Noninvasive Examination of The Adenoids Using Acoustic Analysis

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Abstract
Lateral cephalograms and cone beam computed tomography (CBCT) have been used to examine adenoids. However, these examination methods are invasive because of radiation exposure, and it is unsuitable to screen the young children. An alternative approach may be analysis of voice signals, which contain information on vocal fold vibration and vocal tract morphology. The cepstrum analysis, an acoustic analysis, can extract information on the morphology of the vocal tract. This study aimed to examine adenoids by performing acoustic analysis on nasal sounds.

Fourteen subjects (8 boys and 6 girls; mean age 8.1 ± 1.3 years) were included in the adenoid group and 14 subjects (6 boys, 8 girls, mean age 8.5 ± 1.2 years old) were included as the control group. Lateral cephalogram and CBCT were used for evaluating the anatomical morphology; the wavelength to vocal tract length ratio (WVR) was calculated from the vocal signal of the nasal sound by cepstrum analysis. Then, these parameters were compared between the groups. The identification boundary value of adenoids with WVR was also examined.

A/N, pharyngeal tonsil length, and pharyngeal tonsil thickness was significantly larger, and distance of narrowest part of the airway, PNS1-PNS2 was significantly smaller in the adenoid group than the control group.

In cepstrum coefficients 40, 44, 48, 52, and 56, WVR was significantly smaller in the adenoid group. Additionally, in the range of cepstrum coefficients 44 to 56, 80% or more adenoids was expected to be identified.

The findings suggest that cepstrum analysis could be used to examine adenoids noninvasively.

Keywords:
adenoil,
air way,
acoustic analysis,
malocclusion

Introduction
Pharyngeal tonsils are responsible for protecting against infection in the nasal cavity and are a component of Waldeyer’s lymphatic ring, further composed of the tubal tonsils, palatine tonsils, and lingual tonsil. Following the acquisition of immune function, pharyngeal tonsil enlarged in early childhood, and gradually become smaller with growth (1, 2). However, hypertrophy of the pharyngeal tonsil caused by chronic recurrent inflammatory reaction – also known as adenoids – do not shrink, narrowing of the an airway pharyngeal region and impaired aeration may occur, inhibiting normal nasal breathing and often leading to mouth breathing (2). Long-term mouth breathing in early childhood has been considered an early onset factor of severe malocclusion, accompanied by long face and open bite (2–5). In addition, adenoids and hypertrophy of palatine tonsils is one of the main causes of sleep apnea syndrome (SAS) in children, leading to delays in cognitive and structural development, and deterioration of quality of life (6, 7).

Lateral cephalograms have previously been used to examine adenoids. In recent years, it has become possible to
measure three-dimensional morphological features of the airway and evaluate the airflow ventilation state by using cone beam computed tomography (CBCT) (8). However, these examination methods, while excellent in accuracy, are invasive as they involve radiation exposure. Therefore, it is unsuitable to follow the disease, or to screen young children.

Acoustic rhinometry is a noninvasive examination method which estimates the cross sectional area in the nasal cavity by using the reflection of sound waves generated from the examination nozzle inserted in the nostril (9). However, because the body movement during the examination is unacceptable and the examination nozzle is inserted into the nostrils, cooperativeness cannot be obtained in young children. Furthermore, as the precision gradually decreases from the anterior side to the posterior side of the nasal cavity, it is difficult to examine adenoids located in the nasopharynx.

Contrary, the voice recording is more acceptable for a young child. Voice recording captures voice signals, which contain information on vocal fold vibration and vocal tract morphology. Cepstrum analysis is a method of converting a signal from various information, which is transformed through summation and processing. Cepstrum analysis was first applied to acoustic analyses by Noll et al. in 1964 (10). In addition to acoustic analysis, cepstrum analysis is also applied to other fields such as analysis of seismic waves and radar signals (10–12).

However, no reports to date had analyzed the voice signal of nasal sound by using cepstrum analysis and discriminate the change in the shape of vocal tract caused by the adenoids.

Thus, the aim of this study was to investigate the morphological characteristics of the airway of patients with adenoids, and to examine the usefulness of acoustic analysis in adenoids diagnosis.

Materials and Methods

Subjects

This research was approved by the Matsudo Ethics Committee at Nihon University School of Dentistry (approval number: EC17-029). Subjects were selected among patients who visited the Department of Orthodontics at Nihon University’s hospital at Matsudo, Japan. And we gave consent to subjects and their parents by explaining our research. The patients with the following conditions were excluded: surgical treatment history for nasopharyngeal disease, nasal septum erythema, abnormal nasal resistance value, palatine tonsil hypertrophy, past history of orthodontic treatment, or congenital disease accompanied by abnormality of the facial skeleton. And to test the problem in breathability of the nasal cavities, all subjects underwent measurement of nasal resistance by using rhinomanometry (MPR 3100, Nihon Kohden, Tokyo, Japan). As a result, no participants had a problem in breathability (13).

From the lateral cephalogram, classification was performed using the adenoidal-nasopharyngeal ratio (A/N), a common examination parameter of adenoids (14, 15) (Fig. 1). The grouping of this study was based on the criteria reported by Kolo et al. (2011) (15). Fourteen patients (8 boys, 6 girls, mean age 8.1 ± 1.3 years old) with an A/N of 0.63 or more were referred to as the adenoid group and 14 patients with a normal nasopharyngeal airway with an A/N of less than 0.5 (6 boys, 8 girls, mean age 8.5 ± 1.2 years old) were defined as the control group.

Methods

Measurements of lateral cephalogram

Lateral cephalograms were taken in a seated position,
with the head fixed parallel to the Frankfurt plane, and the
tongue resting at the maximal intercuspal position. Tracing
and measurement of the lateral cephalogram were per-
formed by the same investigator to eliminate inter-rater
error.

Measurements were made according to the methods
outlined by Aoki (2012) (16). Reference points were set and
the reference plane, as well as six parameters, were
measured. These measures included the following: pharynge-
al tonsil length, pharyngeal tonsil thickness, distance of
narrowest part of the airway, PNS1-PNS2, soft palate length,
and soft palate angle (Fig. 2).

Measurement of vocal tract length

The distance between the glottis and nostril (vocal tract
length) was measured from CBCT images. CBCT (KaVo 3D
eXam +, KaVo Dental Systems Japan, Tokyo) was taken in
the seated position, with the head fixed parallel to the
Frankfurt plane, and the tongue resting at the maximal
intercuspal position. All CBCT images were obtained using
the following parameters: 90 kV, 3.6 mAs, 15-second scan
time, and 20 × 19 cm field of view. Slice thickness was set at
0.3 mm and the voxel size was 0.3 × 0.3 × 0.3 mm. The 3D
images were transformed to DICOM (Digital Imaging and
Communications in Medicine) format and displayed using
DICOM viewer (INTAGE station, Cybernet System, Tokyo,
Japan).

For the measurement of vocal tract length, 3 arbitrary
sagittal sections that could be confirmed in a CBCT image
of the nasal cavity in the median face were selected and the
average values were measured three times for each section.
The line used to measure vocal tract length was a line that
passed from the glottis to the nasopharynx through the
center of the airway. The inside of the nasal cavity was a line
passing through the center of the middle nasal meatus, as
the middle nasal meatus is considered to be the mainstream
location of intranasal respiratory airflow reported by Konno
(1969) (17). Measurements were performed using image
processing software (ImageJ 1.51 j 8, National Institutes of
Health, USA).

Test sound recording

Audio recordings were carried out with a unidirectional
condenser microphone (ATM31a; Audio-Technica
Corporation, Tokyo, Japan); the subject was seated with the
microphone placed approximately 20 cm from their mouth
(far enough to be unaffected by expiratory flow). The test
sound was a nasal consonant (/N/), requiring lip closure; the
utterance was performed for 3 seconds.

Speech data were collected at a sample frequency of 22.05 kHz and precision of 16 bits using an Audio-Technica interface (Edirol UA-25EX: Roland Corporation, Shizuoka, Japan). Data were then stored on a personal computer (Vostro; Dell Japan, Inc., Kanagawa, Japan). Extraction of test sound and deletion of silence area were performed using voice waveform analysis and editing software (Acoustic Core, Arcadia Inc., Osaka).

**Cepstrum analysis**

The outline of cepstrum analysis is shown in Fig. 3. In cepstrum analysis, Fourier transforms are used to convert a voice signal in the time domain into a signal in the frequency domain. The cepstrum is defined as the inverse Fourier transform of the logarithm of the estimated spectrum of a signal. A variable of the cepstrum is an inverse Fourier transform of the frequency axis of the spectrum and is called “quefrency” (18). When analyzing cepstrum, the low quefrency region corresponds to vocal tract morphology information and the high quefrency region provides information on the vocal fold vibrations (Fig. 4) (18). The formant, which is included in the transfer characteristic of the low quefrency region, refers to the general form of the resonance characteristic at a number of emphasized peaks observed on the voice signal spectrum. Further, these changes depend on the shape of the vocal tract (19, 20). In this study, we identified the first-anti formant (AF1) that is characteristically recognized in nasal sound.

We performed a cepstrum analysis of voice signals, using acoustic analysis software (Matlab R2016b, Mathworks, USA). While filtering (liftering) the separation, the boundary between the high quefrency region and the low quefrency region was extracted by arbitrary cepstrum coefficients. The frequency of AF1 was specified from the power spectrum of the obtained low quefrency region, and the fundamental wavelength of the subject was calculated (Fig. 5). In this study, the cepstrum coefficients were set to 40, 44, 48, 52, 56, and 60.

**Calculation of wavelength to vocal tract length ratio (WVR)**

The formant frequency varies with the length of the vocal tract. For this reason, to correct for the difference in physique between subjects, vocal tract length was measured from CBCT images. The fundamental wavelength obtained by cepstrum analysis was then divided by the vocal tract length to calculate the WVR.

**Statistical analysis**

The mean values and standard deviations for each morphometry and acoustic analysis variable were calculated. Comparison between the two groups was made using the Mann-Whitney U test, and $P < 0.05$ was considered statistically significant. Also, as a result of acoustic analysis, the discrimination boundary value using WVR was set, and the discrimination rate of adenoid was examined. For between-group comparisons, IBM SPSS statistics 25.0 (IBM Japan, Tokyo, Japan) was used.
Results
Comparison of adenoids and an airway pharyngeal region

There was no statistically significant difference by gender in this study. The results comparing the two group’s anatomical measurements are shown in Table I. A/N \((P<0.01)\), pharyngeal tonsil length \((P<0.05)\), and pharyngeal tonsil thickness \((P<0.01)\) was significantly larger in the adenoid group than in the control group. Distance of narrowest part of the airway \((P<0.01)\), and PNS1-PNS2 \((P<0.05)\) was significantly smaller in the adenoid group than in the control group, but no difference was observed in soft palate length and soft palate angle.

Comparison of WVR

The results from comparison of the WVR calculated from the cepstrum analysis are shown in Table II. In cepstrum coefficients \(40(P<0.05)\), \(44(P<0.05)\), \(48(P<0.01)\), \(52(P<0.05)\), and \(56(P<0.05)\), WVR was significantly shorter in the adenoid group than in the control group. No significant difference was observed in cepstrum coefficient 60.

Comparison of discrimination ratios of the adenoids with WVR as discrimination boundary value

The discrimination ratios of the adenoids for each parameter are shown in Fig. 6. The discrimination boundary values for the cepstrum coefficients were as follows: cepstrum coefficient 44: 0.60 to 0.65, cepstrum coefficient 48 and 52: 0.75 to 0.83, cepstrum coefficient 56: 0.95 to 1.10. To obtain a high discrimination ratio, a value of 0.80 or greater was required. In addition, cepstrum coefficients 40 and 60 were insufficient to obtain optimum discrimination ratios.

Discussion

It has been reported that adenoid-constricted airways induce chronic mouth breathing(2). The A/N proposed by Fujikata (2012) (14) allows for the assessment of adenoid severity in the lateral cephalogram. In addition, with the widespread use of CBCT in recent years, evaluation of three-dimensional airway morphology and evaluation of aeration condition has become possible (8). Feng et al. (2015) (21) compared an airway pharyngeal region by lateral

Fig. 4. Cepstrum

The low quefency region corresponds to vocal tract morphology information and the high quefency region provides information on the vocal fold vibrations.

\(\text{①} \) Low quefency region, \(\text{②} \) High quefency region. Dotted line: This shows “Lifter” which is a function for setting the boundary between two region.
cephalogram and CBCT and found a correlation between A/N and airway volume. In the present study, the lateral cephalogram analysis revealed the adenoid group to be significantly different from the control group in pharyngeal tonsil length, pharyngeal tonsil thickness, and distance of narrowest part of the airway. It was shown that classification of both groups by A/N was appropriate. In addition, the distance of the narrowest part of the airway where obstruction of nasal respiration occurs is less than 5.0 mm; (22) in this study, the distance of the narrowest part of the airway in the adenoid group was in the range of 1.0 to 7.0 mm, and the median value was 4.75 mm. Therefore, the

**Table 1. Comparison of adenoids and an airway pharyngeal region**

|                      | Control group (N=14) | Adenoid group (N=14) | p-value |
|----------------------|----------------------|----------------------|---------|
|                      | Minimum | Median | Maximum | Minimum | Median | Maximum |         |
| A/N ratio            | 0.37     | 0.43   | 0.46     | 0.63     | 0.69   | 0.81     | 0.00**  |
| Pharyngeal tonsil length (mm) | 19.0     | 23.0   | 29.0     | 20.0     | 29.0   | 35.0     | 0.02*   |
| Pharyngeal tonsil thickness (mm) | 0.0      | 2.0    | 4.5      | 2.0      | 6.0    | 7.0      | 0.00**  |
| Distance of narrowest part of airway (mm) | 8.0      | 10.3   | 18.0     | 1.0      | 4.8    | 7.0      | 0.00**  |
| PNS1-PNS2 (mm)       | 16.0     | 21.8   | 27.0     | 9.5      | 18.0   | 26.0     | 0.01*   |
| Soft palate length (mm) | 24.0     | 29.0   | 33.5     | 25.0     | 28.0   | 35.0     | 0.73    |
| Soft palate angle (degree) | 36.0     | 44.8   | 52.0     | 36.0     | 50.0   | 60.0     | 0.06    |

*Mann-Whitney’s U test* Level of significance *; p<0.05 **; <0.01

Fig. 5. Identification of AF1 from the power spectrum of transfer characteristics. Multiple peaks of the waveform represent formants. Nasal sounds can be clearly observed as negative peaks in the valleys between formants, with the anti-formant characteristic of the bifurcated resonance tube of the oral cavity and nasal cavity.
subjects in the adenoid group, it is considered that the breathability has been impaired. Since the adenoids gradually migrate from the most protruding part to the posterior pharyngeal wall, the significant difference between the two groups observed in PNS 1-PNS 2 is attributed to the pharyngeal posterior wall being positioned more forward in the adenoid group.

There was no significant difference in soft palate length and soft palate angle between the two groups. Soft palate is a soft tissue that constitutes the anterior wall of the nasopharynx. Therefore, the form of the pharyngeal amygdala constituting the posterior wall of the nasopharyngeal airway has a large influence on the airway form in the studied subjects.

Nasal sound assessment involves elucidation of the characteristic aspects of the bifurcated resonance tube comprising the nasal cavity and the oral cavity. Further, when sound energy does not pass effectively, an anti-formant occurs on the spectrum (23, 24). Since anti-formant is included in the low quefrency region of the cepstrum,
liftering to separate the boundary with the high quefrency region is important. In this study, through liftering, the low quefrency region of arbitrary cepstrum coefficients was extracted, revealing significantly smaller WVR in the adenoid group for cepstrum coefficients 40, 44, 48, 52, and 56, compared to the control group. This may be explained by differences in the fundamental vibration; in the control group, the fundamental vibration of the vocal tract was from the vocal cord to the nostril, while in the adenoid group, the vibrations of the sound changed in the narrowed part of the airway and the length from the vocal cord to the narrowed part of the airway is reflected in the wavelength as the fundamental vibration. This is consistent with the results that showed the narrowing of the airway occurred to such an extent that breathable obstruction can be anatomically measured in the adenoid group. However, the cepstrum coefficient 60 showed no significant difference between groups. Following liftering, as the cepstrum coefficient increased, the components of the high quefrency region were also extracted, creating a complicated waveform in the outline of the power spectrum (23). Therefore, AF1 was then calculated to be a small value and the error between subjects increased.

Moreover, in this study, obtaining a discrimination rate of 80% or greater was likely when using WVR as the discrimination boundary value for the adenoids, depending on the parameters set for cepstrum coefficients between 44 and 56. This suggests that extraction of the low quefrency region is insufficient for cepstrum coefficient 40, and for cepstrum coefficient 60, it is a result of extracting an abundance of the high quefrency region. As stated earlier, when cepstrum analysis is applied to adenoid identification, the appropriate cepstrum coefficient is in the range of 44 to 56. However, even within this range, about 20% of the subjects were misdiagnosed. From this, it is difficult to use this examination method for deterministic diagnosis, because it is considered that there are individual differences in appropriate cepstral coefficients.

**Conclusion**

The airway narrowed by the adenoids shortened the fundamental wavelength. It is indicated that cepstrum analysis is able to discriminate the adenoids.

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