsuperscript{13} The time course of hair cell tip link regeneration suggests that this process may underlie recovery from temporary threshold shift induced by noise exposure.\textsuperscript{26,35}

Our study, which was designed to further evaluate our findings of HFHL after MVD for TGN, GN, or GPN, has some limitations. Our study population included patients who had preoperative and postoperative audiograms, so it is possible that the incidence of HFHL could be a bias toward people who obtained audiograms. These patients may have had symptoms and hence may have wanted to undergo diagnostic testing. We did not procure long-term follow-up audiograms to evaluate hearing improvement. These tests might be useful because studies in humans\textsuperscript{14} have shown that the changes take place in the near-to-immediate term after the procedure, and the majority of patients may improve.

Conclusions

HFHL primarily on the ipsilateral side may be due to drill-induced noise and/or transient loss of cerebrospinal fluid during MVD for TGN, GPN, or GN. Changes in intraoperative BAEPs during MVD were not useful in predicting HFHL. Follow-up studies and repeat audiological examinations may be helpful in evaluating the time course and prognosis of HFHL.

References

21. Patel A, Kassam A, Horowitz M, Chang YF: Microvascu-

<table>
<thead>
<tr>
<th>Variable</th>
<th>HFHL</th>
<th>NHFHL</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency wV (ms) ± SD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>6.51 ± 0.40</td>
<td>6.46 ± 0.40</td>
<td>0.52</td>
</tr>
<tr>
<td>Change max</td>
<td>8.46 ± 1.98</td>
<td>7.79 ± 1.57</td>
<td>0.061</td>
</tr>
<tr>
<td>Change max vs baseline</td>
<td>1.29 ± 0.28</td>
<td>1.21 ± 0.24</td>
<td>0.14</td>
</tr>
<tr>
<td>Baseline</td>
<td>0.33 ± 0.12</td>
<td>0.32 ± 0.10</td>
<td>0.93</td>
</tr>
<tr>
<td>Change max</td>
<td>0.24 ± 0.17</td>
<td>0.25 ± 0.12</td>
<td>0.75</td>
</tr>
<tr>
<td>Change max vs baseline</td>
<td>0.70 ± 0.44</td>
<td>0.81 ± 0.40</td>
<td>0.22</td>
</tr>
<tr>
<td>Baseline</td>
<td>4.53 ± 0.39</td>
<td>4.50 ± 0.33</td>
<td>0.62</td>
</tr>
<tr>
<td>Change max</td>
<td>6.79 ± 2.91</td>
<td>5.87 ± 2.25</td>
<td>0.074</td>
</tr>
<tr>
<td>Change max vs baseline</td>
<td>1.51 ± 0.63</td>
<td>1.29 ± 0.50</td>
<td>0.053</td>
</tr>
</tbody>
</table>

NHFHL = no high-frequency hearing loss; wV = Wave V; wI–V = Waves I–V.


**Author Contributions**

Conception and design: Thirumala. Acquisition of data: Thirumala, Dasyam, Shankar, KRK Sarma, DRK Sarma. Analysis and interpretation of data: Thirumala, Meigh, Dasyam. Drafting the article: Thirumala, Meigh, Dasyam. Critical revising of the article: Thirumala, Meigh, Habeych, Crammond, Balzer. Reviewed submitted version of manuscript: Thirumala, Meigh, Habeych, Crammond, Balzer. Approved the final version of the manuscript on behalf of all authors: Thirumala. Statistical analysis: Meigh, Dasyam. Administrative/technical/material support: Thirumala. Study supervision: Thirumala.

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