For the patients with velopharyngeal incompetence either by cleft palate or paralysis of the velopharynx, severe functional disturbance of the soft palate may result in regurgitation of foods into nasal cavity during the swallowing process and in excessive nasal resonance during phonation. The medical term for the latter condition is hypernasality or rhinolalia aperta. On the other hand, an obstruction of the nasal cavity by nasal polyps or various tumors, or an obstruction of the nasopharyngeal cavity by adenoid enlargement or angiofibroma may severely reduce nasal resonance, and the condition is termed hyponasality or rhinolalia clausa.

In the cases of phonating disturbances from abnormal nasal resonance, it may be difficult even for the trained ENT specialists to differentiate hypernasality from hyponasality just by listening to the diction. In most cases, the observation may be described in such statement as “abnormally pronounced nasal sound.” Therefore, in order to properly differentiate any abnormality, an anatomical assessment of the soft palate, the movement of the soft palate on phonation, and the evaluation of the nasal cavity are necessary. The speech pathologist or speech therapist should examine the presence of any faulty pronunciation of consonants through a reading test as well as hyperresonance during vowel phonation.

When the speech disorder due to nasal resonance disturbances is treated by surgical procedures or a speech therapy, an objective means to evaluate the im-
provements made by the treatment are needed. Some of the conventional semi-objective methods include the mirror clouding test, the nasal vibration test, and the nares occlusion test of exhalatory efficiency.4

In the mirror clouding test,4 the subject reads sentences containing many nasal consonants and sentences with no consonants, while holding a cold metal mirror in front of the nasal aperture. An unusually heavy clouding while reading the sentences with no nasal consonants constitutes heavy nasal emission, therefore hypernasality. On the other hand, if unusually little clouding occurs during the reading of sentences with many nasal consonants, an obstruction of the nasal passage and hyponasality may be suspected. Although the extent of the clouding may be used to quantitatively evaluate the severity of the condition up to a certain point, objective measurement may be difficult to perform.

The nasal vibration test4 involves the examiner placing his or her finger on the subject’s ala nasi in order to detect the vibration while the subject is reading various sentences and words with or without nasal consonants. Again, however, this test also lacks objectivity.

The nares occlusion test of exhalatory efficiency4 evaluates how long a subject can count numbers out loud after one deep inhalation. First, the subject executes the procedure normally and then repeats the procedure while obstructing the nasal passages with fingers. Although the test is less than ideal, comparison of the results between two sessions allows some quantitative estimation of the nasal emission.

More objective tests have been developed. Employing several kinds of sensors to detect air pressures and currents within the nasal and oral cavities, Warren5 reported a method that could indirectly estimate the area of velopharyngeal orifice. Fletcher6 measured sound levels emanating from the nasal and oral cavities and used the ratio of the two values to calculate the nasal resonance. The result obtained by this method showed high correlation with the judgment of nasal resonance disorders made by phoniatrical specialists.7 Currently, the measuring device is marketed under the brand name Nasometer.

Using a piezoelectric sensor in the present study, the authors attempted to enhance the nasal vibration test with better objectivity and quantitative potential. In order to test the efficacy of the procedure and the device, it was clinically applied to three groups of subjects with either normal resonance, hypernasality, or hyponasality.

MATERIALS AND METHODS

The detection device
A piezoelectric-type vibratory sensor commonly used in a telephone (PKD20EW-01R, Murata Co., Kyoto, Japan) was prepared. In order to minimize the effects from the oral cavity, a slight modification was made by covering the sensor with duralumin, except for the receiving area where a metal tube 30 mm in length and 5 mm in diameter was attached (Figure 1). The end of the metal tube was to make a contact flush to the ala nasi of a subject, thus preventing any changes of the sound pressure through the air from affecting the sensor. The whole sensor unit was attached to a headband commonly used for ear, nose, and throat (ENT) examinations (Figure 2).

A preamplifier, a power supply, a filter, and an isolation part were prepared and assembled by medical engineers. The input was digitized with a 12-bit analog/digital (A/D) board (DT2821, Marlboro, MA) and analyzed with computer software (CSpeech 3.1, Madison, WI). Three channels within the software were used; the first channel for acoustic waveforms from the microphone, the second channel for the signals from the vibratory sensor, and the third channel for the envelopes of the vibratory signals in order to enhance the measurement (Figure 3).

FIGURE 1. Nasal vibratory sensor: a piezoelectric receiver for telephone (PKD20EW-01R), left, and a modification by coating with duralumin and a small hollow tube tip.
Measurement of nasal resonating vibration

The sensor was attached to the ala nasi after a gentle rubbing with alcohol, and a microphone was placed 15 cm in front of the mouth to pick up the acoustic signals. The subjects were asked to pronounce the vowel /a/ and the nasal consonant /ng/ as well as the sentences containing mainly nasal consonants (/mama/ passages in Korean) and the sentences with no nasal consonants (/papa/ passages in Korean).

Instead of using absolute values of the vibration, the ratio of the /ng/ values to the /a/ values were calculated and used for detection and differentiation of the nasal resonatory disorders, since the contact status between the ala nasi and the sensor might affect the results. The ratio of the signals from the /mama/ passages to the signals from the /papa/ passages were used for similar reasons. The signal strength was calculated from the envelopes and the baseline values from channel 3 were
calculated with computer software (ImagePro II, Media Cybernetics, Silver Spring, MD) aiding in the calculation of the areas between the two (Table 1).

The extent of the nasal obstruction was measured by the ratio of signals from /a/ with the cul-de-sac resonation induced by blocking the nose with a finger to the same pronunciation without the obstruction. The same procedure was repeated with the nasal consonant /ng/ (Figure 4, Table 1).

Clinical applications
The measuring procedure was applied to three groups: (1) control group with 10 normal subjects (5 males, 5 females, mean age 32); (2) hypernasality group with 10 subjects with either congenital cleft palate, submucous cleft palate, or functional velopharyngeal incompetence (6 males, 4 females, mean age 34); (3) hyponasality group with 10 subjects with nasal polyposis (5 males, 5 females, mean age

**TABLE 1. Calculation and Analysis of the Nasal Vibration**

<table>
<thead>
<tr>
<th>A. Measurement for hypernasality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vowel /a/, and nasal consonant /ng/:</td>
</tr>
<tr>
<td>ratio of /ng/ /a/</td>
</tr>
<tr>
<td>2. /mama/ passage (eight-syllable phrase that contains eight nasal consonants), and /papa/ passage (eight-syllable phrase that contains no nasal consonant):</td>
</tr>
<tr>
<td>ratio of /mama/ passage /papa/ passage</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B. Measurement for hyponasality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Vowel /a/, and vowel /a/ with occlusion:</td>
</tr>
<tr>
<td>ratio of /occ/a/ /a/</td>
</tr>
<tr>
<td>2. Nasal consonant /ng/, and nasal consonant /ng/ with occlusion:</td>
</tr>
<tr>
<td>ratio of /occ/ng/ /ng/</td>
</tr>
</tbody>
</table>

**FIGURE 4.** Measurement of the nasal vibration with occlusion by a finger in order to induce cul-de-sac resonation.
The ratio of /ng/ to /a/ and the ratio of /mama/ to /papa/ passages were calculated, as well as the ratio of /a/ and /ng/ with cul-de-sac resonance to passages with no obstruction.

**Statistical analysis**

A paired t-test was used to compare the groups ($P < 0.05$).

**RESULTS**

The mean ratio of /ng/ to /a/ in the normal group (Figures 5 and 6) was 8.2 ($\pm 2.1$), whereas the mean ratio of /mama/ passages to /papa/ passages was 10.0 ($\pm 2.1$) (Figure 10). In the hypernasality group (Figures 7 and 8), these ratios were 2.5 ($\pm 0.4$) and 2.2 ($\pm 0.3$) respectively, while the ratios were 6.7 ($\pm 1.6$) and 7.0 ($\pm 1.7$), respectively, in the hyponasality group (Figure 10). Compared with the normal group, the hypernasality group showed a statistically significant difference ($P < 0.05$), while the hyponasality group showed no significant difference. The difference between the hypernasality and the hyponasality groups was also significant ($P < 0.05$).

When the cul-de-sac resonance was induced by blocking the nose with a finger on the testing side during the pronunciation of /a/, the mean ratio of increase was 2.6 ($\pm 0.2$) in the normal group (Figure 9) and 2.8 ($\pm 0.2$) in the hypernasality group, while the increase was minimal at 1.2 ($\pm 0.1$) in the hyponasality group (Figure 11). Statistically significant differences were noted between the normal and the hypernasality groups, and between the hypernasality and the hyponasality groups ($P < 0.05$).

When the cul-de-sac resonance was induced during the pronunciation of /ng/ and compared to /ng/ without occlusion, the signals increased in the normal group by 3.0 ($\pm 0.4$) and 3.2 ($\pm 0.3$) in the hypernasality group, while the increase was minimal in the hyponasality group at 1.2 ($\pm 0.1$) (Figure 12). Statistically significant differences were noted between the normal and the hyponasality groups, and between the hypernasality and hyponasality groups ($P < 0.05$).

**DISCUSSION**

The nasal resonance disorders can be grouped into either hypernasality with nasal emission or hyponasality. Some of the conditions that can cause hypernasality include organic disorders such as cleft palate, submucous cleft palate, and traumatic palatal defect as well as the secondary slowing of the soft
palate movements caused by either neurological or psychological reasons. Hyponasal conditions may be caused by rhinosinusitis, allergic rhinitis, nasal polypsis, adenoid vegetation, and tumors in the nasopharynx. 

Hyponasality is frequently related to anatomical or functional disturbances in the soft palate. The soft palate consists of five muscles (tensor veli palatini, levator veli palatini, palatopharyngeus, palatoglossus, and uvular) and these muscles do not contract...
during normal nasal breathing, leaving the velopharyngeal isthmus wide open. However, in the second stage of swallowing (pharyngeal phase), these muscles do contract, occluding the velopharyngeal isthmus and thus preventing the regurgitation of food or saliva. Normally, the pronunciations of all vowels and consonants, excluding the nasal consonants, lead to the occlusion of the velopharyngeal isthmus, pre-
FIGURE 10. Comparison of ratio of /ng/ /a/ and ratio of /mama/ passage /papa/ passage in normal control, hypernasality, and hyponasality groups.

FIGURE 11. Comparison of ratio of /a/ with occlusion /a/ in normal control, hypernasality, and hyponasality.
cluding hypernasality. For the nasal consonants, the exhalatory air is channeled to the nasal cavity, resulting in the nasal resonance.8-10

Some of the phonating or linguistic disorders caused by the functional disturbance of the soft palate are as follows: excessive hypernasality during the pronunciation of vowels or voiced consonants, nasal emission during the pronunciation of power consonants, compensatory articulation, retardation of speech and linguistic development in children, phonation disturbances caused by auditory disorders, etc.4

For the evaluation of the soft palate function, a flexible nasopharyngoscope may be effective, and, by means of attaching a camera, a videoendoscopic examination is possible which is useful in the objective evaluation of the results of surgery or speech therapy. Through the endoscope, the examiner can observe soft palate movement during the pronunciation of vowels and can record the movement not only of the posterior pharyngeal walls but also of the lateral pharyngeal walls. In addition to the above methods, the video fluoroscopic studies and electromyography (EMG) are also available.8-11

For the evaluation of nasal resonance, the sound spectrographic analysis of the recorded sound is commonly used. A normal nasal consonant sound registers the first formant at around 250 Hz, which is much lower than the frequency from a normal vowel. The second formant is registered at around 2500 Hz, which is much higher than that of a vowel.12-14 Therefore, in a hypernasal condition, the pronunciation of a vowel accompanies a nasal resonance, thus greatly affecting the usual formant frequencies. In a hyponasal condition, the intensity of the resonance frequencies F1 and F2 is markedly reduced, however, the sound spectrographic analysis alone may not be sufficient to differentiate nasal resonance from oral resonance.

As stated above, some of the traditional semi-objective methods to evaluate nasal resonance include the mirror clouding test, the nares occlusion test of exhalatory efficiency, and the nasal vibration test. However these methods had limitations in quantitative and objective evaluation of the nasal resonance.4 Rhinomanometry and acoustic rhinometry, both of which play a role in evaluating nasal resistance and
nasal airflow, can also detect problems with velo-pharyngeal insufficiency. The pressure/flow technique reported by Warren used the pressure and the current in the nasal and oral cavity to calculate the area of the nasopharyngeal passage, however, this method is costly since it requires many sophisticated devices.

Recently, some methods that can objectively evaluate nasal resonance have been reported. One such method, which measures a tonar that could express the ratio of sonic resonations in oral and nasal cavities, showed 0.8 correlation to the subjective judgment of examiners. A modification of this method led to the development of a computerized measuring device (Nasometer, Kay Elemetrics, Lincoln Park, NJ) which detected the acoustic energy from the nasal and oral cavities through the microphones, and it is the most popular method currently used in many institutions.

The device used in the present study is a modification of the nasal vibration test. The sensor used in the device is relatively easily available, and, once the control portion is made, a personal computer and the multipurpose sound analysis software (CSpeech) can be used. Furthermore, the test uses the ratio of the vowel to the nasal consonant instead of any absolute values, thereby reducing the procedural errors and aiding in the differentiation of normal and hypernasal conditions.

In the normal group and the hyponasality group, because the functions of the velopharynx are intact, when phonating a vowel /a/ the velopharyngeal port is closed and the nasal vibration is small. Conversely, while phonating a nasal consonant /ng/, the velopharyngeal port is wide open, and the resonating nasal vibration is quite large. Meanwhile, in the hypernasality group, the nasal vibration score measured high not only when the subject phonated a nasal consonant /ng/ but also when the subject phonated a vowel /a/, because the velopharyngeal port is open wide. Thus, the /ng/ to /a/ ratio is much smaller in the hypernasality group than in either the normal or hyponasality group.

In the hyponasal group (where all subjects had nasal polyposis), the /ng/ to /a/ ratio is smaller than in the normal group (however, this is not statistically significant in this study). This seems to be caused by the lack of space in the nasal cavity for resonation because this space is already occupied by nasal polyps. However, when cul-de-sac resonation is induced, the hyponasal condition can be differentiated from either the normal or hypernasal conditions, since the vibrations do not vary. Those with hyponasality already have a blockage somewhere in the nasal cavity and induce cul-de-sac resonation by occluding the nostril, thereby producing no additional resonating vibration in the nasal cavity.

The nasometer measures the nasality score, derived from the ratio of nasal sound energy to oral sound energy. However, this device could also measure not only the absolute value of resonating nasal vibration, but also the ratio between a vowel and a nasal consonant and/or the ratio between a vowel with cul-de-sac resonation and a vowel. For a more definite evaluation of the efficacy of the device, further studies are needed on pretreatment and post-treatment changes in nasal resonance in patients with congenital cleft palate, chronic rhinosinusitis, and soft palate paralysis.

CONCLUSION

A new nasal vibration testing device that could objectively measure the nasal resonating vibration was developed using a piezoelectric sensor. The new device could be one objective means of detecting nasal resonatory disorders and readily differentiating hypernasality and hyponasality.

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REFERENCES

7. Dalston RM, Warren DW. Comparison of Tonar II, pressure-flow and listener judgment of hypernasality in the assessment