ORIGINAL

Effects of vocal nodules on acoustic characteristics of voice in children : an acoustic analysis of voice

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Abstract : Objective : In the present study, an attempt was made to evaluate the acoustic characteristics of voice in pediatric patients with vocal nodules using acoustic analysis of voice. Methods : Thirty-five pediatric patients with vocal nodules and 32 control children without dysphonia were enrolled in this study. Their voice samples were analyzed using the Multi-Dimensional Voice Program. Acoustic parameters of voice, such as pitch period perturbation quotient (PPQ), amplitude perturbation quotient (APQ), and noise-to-harmonic ratio (NHR), were measured. Results : In phonation at a loudness of over 80 dBA, the PPQ, APQ, and NHR values of the voice significantly increased in children with vocal nodules than in the control children without dysphonia. The sensitivities and specificities of PPQ, APQ, and NHR for prediction of vocal nodules in children were 62.86% and 84.38%, 74.29% and 75.00%, and 31.43% and 93.75%, respectively. Discussion : The present findings suggest that vocal nodules affect vocal fold vibration, resulting in impaired control of pitch and loudness leading to increased noise components. NHR could be used to evaluate the efficacy of treatment, such as voice rehabilitation, in pediatric patients with vocal nodules because of its high specificity for prediction of vocal nodules in children. J. Med. Invest. 68 : 276-279, August, 2021

Keywords **:** *vocal nodules, pediatric patients, dysphonia, acoustic analysis of voice*

INTRODUCTION

The prevalence of dysphonia is approximately 6% among children aged eight years (1). Dysphonia develops mainly in children aged 7-12 years, predominantly boys, and vocal nodules are the most common cause of dysphonia in childhood (2). Vocal abuse and incorrect use of the voice are the main predisposing factors for vocal nodules (3). Vocal nodules are diagnosed using video-stroboscopic examinations in adult patients. However, pediatric patients hardly accept the examination because of their lack of collaboration and patience (4), which prevents regular follow-up of patients' laryngeal findings. For the assessment of voice disorders in children, multi-dimensional assessments, including perceptual and objective voice evaluations, have been recommended by the European Laryngological Society (5). In addition, a minimum protocol for the pediatric voice clinic recommended measuring acoustic parameters of voice in pediatric patients with dysphonia (4). Recently, the objective and quantitative acoustic analysis of voice has been clinically used as a complementary assessment method for diagnosis of vocal nodules in children and for follow-up assessment during voice rehabilitation (6).

In the present study, an attempt was made to evaluate the acoustic characteristics of voice in pediatric patients with vocal nodules using acoustic analysis. However, it has been reported that acoustic parameters of voice vary with different loudness of phonation in children (7). Therefore, in Experiment 1 of the present study, we first examined the effects of predefined or comfortable loudness of phonation on acoustic parameters of voice, such as pitch period perturbation quotient (PPQ), amplitude perturbation quotient (APQ) (8), and noise-to-harmonic ratio (NHR) (9) in children without dysphonia. In Experiment 2, we compared acoustic parameters of voice in pediatric patients with vocal nodules to those in control children without dysphonia. Finally, we performed receiver operating characteristic (ROC) analysis to identify the best acoustic parameters of voice for prediction of vocal nodules in children.

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METHODS

Experiment 1

Participants

In Experiment 1, 21 children (11 boys and 10 girls, mean age : 7.86 ± 1.56 years) with no vocal symptoms or history of phoniatric disorders were enrolled. The voice quality of all participants was evaluated as euphonic by otolaryngologists in auditory-perceptual evaluation. This study was approved by the Committee for Medical Ethics of Tokushima University Hospital. Written informed consent was obtained from a parent of each child prior to the experiment.

Recordings

Each child's voice was recorded while he or she was seated in a quiet room (in a sound-attenuated room with an ambient noise level below 30 dB). Recordings were obtained using a microphone (Ultra-Linear Measurement Condenser Microphone ECM8000, Behringer, Japan) placed on a stand at a distance of 10 cm and at an angle of 45° from the child's lips to reduce aerodynamic pop noise, with a sampling rate of 44.1 kHz and 16-bit quantization. Task instructions were given by the examiner prior to the recording. Three samples of sustained vowel /e/ recordings for 3 seconds were obtained under the instruction to phonate at a loudness of over 80 dBA, confirmed using a sound-level meter (Audio Analyzer PAA3, Phonic, Japan) and at a comfortable loudness with an instruction of conversational pitch and loudness. The sound pressure level of the recorded voice was calibrated by recording of a pure tone of 62 dBA at 1 kHz generated by a sound calibrator (NC-74, Rion, Tokyo, Japan). Brockmann-Bauser, *et al*. reported the voice SPL in phonation at a comfortable loudness ranged from 62.7 to 93.8 dBA in children (10).

Experiment 2

Participants

In Experiment 2, 35 pediatric patients with vocal nodules (31 boys and 4 girls, mean age : 7.46 ± 1.46 years) and 32 control children with no vocal symptoms or history of phoniatric disorders (24 boys and 8 girls, mean age : 8.53 ± 1.61 years) were enrolled. Vocal nodules in these pediatric patients were diagnosed by otolaryngologists using video-laryngoscopic examination. Stroboscopic illumination was not applied because all patients could not sustain the vowels in a relaxed manner during the examination. The voice quality of the control children was evaluated as euphonic by otolaryngologists in auditory-perceptual evaluation. There was no sex ratio difference between pediatric patients with vocal nodules and control children ($p = 0.15$). This study was approved by the Committee for Medical Ethics of Tokushima University Hospital. Written informed consent was obtained from a parent of each pediatric patient with vocal nodules and control child prior to the experiment.

Recordings

The parameters of the voice recordings were similar to those in Experiment 1. Three samples of sustained vowel /e/ recordings for 3 seconds were obtained for all the participants under the instruction to phonate at a loudness of over 80 dBA.

Acoustic analysis

All recordings were analyzed using the Multi-Dimensional Voice Program (MDVP, Kay Pentax, USA) (11) in both experiments. A second mid-vowel portion of each sample without the onset and offset of phonation was prepared for analysis. The acoustic parameters of PPQ, APQ, and NHR were measured in three samples from each child, and the avalage value was used for statistical analyses.

Statistical analysis

The F test and paired t-test were used in Experiment 1, and Chi-square for independence test, Student's t-test and ROC analysis were used in Experiment 2 for statistical analysis using Statcel version 4 (OMS Publishing Inc., Saitama, Japan) and statistical software EZR (12). $p < 0.05$ was considered statistical significant. The optimum cut-off values were defined using the points closest to (0, 1) on the ROC curve.

RESULTS

Experiment 1

The variances of PPQ and NHR, but not APQ, in phonation at a loudness of over 80 dBA were significantly lower than those in phonation at a comfortable loudness in children without dysphonia ($p < 0.01$) (Table 1). The mean values of PPQ, APQ, and NHR in phonation at a loudness of over 80 dBA were significantly lower than those in phonation at a comfortable loudness in children without dysphonia ($p < 0.01$) (Table 1).

Table 1. PPQ, APQ and NHR in phonation at a loudness of comfortable loudness and over 80 dBA in children without dysphonia

Parameters		Comfortable phonation	>80dBA phonation	p value
PPQ(%)	Mean ± SD	1.37 ± 0.58	0.51 ± 0.32	<0.0001
	Range	0.49-2.75	0.11-1.53	
	Variance	0.3413	0.1002	0.0086
APQ(%)	Mean ± SD	3.69 ± 0.99	2.77 ± 1.01	<0.0001
	Range	2.69-6.99	1.58-6.22	
	Variance	0.9764	1.0065	0.9352
NHR	Mean ± SD	0.14 ± 0.04	0.12 ± 0.01	0.0049
	Range	0.10-0.24	0.10-0.16	
	Variance	0.0013	0.0002	<0.0001

Experiment 2

The mean values of APQ, PPQ, and NHR in the pediatric patients with vocal nodules were significantly larger than those of the control children without dysphonia (PPQ in Fig. 1, $p < 0.01$, APQ in Fig. 2, $p < 0.01$, HNR in Fig. 3, $p < 0.05$). The abilities of PPQ, APQ, and NHR to predict vocal nodules were assessed using ROC analysis. The optimum cut-off value of PPQ was 0.774 for prediction of vocal nodules in dysphonic children with a sensitivity of 62.86% and a specificity of 84.38%. The optimum cut-off value of APQ was 2.902 with a sensitivity of 74.29% and a specificity of 75.00%. The optimum cut-off value of NHR was 0.142 with a sensitivity of 31.43% and a specificity of 93.75% (Table 2).

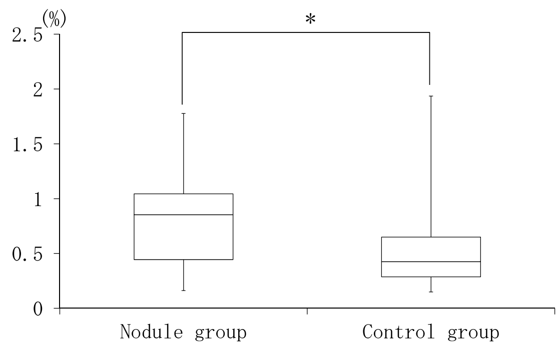

Figure 1. PPQ in pediatric patients with vocal nodules and control children without dysphonia. PPQ (pitch period perturbation quotient). *$p < 0.01$.

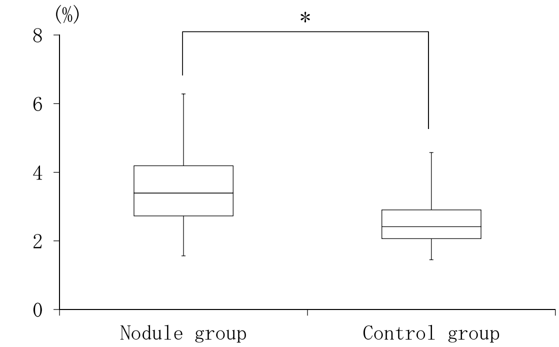

Figure 2. APQ in pediatric patients with vocal nodules and control children without dysphonia. APQ (amplitude perturbation quotient). *$p < 0.01$.

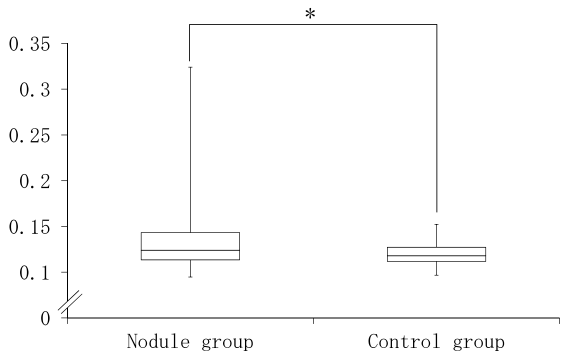

Figure 3. NHR in pediatric patients with vocal nodules and control children without dysphonia. NHR (noise-to-harmonic ratio). *$p < 0.05$.

Table 2. Cut-off value, sensitivity and specificity of PPQ, APQ and NHR

Parameters	Cut-off	Sensitivity (%)	Specificity (%)
PPQ	0.774	62.86	84.38
APQ	2.902	74.29	75.00
NHR	0.142	31.43	93.75

DISCUSSION

Although phonation at a comfortable loudness was used in acoustic analysis of voice in children according to the recent guideline (4), it was reported that acoustic parameters of voice varied with different loudness of phonation in children (7). In adults, acoustic parameters of voice are reliably measured in phonation at a loudness of over 80 dBA (13). In Experiment 1, the variances of PPQ and NHR, but not APQ, in phonation at a loudness of over 80 dBA were smaller than those in phonation at a comfortable loudness in children without dysphonia. These findings suggest that phonation at a predefined loudness of over 80 dBA increases the reliability of acoustic parameter measurements of voice in pediatric patients without dysphonia. The values of PPQ, APQ, and NHR in phonation at a loudness of over 80 dBA were smaller than those in phonation at a comfortable loudness in children without dysphonia. Brockmann-Bauser *et al*. also reported that the values of jitter (similar to PPQ) and shimmer (similar to APQ) decreased in phonation at the predefined loudness of over 80 dBA in children (10). Because subglottal pressure and medial compression of the vocal folds increased during loud phonation, the present findings suggest that the vibratory pattern of the vocal folds became stable in phonation at a loudness of over 80 dBA, resulting in decreased PPQ, APQ, and NHR values. Therefore, we decided to use phonation at a loudness of over 80 dBA in acoustic analysis of voice in pediatric patients with vocal nodules in Experiment 2.

In Experiment 2, we performed acoustic analysis of voice in phonation at a loudness of over 80 dBA using MDVP, and found that PPQ, APQ, and NHR values increased in children with vocal nodules than in the control children without dysphonia. Vocal nodules are mediolaterally symmetrical submucosal lesions at the anterior midsection of the vocal folds, and develop due to overuse of the voice, repeated vocal abuse over time, and vocal strain (14). Because PPQ and APQ are indices of frequency and amplitude perturbation of voice, respectively, these findings suggest that vocal nodules on bilateral vocal folds affect the control of pitch and intensity of the voice. It was reported that the value of PPQ of the voice was affected by the width of the vocal nodules in pediatric patients (15) and that vocal polyp, a unilateral vocal mass lesion, had greater effect on vocal vibration to induce higher elevations of jitter and shimmer (similar to PPQ and APQ, respectively) than bilateral vocal nodules (16). Taken together with the present findings, it is suggested that vocal nodules, as a mass lesion on bilateral vocal folds, affect the vibration of vocal folds, resulting in impaired control of pitch and loudness of the voice. Gramuglia *et al*. also reported that children with vocal nodules showed elevations in PPQ and APQ of voice (17).

The elevation in the value of NHR of the voice in children with vocal nodules in the present study is consistent with previous reports (17, 18). Because NHR is an index of the noise component, the findings suggest that vocal nodules on bilateral vocal folds produce a noise component, an essential element of dysphonia. It has been reported that the value of HNR (a semantic inverse of NHR) of voice is affected by the mediolateral width of the vocal nodules in children (15). Therefore, the increased NHR in the present study suggests that glottal insufficiency due to protruded vocal nodules exacerbates noise components in voice signals.

Although the video-stroboscopic examination is considered the best modality for diagnosing and assessing vocal nodules, it is difficult for pediatric patients to cooperate with an uncomfortable examination (4). Therefore, there ia an essential need for quick, non-invasive, and well-tolerated methods, such as computer-assisted voice analysis, for pediatric patients. In general, the clinical evaluation of voice disorders consists of diagnosis and monitoring steps. It would be ideal for both steps to be examined using a non-invasive modality. For this purpose, the degree of sensitivity of the examination is crucial for the diagnosis. In the present study, sensitivites and specificities of the three acoustic parameters were evaluated to predict vocal nodules in children. Among the three vocal parameters, sensitivity was highest in APQ. However, its value of 74.28% is too low for screening and diagnosing the presence of vocal nodules in children. Therefore, acoustic analysis seemed not to be suitable for the diagnosis of pediatric voice disorders. That is, an invasive method of video-stroboscopy/laryngoscopy is still necessary for diagnosis. Because the highest specificity of 93.75% in NHR demonstrates its ability to designate an individual who does not have the disease, it is suggested that NHR can monitor the efficacy of treatment, such as voice rehabilitation, in pediatric patients with dysphonia. Moreover, it was reported that jitter (similar to PPQ), shimmer (similar to APQ), and NHR improved after voice therapy in children with vocal nodules (19, 20). Therefore, regular follow-up using NHR combined with PPQ and APQ could be acceptable for monitoring pediatric patients with vocal fold nodules if an occasional video-stroboscopy/laryngoscopy is performed.

CONCLUSION

Because the variances of PPQ and NHR, but not APQ in phonation at a loudness of over 80 dBA were smaller than those in phonation at a comfortable loudness in children, we used phonation at a predefined loudness of over 80 dBA in acoustic analysis of voice using MDVP in pediatric patients with vocal nodules. Of the three acoustic parameters, NHR could be used to evaluate the efficacy of voice rehabilitation in pediatric patients with vocal nodules because of its high specificity for prediction of vocal nodules in children.

CONFLICT OF INTEREST

The authors declare no conflicts of interest in this study.

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