The effect of nasal speaking valve on the speech under experimental velopharyngeal incompetence condition

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SUMMARY Velopharyngeal incompetence (VPI) is a contributing factor to speech disorders, frequently accompanying disorders, such as cleft palate, congenital paralysis of the soft palate, and cerebrovascular disease. For the treatment of these types of dysarthria, a Nasal Speaking Valve (NSV), which regulates nasal emission utilizing one-way valve, has been reported to be effective. As the unpleasantness while wearing the NSV was less than that with the conventional Palatal Lift Prosthesis, the NSV could be worn for a longer period of time. As NSV is inserted into the nostrils, this device could easily be provided for edentulous patients. This study aimed to evaluate the effect of NSV on experimentally induced VPI condition. Intelligibility of monosyllabic speech, intelligibility of conversational speech, nasalance score and acoustic analysis were used to evaluate the effect of NSV. Local infiltration anaesthesia was achieved to the area of levator veli palatini muscle and tensor veli palatine muscle of seven adult male subjects. In all subjects, remarkable suppression of the soft palate movement could be observed after the local infiltration anesthesia. Although the utterance supported by NSV under the experimentally induced VPI condition was less natural than the normal utterance, the intelligibility was markedly improved by the device. From the results of this study, the acoustic properties of NSV on the pure VPI condition, which was enabled by the newly established experimental induction, were revealed. This experimental model was also proved to provide a basis for the improvement in the treatment modalities for VPI.

KEYWORDS: velopharyngeal incompetence, palatal lift prosthesis, dysarthria, intelligibility, speech, hypernasality

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Introduction

Velopharyngeal incompetence is a contributing factor to speech disorders, frequently accompanying disorders such as cleft palate, congenital paralysis of the soft palate, and cerebrovascular disease. The velopharyngeal valving mechanism regulates resonation and speech utterance and partakes in non-speech oral activities such as swallowing, blowing, sucking, and whistling. Velopharyngeal incompetence implies the presence of hypernasality, inappropriate nasal escape, and decreased air pressure during the production of oral speech sounds (weak pressure consonants) (1). Generally, behavioural interventions are reserved for those with mild or inconsistent velopharyngeal incompetence, whereas prosthetic or surgical management is typical in case with severe and consistent incompetence (2). The selection of an intervention approach also depends to some extent on the stability of the problem. If a speaker is improving rapidly (e.g. following brain injury), the decision not to intervene directly to improve velopharyngeal function is frequently made (2). For speakers with relatively stable velopharyngeal incompetence condition, treatment strategy includes both surgical and prosthetic procedures (3–7). One prosthetic treatment is a rehabilitative procedure employing a palatal lift prosthesis (PLP) to recover impaired speech (7–16). Because of discomfort while
wearing a PLP, such as difficulty in swallowing or vomiting reflex, a PLP requires rigorous clinical adjustment. While a well-adjusted PLP would result in satisfactory patient acceptance, patients sometimes have difficulty with appropriate adjustment for becoming accustomed to using the prosthesis. Some patients wear the PLP only when they must speak, and some even abandon wearing the prosthesis. As the PLP requires sufficient retention to the dental arch or palate, constructing a PLP for edentulous patients can be difficult or even impossible. Suwaki et al. (17) reported a device, nasal speaking valve (NSV), which improved dysarthria caused by the velopharyngeal incompetence. The NSV is a removable device inserted in the nostrils with a custom-made hard outer shell structure. One-way valves inhibiting exhalation through the valve and enabling free inhalation are inside. The NSV was reported to improve markedly dysarthria caused by velopharyngeal incompetence. As the unpleasantness while wearing the NSV was less than that with the PLP, the NSV could be worn for a longer period of time. Although the NSV is effective for dysarthria under VPI condition, it is sometimes difficult to cope with complicated patients suffering from VPI and dysfunctions of other articulation organs. Therefore, to understand the exact ability and to clarify the indication of NSV, it would be of great importance to observe and measure the effect of NSV worn under pure VPI condition.

This study aimed (i) to establish a model VPI by applying local infiltration anesthesia to healthy human soft palate and (ii) to evaluate the effect of NSV on pure VPI condition using the model VPI subject.

Materials and methods

Subjects

Seven adult males (mean age, 26.3 ± 1.9 years) served as subjects in this study. All subjects were native speakers of Japanese with normal hearing and no signs and symptoms related to the abnormality of the vocal cords. Infiltration anesthesia was conducted on the subjects to induce experimentally VPI as subsequently described. The NSV was made for each subject (Fig. 1). The plane view of the NSV is shown in Fig. 2. Schematic diagram of the wearing the NSV on the sagittal section through a nasal cavity is shown in Fig. 3.

Fig. 1. Nasal speaking valve. (a) Patient wearing the NSV. (b) Lateral view. (c) Frontal view.

Fig. 2. Plane view of the NSV.
Experimental ethics

The study was approved by the Ethics Committee of Okayama University (approval no. 370). All experiments were conducted in accordance with the Edinburgh Revision of Helsinki Declaration.

Fabrication of NSV

The NSV was made according to the method reported by Suwaki et al. (17), as outlined below. A small amount of putty vinyl polysiloxane impression material* was inserted separately into the right and the left nostrils. Then a small portion of light body vinyl polysiloxane impression material (Exafine injection*) was applied to the peripheral part of each nostril to assure peripheral seal. The two impression plugs were connected to record the relative position using vinyl polysiloxane occlusal registration material (Exabite II*). For a final cast of the nose, silicone impression material† was poured in the impression after boxing. On the final cast, the outer NSV shell was waxed up, and resin‡ was poured in after embedding and dewaxing. A one-way valve, allowing only inhalation, was installed on the outer end of each shell. A resin mesh trap was installed at the inner end of the shell as a security trap in case the valve falls because of an unexpected fracture.

Experimental design

Voice samples under normal condition (control) were recorded for each subject. All utterances and voice samples were recorded using a digital recording system§ in a speech therapy room. NSV was made for each subject after the impression of the nostrils. Local infiltration anesthesia was achieved by the injection of 2% Lidocaine with 1/80 000 epinephrine¶ to the area of levator veli palatini muscle and tensor veli palatine muscle, two entry points for each side. The effect of the local anesthesia for each subject was confirmed by the observation of the movement suppression of the soft palate during the pronunciation of /a/. Under the anaesthetic condition, the adjustment of the valve margin of NSV was achieved for each subject to minimize hyponasality sound. The sound data were recorded under the anaesthetic condition without wearing NSV (ANE) and with wearing NSV (ANE + NSV). Each recording session included recordings for intelligibility of monosyllabic speech, intelligibility of conversational speech, nasalance score and acoustic analysis as subsequently described. At the end of the whole experimental session under the anaesthetic condition, additional nasalance score evaluation was achieved (ANE-CNFRM) to confirm the functional effect of the local anesthesia. At 2 days after the above experiment, the sound data with wearing NSV under normal condition (control + NSV) were recorded.

Evaluation methods

Intelligibility of monosyllabic speech Recording for intelligibility of monosyllabic speech (IMS) was performed on the subject in a speech therapy room. The subject was asked to utter monosyllables as clearly as possible, with a pause in between each utterance. Japanese syllable-list, which contains 100 randomized monosyllables, was used. All utterances were recorded using a digital recording system as previously described. The listening evaluation was conducted in a quiet room. Each recorded utterance was played back at an average sound pressure level of 70 dB to three untrained seven listeners (one male, six females), who had never heard the utterance of the subject. The listeners were asked to write down the Japanese syllables that they heard. An

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*Exafine putty type; GC, Tokyo, Japan.
†Wirosil; Bego, Bremen, Germany.
‡Palapress vario; Heraeus Kulzer GmbH & Co. KG, Hanau, Germany.
§UA-3FX; Roland Co., Hamamatsu, Japan.
¶Lignospan; Nippon Shika Yakuhin, Shimonoseki, Japan.
The IMS score was determined as the mean percentage of correct responses from the seven listeners.

*Intelligibility of conversational speech (ICS)* For assessing conversational speech, this study used direct magnitude estimation (DME), whose reliability for evaluating hypernasal speech was confirmed by Whitehill (18). In DME, an investigator assigns a number to a standard stimulus sample referred to as the modulus. Listeners were required to rate all the recorded one minute short speech of each subject relative to the magnitude of the modulus. A standard recorded tape of hypernasality level two in the series of dysarthria** was used as a modulus in this study, and a modulus of 100 was assigned. In DME, the individual short speech record, with an attribute perceived to be twice as good as the modulus, is assigned a value of 200, and a sample with an attribute perceived to be half as good as the modulus, is assigned a value of 50.

*Nasalance score* Nasalance scores were obtained using a Nasometer 6200†† that samples the oral and nasal energy associated with speech simultaneously by means of two unidirectional microphones positioned in front of a speaker’s mouth and nose and separated by a metal plate. Nasalance values are computed according to the following formula: Nasalance score = [(nasal/-nasal + oral values)100].

The recorded sample consisted of stimulus vowels, nasal consonants (/ma/, /mi/, /mu/, /me/, /mo/), and the Kitsutsuki passage (19). The Kitsutsuki passage is composed of four sentences without any Japanese nasal sounds. The patient read the passage three times. For the Kitsutsuki passage, mean value of the sound expression time was calculated. For the evaluation of the nasalance score of nasal consonants, mean value of the maximal values of the nasalance score in each sound expression time of the five nasal consonants (/ma/, /mi/, /mu/, /me/, /mo/) was calculated. Statistical analysis was performed using the mean resulted values from three trials of the above nasal consonants nasalance score evaluation.

*Acoustic analysis* The five Japanese vowels, /a/, /e/, /i/, /o/ and /u/, were used as the sample vowel sounds. Each subject was asked to take a short breath and to sustain the vowel sound for 3–4 s. Acoustic analysis was performed using Multi-Speech 3700†† according to the report by Sumita et al.(20). From the amplitude-by-time waveform, a segment of 1 s duration from the middle portion was extracted for further analysis. The formant frequencies were calculated using an auto-correlation method of LPC. An LPC filter with 12 coefficients was chosen. The LPC spectra provided an amplitude-by-frequency display of the vowel. The centre frequencies of the first three spectral peaks were extracted from the LPC spectra as Formant 1 (F1) and Formant 2 (F2). The corresponding bandwidths for F1 and F2 were calculated automatically by the software system, and numeric results were provided in Hz. In addition, a peak was rejected as spurious if it was found to have a bandwidth >500 Hz. The F1 range and the F2 range were defined, respectively, as the difference between the minimum and the maximum frequency of the five vowels plotted on the F1–F2 plane in each subject. The F1 range was the width along the X-axis and the F2 range was the width along the Y-axis on the F1–F2 plane of five vowels.

All statistical analyses were performed on a personal computer with the statistical package Sigmasstat3.1††. For IMS, ICS, nasalance score and acoustic analysis, repeated measures analysis of variance of Ranks and Tukey test were used.

**Results**

In all the subjects, remarkable suppression of the soft palate movement could be observed for the pronunciation of /a/ after the local infiltration anesthesia. Typical hypernasality was also confirmed by hearing impression. IMS for each experimental condition is shown in Fig. 4. The score of IMS in the ANE condition was significantly lower than those in the control condition (P < 0.05). The IMS scores in the control condition and in the control + NSV condition showed a similar value. The score of IMS for every subject in the ANE + NSV condition showed higher values than the ANE condition. In addition, the IMS scores observed for the ANE + NSV was higher than 77.7 as shown in Fig. 4.

Figure 5 shows the results regarding the ICS, which was evaluated by means of the direct magnitude
estimation method. The score of ICS in the ANE condition was significantly lower than those of the control condition (\(P < 0.01\)). The score of ICS in the ANE + NSV condition was significantly higher than those of the ANE condition (\(P < 0.01\)), showing that intelligibility of conversational speech was significantly improved by the use of NSV. The score of ICS in the control + NSV condition was significantly lower than that of the control condition (\(P < 0.01\)).

Figure 6 shows the results of the nasalance score, which was evaluated using the recording of ‘Kitsutsuki’ passage. Significant differences were observed (\(P < 0.01\)) between each condition except for between Control and Control + NSV and between ANE and ANE-Confirm. Figure 7 shows the results of the mean Nasalance score of /\(\text{ma}\)/, /\(\text{mi}\)/, /\(\text{mu}\)/, /\(\text{me}\)/ and /\(\text{mo}\)/. The mean value for the five nasal consonants was summarized for each experimental condition. Although the Nasalance Score under NSV condition tended to show slightly lower values, no significant difference of Nasalance Score could be observed among these five conditions.

Figure 8 shows the result of the F1 and F2 scatter diagram of each experimental condition. Values are scattered in the ANE condition in comparison with control, and, values of ANE + NSV are assembled in comparison with ANE. Figure 9 shows the results of the F1 range for each experimental condition. The F1 range of the ANE condition was significantly lower than that of control and control + NSV (\(P < 0.01\)). The F1 range of the ANE + NSV condition was significantly higher than that of ANE (\(P < 0.01\)). Figure 10 shows the result of F2 range. The F2 range did not show any significant difference among the four experimental conditions.

Discussion
In the field of motor speech disorders, research on velopharyngeal incompetence has been achieved by incorporating real VPI patient (7–16). However, it is
rather difficult to find a patient with VPI and without other disorders in articulation organs. For the evaluation of the treatment modality, adopting a subject only with VPI would be necessary to achieve appropriate relevancy. In this study, experimental VPI was induced by the injection of local infiltration anesthesia to the soft palate of the healthy volunteer. In all the subjects, the movement of the soft palate was remarkably suppressed. The nasalance Score for the ‘Kitsutsuki’ passage for the subjects in Control condition was 10% in average. This mean score is consistent with the previous report by Tachimura et al. (19), which evaluated the score for normal adult Japanese speakers of mid-west Japanese dialect, thus supporting the fact that every subject in this study has no velopharyngeal disorders. The mean nasalance score for Kitsutsuki passage in ANE condition was 60.9%, which was higher than the average score of 33.5% for the repaired cleft palate patient reported by Tachimura et al. (21). In their report, the second highest value of nasalance score reported for the repaired cleft palate patient was 56.6% and was similar to the value for the ANE condition in this study. These results support the validity of the experimentally induced VPI in this study from the standpoint of nasal emission. No research article, which induced this kind of experimental VPI, could be found in our literature search. This method to induce experimental functional VPI would be useful for further investigation in this field.

Intelligibility of monosyllabic speech evaluation revealed that wearing NSV caused a marked improvement in the intelligibility score of monosyllabic utterance from 51% to 90% on average under the experimental VPI condition, which was almost equivalent to the score of control level. Meanwhile, ICS evaluation revealed that wearing NSV also caused a marked improvement in the direct magnitude estimation score from 28% to 51% of the control level. As this recovery could be observed in all the subjects, it was revealed that the NSV has a substantial effect for the treatment of dysarthria caused by the functional velopharyngeal incompetence.

Two methods were used to produce numerical objective coefficient regarding the hearing impression in this study, which are IMS and ICS. Although both methods are used for the evaluation of hearing impres-
sion, they are regarded as evaluating different aspects of the impression. IMS is intended to evaluate the intelligibility of single syllable, thus unrelated to the prosody. On the contrary, ICS is intended to focus mainly on the comprehensive ability of daily conversation which might also include the phonetic quality. In the experimental condition of this study, velopharyngeal functions of the subjects under the conditions of Control and control + NSV are completely normal. Therefore, as the resonance structure should not be affected by NSV, difference between these two conditions would be caused by the difference in the exhalation. Comparison of these two conditions revealed a marked reduction in ICS, whereas IMS showed rather stable values independent of the conditions. These results indicate that there exists a reduction in the voice quality by wearing NSV, which could not be digitalized by IMS. In other words, it was revealed that NSV would not reduce the very simple intelligibility, which would be typified by monosyllabic speech. However, it was also revealed that NSV would reduce the natural comprehensive intelligibility, which can be evaluated, for example, by the direct magnitude estimation method employed in this study. ICS for ANE + NSV was better than that for ANE. However, it was still lower than that for control + NSV. On the contrary, IMS showed a marked improvement, which is almost equivalent to the control condition. Namely, although the utterance supported by NSV would be less natural than the normal utterance, it was suggested that the improvement would be enough to make the utterance understandable. The marked improvement in IMS means that the speech function recovered to the level that, at least, syllabic speech could be understood correctly. This is a considerable clinical significance of the NSV. Further improvement in the NSV, which aims at better quality of the voice, would be necessary.

The formant analysis in this study showed a significant difference in the F1 range rather than in the F2 range under the experimental VPI condition. This is not consistent with the acoustic analysis on F2 range reported by Sumita et al. (20) on the maxillectomy patients. These changes observed in formant analysis were caused by the experimentally induced VPI condition. As other acoustic organs of the subjects were intact, these properties observed in the acoustic analysis could be regarded as the intrinsic properties of VPI. Sumita et al. speculated that the decrease in F2 value observed in the maxillectomy patient would be caused by the large space in the superior frontal portions of the vocal tract produced by the morphological connection between oral and nasal cavities. On the contrary, no morphological difference of the vocal tract, compared with the normal condition, exists in the experimental VPI subject. However, during the specific utterance, which needs the functional closure of nasal cavity by the soft palate, the vocal tract incorporates the additional resonance chamber of nasal cavity because of the experimental VPI. Therefore, the decrease in the F1 range observed in ANE condition might be the result of the influence by nasal formant and anti-formant caused by the branched vocal tract (22). As the NSV is designed to close the nostrils, it could affect the acoustic properties of the vocal tract. However, from the results of the digital acoustic analysis in this study, it was revealed that NSV could make the F1 F2 range recovered equivalent to the normal condition. These findings would provide an important basis for the future acoustic analysis on other related dysfunctions or dysarthria.

Velopharyngeal incompetence, if not treated adequately, sometimes affects other motor functions related to speech. For example, VPI could be a cause for the functional insufficiency of respiratory support, even though the respiratory function itself was not physically handicapped (23). Moreover, VPI could bring about maladaptive compensatory adjustments in other aspects of speech. To avoid these undesirable compensatory maladaptations or the secondary impairment of utterance, it would be desirable to accommodate VPI in an early stage of the speech rehabilitation. From this standpoint, intervention with prosthodontic appliances, like palatal lift prosthesis, has been regarded as desirable to achieve before these maladaptive compensatory adjustments. Fabrication process of NSV is much simpler than the conventional palatal lift prosthesis, and the physical strain of a patient forced on the NSV adjustment is also very limited. The simplicity in the fabrication and adjustment of NSV would be an important advantage of this appliance, especially compared with the conventional palatal lift prosthesis, which requires certain period of time before the patient’s adaptation to the prosthesis. As NSV is inserted into the nostrils, this device could easily be provided for edentulous patients.

Stewart and Rieger (24) reported a clinical VPI case that was treated with nasal obturator. The patient was reported to be rehabilitated that he was able to make
smooth conversation after 2 years use of the obturator. The obturator was made with silicone rubber material, which completely blocks both inhalation and exhalation. Therefore, because of the necessity of mouth breathing, the possibility of the drying of mouth and throat was suggested. Hakel et al. (25) reported a nasal obturator with a one-way valve, which was fabricated utilizing a commercially available nasal filter. They reported the recovery of speech performance by wearing the device and also obvious air escape between the external surface of the obturator and the interior nasal walls as the obturator were not custom-fit for each speaker. As the NSV in this study was made custom-fit to each personal nostril, it was possible to control exhalation accurately. To avoid mechanical irritation, which would cause pain on nasal mucosa and snivel, custom fitting would be desirable to allow successive use of the device. Moreover, once complete fit of the device to the interior surface of the nostril is achieved, fine adjustment of the device to allow controlled constant and least flow of exhalation, which could minimize hyponasality, becomes possible. As was revealed by the results of nasalance score for nasal consonants, NSV did not cause a significant decrease in the score. These results suggest that the NSV, which is adequately adjusted to allow controlled exhalation, could minimize the effect on nasal consonants. From these results of this study, employing experimental VPI subjects, some acoustic and phonetic features of simple VPI and the phonetic effect of NSV were revealed. Further investigation would be necessary to clarify the comprehensive effect of this device on the oral and speech rehabilitation.

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