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Effect of adenoids and tonsil tissue on pediatric obstructive sleep apnea severity determined by computational fluid dynamics

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ABSTRACT

Study objective: Obstructive sleep apnea (OSA) is a respiratory disorder caused by the obstruction of the upper airway during sleep. The most common cause of pediatric OSA is adenotonsillar hypertrophy. Adenotonsillectomy is the first-line treatment for pediatric OSA; however, OSA persists in a significant number of patients due, in part, to the method of evaluating enlarged adenoids and tonsil tissue (AT). The reason for these effects on OSA severity is not clear. This study aimed to establish a method to diagnose the need for adenoidectomy or tonsillectomy.

Methods: Twenty-seven Japanese children (mean age 6.6 years) participated in this study, undergoing polysomnography and computed tomography examination. Pharyngeal airway morphology (AT size, volume, and cross-sectional area [CSA]) and pressure on the upper airway were evaluated at each site using computational fluid dynamic analysis.

Results: Apnea hypopnea index (AHI) showed a strong linear association with maximum negative pressure (P_{max}) (AHI = -0.055* P_{max} -1.326, R^2 = 0.805). The relationship between minimum CSA (CSA_{min}) and P_{max} was represented by an inversely proportional fitted curve (P_{max} = -4797/ CSA_{min} -5.1, R^2 = 0.507). The relationship between CSA_{min} and AHI was also represented by an inversely proportional fitted curve (AHI = 301.6/ $CSA_{min}^{1.22}$, R^2 = 0.680). P_{max} greatly increased if CSA_{min} became ≤ 30 mm^2. The negative pressure of each site increased when CSA measured ≤ 50 mm^2.

Conclusions: In children, when the CSA for each site is ≤ 50 mm^2, AHI is likely to be elevated, and the patient may require tonsillectomy or adenoidectomy.

Keywords: adenoid, tonsil, airway negative pressure, computed fluid dynamics, obstructive sleep apnea, pediatrics

BRIEF SUMMARY

Current Knowledge/Study Rationale:

Indication of adenoidectomy and tonsillectomy for obstructive sleep apnea (OSA) in children is important to determine treatment strategies. However, the adaptive decision method of the current method is insufficient.

Study Impact:

The purpose of this study was to determine a new adaptive evaluation method to determine the usefulness of adenoidectomy or tonsillectomy in pediatric OSA. We determined that adenoidectomy and tonsillectomy can improve treatment results for pediatric OSA.

INTRODUCTION

Obstructive sleep apnea (OSA) is a respiratory disorder caused by the obstruction of the upper airway during sleep.[1] The prevalence of OSA in children is approximately 1.2–5.7 %.[2, 3] Hypertrophy of the adenoidal and tonsillar tissue (AT) is thought to be one of the primary anatomical causes of OSA in the pediatric population.[4] Therefore, adenotonsillectomy is considered the first-line treatment for pediatric patients with OSA.[4, 5] AT size assessment during the presurgical physical examination is often used as a key component of clinical decision-making, specifically to estimate the potential success or failure of adenotonsillectomy.

The success rate of adenotonsillectomy for pediatric OSA is variable, ranging from 27.2 to 82.9%.[6] Nolan et al.[7] reviewed 20 studies that determined if tonsillar size was related to OSA. Eleven of the 20 studies concluded there was an association between tonsil size, and showed that diagnosis of OSA was possible using varying statistical techniques, either liner or logistic regression analysis, and correlations. However, the other nine studies did not find an association. The review concluded that there was a weak association between tonsillar size and diagnosable OSA in pediatric patients. Therefore, it is not clear how much AT enlargement causes OSA. Bally et al.[8] reported that these evaluation methods not only require further evaluation, but also must determine the effect that enlarged adenoids and tonsils have on the airway.

In children without OSA, pharyngeal airway volume is 29718.6 mm^3, and in children with OSA, the volume is 17387.4 mm^3, as determined by Van Holsbeke et al.[9] This study also determined that small volume of the pharyngeal airway is characteristic in children with OSA and that the pharyngeal airway of children with OSA greatly narrows at inhalation.[1] This decrease in size is regarded as a consequence of major negative pressure occurring during inhalation.[10] Therefore, not only the degree of enlargement of AT but also the airway size at the AT site and the negative AT pressure at inhalation are thought to influence airway obstruction.[11]

OSA severity reflects ventilation condition of the whole upper airway. Therefore, it is necessary to investigate the syndrome concerning nasal obstruction. A case of increased obstruction affects OSA severity of the pharyngeal airway.

Recently, we have been able to evaluate the ventilation condition of each upper airway site by using computational fluid dynamics (CFD).[10] CFD can evaluate the flow of air in a manner similar to that during actual breathing, even in cases of upper airways with complicated morphologies.[12] As we used CFD, which was only able to evaluate the ventilation condition for the nasal airway, only children without nasal obstruction could be selected for the study.

The purpose of this study is to identify the factors influencing OSA disease severity by investigating the relationships between pharyngeal airway morphology (e.g., AT size, volume, and cross-sectional area [CSA]), negative pressure of the pharyngeal airway by CFD, and OSA disease severity. Factors identified in this study may help to predict the need for adenoidectomy or tonsillectomy.

METHODS

Patients

Thirty-three patients (25 boys, 8 girls) treated at a national university hospital (Yamanashi, Japan) for OSA were included in this retrospective study. The inclusion criteria for the study included children aged 3 to 13 years who had under gone polysomnography (PSG) and CT scan for diagnosis. PSG was used to measure the apnea hypopnea index (AHI). Apnea was defined as the complete cessation of airflow for two respiratory cycles, and hypopnea was defined as a 50% reduction in oronasal airflow for 10 seconds with at least 3% desaturation. The AHI was calculated as the number of apnea and hypopnea events per hour of sleep.[13] Severe OSA was defined as an AHI of 15 or more. CT scanning was non-routine; it was performed only for cases (e.g., adenoidectomy or tonsillectomy candidate, severe maxillofacial form abnormality) in which detailed examination of the morphology of the upper airway was needed. A CT scan was only performed when CT scan data required for OSA treatment outweighed the risk of the radiation. A craniocervical inclination of 95° to 105° was used as seen in previous work[14] because the volume of the airway is influenced by head posture. The exclusion criteria for the study included nasal obstruction with a nasal airway resistance greater than 0.5 Pa/ml/sec. Because nasal obstruction affected OSA severity, it was unclear in these cases whether OSA severity was due to adenoid or/and tonsil hypertrophy.[15, 16] Other exclusions were craniofacial or growth abnormalities, a history of tonsillectomy or adenoidectomy, or treatment for systematic disease. The final patients included in this study were 27 children (21 boys, six girls; mean age 6.6 ± 2.2 years). On the basis of a previous study,[10] the correlation coefficient was set to .60. With the significance and power set to .05 and .80, respectively, the correlation coefficient showed that the required sample size was 20. This study was approved by the institutional review board of Kagoshima University, Japan, (180073 (657) Epi-ver. 5) and Yamanashi University, Japan (1594). Due to the study's retrospective nature, the need for obtaining informed consent was waived.

Method

Polysomnography and the CT scan method were previously reported.[17] Adenoid and tonsil hypertrophy was evaluated. AT growth was evaluated in reference to past studies as AT grade.[15, 16, 18, 19] Morphological evaluation of the pharyngeal airway (pharyngeal airway volume [volume] and cross sectional area [CSA]) was previously reported[17]. Minimum CSA in the pharyngeal airway (CSA_{min}), smallest CSA in the nasopharyngeal airway (NA) (CSA_{NA}), smallest CSA in the retropalatal airway (RA) (CSA_{RA}), and smallest CSA in the oropharyngeal airway (OA) (CSA_{OA}) were all measured.

Adenoids

The midsagittal plane between the posterior outline of the soft palate and the closest point on the adenoid tissue from CT images was measured to classify the relative size of the adenoids into 5 grades (Figure 1A–E). In addition, the nasopharyngeal airway was modeled three-dimensionally by reversing the size of adenoids for visualization.[15]

Tonsils

The narrowest distance between the tonsils in the mid-coronal plane was used to classify their relative sizes into 5 grades (Figure 1F–J). The oropharyngeal airway was three-dimensionally modeled by reversing the size of adenoids for visualization.[19]

Evaluations of ventilation conditions of the nasal airway, NA, RA, and OA were conducted. The method of analysis of the ventilation condition using CFD of the nasal airway and the upper airway was carried out according to a previous report[17] (Figure 1D and E). The nasal resistance was calculated from external naris, choanal difference in pressure, and flow quantity obtained in CFD using the nasal airway model.

The upper airway three-dimensional model obtained with CFD at inhalation was used to evaluate multiple values. First, it evaluated maximal negative pressure (P_{max}) in the upper airway. P_{max} is defined as the largest value measured in the upper airway. Second, it evaluated the pressure change in NA (ΔNA), the difference in the pharyngeal airway pressure between the choana and pharyngeal airway at the palatal plane. Third, it evaluated the pressure change in RA (ΔRA), where a difference in adenoid and palatine tonsil length influence pressure. This was determined by calculating the difference in the pharynx airway pressure between the palatal plane and tip of the soft palate. Finally, pressure changes in OA (ΔOA) were evaluated by calculating the difference in the pharynx airway pressure between the tip of the soft palate and the bottom of the epiglottis, equivalent to the palatine tonsil.

Statistics

All data were analyzed blindly. Depending on distribution, Pearson's (using AHI and morphological values) and Spearman (using AHI and CFD values) correlation coefficients (R_s) were used to evaluate relationships between OSA severity (AHI), pharyngeal airway morphology (AT grade, volume, and CSA), and pharyngeal airway functional value (pressure determined with CFD). Non-linear regression was used to describe the relationship between the measurement values. Multiple regression was used to examine all measured values that had greater influence on AHI. For all tests, $P < 0.05$ was considered statistically significant. For intra- and inter-examiner reliability, a random number generator was used to select ten patients. The measurements were repeated 1 week after the initial measurements. Both intra- and inter-examiner reliability tests exhibited high correlations ranging from 0.965 to 0.981 for all measures.

RESULTS

The mean, standard deviation, minimum, and maximum of characteristics of patients in this study are listed in Table 1. AHI was 7.38 ± 7.00 events/hr and P_{max} was -159.30 ± 114.87 Pa. Adenoid grade was 3.41 ± 0.93

degree and tonsil grade was 4.07 ± 0.96 degrees. Table 1 describes the correlation between AHI and morphological values and pressures. AHI was significantly negative correlated to ΔOA pressure and P_{max} (R_s = -0.838, P < 0.001, R_s = - 0.838, P < 0.001, respectively). A significantly negative correlation also existed between AHI, CSA_{NA}, CSA_{RA}, and CSA_{min} (R_s = - 0.384, P < 0.048, R_s = - 0.442, P < 0.021, R_s = - 0.485, P < 0.010, respectively). However, AHI was not significantly correlated with airway volumes. A significantly positive correlation existed between AHI and AT grade (R_s = -0.427, P < 0.026, R_s = - 0.399, P < 0.039, respectively). Table 2 describes pressure and morphological values.

CSA_{min} was significantly correlated with P_{max} (R_s = 0.849). Each site of CSA_{NA}, CSA_{RA}, and CSA_{min} was significantly correlated with pressure change of each site (R_s = 0.853, 0.842, 0.865). NA volume was significantly correlated with pressure change of NA (R_s = 0.743). However, RA and OA volumes were not significantly correlated with the pressure change at each corresponding site.

AHI showed strong linear association between P_{max} (Figure 2A-a, AHI = - 0.055* P_{max} - 1.326 R^2 = 0.805, P < 0.001). The relationship between AHI and CSA_{min} was represented by a fitted curve shown in inversely proportional data (Figure 2A-b, AHI = 301.6/ CSA_{min} 11.22, R^2 = 0.680, P < 0.001). AHI increased suddenly if CSA became 30 mm^2 or less.

The relationship between P_{max} and CSA_{min} was represented by an inversely proportional fitted curve (Figure 2A-c, AHI = -4797/ CSA_{min} -5.1, R^2 = 0.507, P < 0.01). Negative pressure quickly increased by more than -120 Pa if CSA_{min} measured 30 mm^2 or less. The distributions between the $CSA_{NA,}$ $CSA_{RA,}$ and $CSA_{OA,}$ and the pressure of each site in this study, are shown in Figure 2A-d – 2A-f. The relationship between $CSA_{NA,}$ $CSA_{RA,}$ and CSA_{OA} and corresponding pressures was represented by an inversely proportional fitted curve. Negative pressure increased if $CSA_{NA,}$ $CSA_{RA,}$ or CSA_{OA} increased from 30 mm^2 to 50 mm^2 or less.

The distributions of AHI, pressure, CSA, and volume of each site compared to AT grade is shown in Figure 2B-a–h. The values of AHI for AT grade, negative pressure, airway volume, and CSA of each site were widely distributed.

Multiple regression analysis was performed to examine AT grade, pharyngeal airway volume and cross section, and negative pressure at inhalation. This determined which endpoint had the greatest influence on AHI, which our study revealed to be P_{max} ($\beta = 0.889$, $P < 0.001$).

When CSAmin of the site was 30 mm^2 or less, adenoidectomy or tonsillectomy was usually completed (Figure 5A, B, and E). Furthermore, when the pharyngeal airway (including AT) had multiple sites with a CSA measuring 50 mm^2 or less, major negative pressure increased, even if it did not occur alone. When nasal obstruction was severe, negative pressure of the pharyngeal airway increased and obstruction occurred.

DISCUSSION

This study showed that P_{max} had the greatest influence on AHI. AT grade was not the greatest influencer of P_{max} as expected. Instead, CSA_{min} had the greatest influence on P_{max}. As a result, AHI was affected when CSA was 50 mm^2 or less. AHI became severe when CSA measured 30 mm^2 or less. From these results, we concluded that when each site's CSA_{NA}, CSA_{RA}, and CSA_{OA} were 50 mm^2 or less, this indicated the need for adenoidectomy or tonsillectomy.

Concerning the influences that P_{max} has on AHI, Arens et al.[1] reported that the pharyngeal airway greatly decreased in size at inhalation in children with OSA. Their hypothesis was that the pharyngeal airway shrunk due to great negative pressure at inhalation. Based on this study, we have found a strong association between AHI and negative pressure and determined that negative pressure is associated with obstruction. CSA showed strong association with AHI because P_{max} was heavily influenced by CSA. From previous reports[1, 10] and our present results, a small CSA in patients caused negative pharyngeal airway pressure at inhalation. During sleep, muscles of the pharyngeal airway relaxed but collapsed due to large negative pressure. Therefore, we concluded that negative pressure affected AHI.

Previous studies in adults show the relationship between a nasal airway cross section and nasal resistance.[20] Relationships between constricted pharyngeal airway cross sections and negative pharyngeal airway pressure were reported to show the relationship of inversely proportional relations, similar to the past study.[21, 22] Previous studies reported negative pressure increases when cross sections of the pharyngeal airway are 100 mm^2 or less.[21, 22] In our study, a change of pressure was measured at 50 mm^2 or less. Because our patients were children (mean age 6.6 years old), this discrepancy may be due to decreased size of the pharyngeal airway and a subsequent change in flow rate. This study determined that the relationship between CSA and pressure was similar to that in previous studies.[21, 22]

When CSA_{min} was 30 mm^2 or less, the pharyngeal airway exhibited increased negative pressure, and collapse of the pharyngeal airway was expected due to muscle relaxation. Previous studies showed that CSA in children with OSA is small.[9, 23] Van Holsbeke et al.[9] reported that CSA in Belgian children (mean AHI = 8.7) was 17.9 mm^2, measured at the time the patients awoke from CT sedation, as in this study. Similar CSA results were obtained when comparing OSA severity in children in the present study and the results of Van Holsbeke et al.[9] However, in previous studies,[9, 23] only mean CSA values were shown. The need for adenoidectomy or tonsillectomy was not considered in every case individually. However, we believe we can easily determine the need for adenoidectomy or tonsillectomy using three-dimensional morphological and CFD evaluations. Additionally, negative pressure tended to moderately increase when CSA was less than 50 mm^2. This showed a relationship between $CSA_{NA,}$ $CSA_{RA,}$ and CSA_{OA} and the change of the pressure of all parts. In this case, a CSA of 50 mm^2 or less should be considered as indication of adenoidectomy or tonsillectomy.

In a previous drug-induced sleep endoscopy study,[24] it was reported that even a small AT grade or large pharyngeal airway may be obstructed during sleep. When the upper airway is obstructed, major negative pressure occurs in the lower airway.[10, 25] For example, our data showed that severe nasal obstruction can cause negative pressure of the pharyngeal airway, even if CSA of pharyngeal airway is large and AT grade is small. When the pharyngeal airway form determined AHI, which reflected the ventilation of the upper airway, cases of nasal obstruction were excluded. However, adenoids may affect nasal airway ventilation even after conventional rhinomanomery.[26, 27] Isolating the nasal airway to evaluate the ventilation condition was difficult. This study excluded the possibility of a nasal obstruction because we were able to evaluate CFD for ventilation conditions of the upper airway. We were also able to evaluate the ventilation condition of each pharyngeal airway site. CFD proved to be a useful method to determine airway ventilation. We were able to use CFD to analyze the pharyngeal airway and determine an association between pharyngeal airway pressure, pharyngeal airway size, and OSA severity.

Several epidemiologic studies[6-8] examined AT grade and its relationship to OSA. However, these studies[6-8] only examined the association statistically without discussing mechanism. Therefore, a consensus was not reached concerning the association between AT grade and OSA severity until now. In this study, the relationship between AHI and AT grade was examined. As a result, this study only showed weak correlation between AT grade and AHI.

For AT grade, the values of not only AHI but also CSA, volume, and pressure changes were distributed widely (Figure 2B-c–h). As a result, we showed cases in which AT grade did not associate with each CSA. In contrast, there were cases in which AT grade strongly associated with each CSA. Therefore, because it is difficult to determine CSA that influences ventilation condition from AT grade, there was no strong association between AT grade and AHI. When the extraction was based on the AT grade, it was less clear that adenoidectomy and tonsillectomy would be indicated for an elevated AHI. From these results, we concluded that CSA evaluation was more effective than AT grade evaluation in determining a patient's need for adenoidectomy or tonsillectomy.

This study had several limitations. The sample size was small, and the analysis of the rigid model was performed using awakening CT data. Because awakening CT data was different from sleep CT data, it was difficult to define the characteristics of OSA. However, our study was able to characterize the airflow properties of children with OSA. These data clearly showed that CFD-evaluated values were correlated with AHI. Further research comparing the patient outcomes of AT by CSA analysis is warranted to confirm the efficacy of CSA. In addition, this study was not able to examine the effect of obesity. A similar study for children with obesity is necessary.

Clinical implications

The past study showed that the association between the degree of AT enlargement and pediatric OSA was weak. In this study, however, CSA was more closely associated with OSA disease severity than with the degree of

AT enlargement, and was therefore, thought to be useful as a criterion for AT. When CSA for each site equals 50 mm^2 or less, adenectomy or tonsillectomy may be necessary.

ABBREVIATIONS

AHI: apnea hypopnea index

CFD: computational fluid dynamics

CSA: cross sectional area

CSA_{min}: minimum CSA

CSA_{NA}: CSA of NA

CSA_{OA}: CSA of OA

CSA_{RA}: CSA of RA

ΔNA: Pressure changes in NA corresponding to adenoids part

NA: nasopharyngeal airway

NAv: NA volume

ΔOA: Pressure changes in OA corresponding to tonsil part

OA: oropharyngeal airway

OAv: OA volume

Pav: Pharyngeal airway volume

P_{max}: maximum negative pressure

ΔRA: Pressure changes in RA where adenoids and palatine tonsil influence

RA: retropalatal airway

RAv: RA volume

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FIGURE LEGENDS

Figure 1 Measurement of adenoid and tonsil size.

Measurement of relative adenoid size (A–E).

Upper figure: mid sagittal plane. Middle figures: cross section of nasopharyngeal airway of closest part. Lower figure: three-dimensional nasopharyngeal airway model from the right rear. The distance in the midsagittal plane from the posterior outline of the soft palate to the closest point on the adenoid tissue from CBCT images was used to classify the relative size of the adenoids into five groups.

A: Grade I was not present in adenoid.

B: Grade Il adenoid extended quarter of the way to the midline (yellow arrow).

C: Grade IIl adenoid extended halfway to the midline (yellow arrow).

D: Grade IV adenoid extended three quarters of the way to the midline (yellow arrow).

E: Grade V adenoid partially occluded the airway (red arrow).

Measurement of relative palatine tonsil size (F–J)

Upper figure: coronal plane of oropharyngeal airway of closest part. Middle figure: horizontal plane of oropharyngeal airway of closest part. Lower figure: three-dimensional oropharyngeal airway model from the right rear.

F: Grade I was not present in hyperplasia of palatine tonsil.

G: Grade lI tonsils extended quarter of the way to the midline (yellow arrow).

H: Grade IlI tonsils extended halfway to the midline (yellow arrow).

I: Grade IV tonsils extended three quarters of the way to the midline (yellow arrow).

J: Grade V tonsils were completely obstructing the airway, also known as "kissing" tonsils (red arrow).

Figure 2 Relationships measurement variables

A: Relationship of AHI and maximum negative pressure (P_{max}) and cross-sectional area. Relationship of

A-a: AHI and $P_{max;}$ **A-b**: AHI and minimum cross-sectional area (CSA_{min})**;** **A-c**: P_{max} and CSA_{min}**;** **A-d**: pressure changes at NA and cross-sectional area at NA site**;** **A-e**: pressure change at RA and cross-sectional area at RA site**;** and **A-f**: pressure change at OA and cross-sectional area at OA site.

B: Association between enlargement of adenoids and the palatine tonsil (AT) and AHI, pressure change, airway volume of each site, and cross-sectional area (CSA) of each site. Each grade of AT did not correlate to the variables (AHI, negative pressure, airway volume, and CSA). Relationship of **B-a**: AHI and Adenoide grade; **B-b**: AHI and tonsil grade; **B-c**: CSA_{NA} and Adenoide grade; **B-d**: CSA_{OA} and tonsil grade; **B-e**: ΔNA and Adenoide grade**;** **B-f**: ΔOA and tonsil grade; **B-g**: NAv and Adenoide grade; and **B-h**: relationship of OAv and tonsil grade.

CSA: cross sectional area, CSA_{min}: minimum CSA, CSA_{NA}: CSA of NA, CSA_{OA}: CSA of OA, CSA_{RA}: CSA of RA, NA: nasopharyngeal airway, ΔNA: Pressure changes in NA corresponding to adenoids, OA: oropharyngeal airway, ΔOA: Pressure changes in OA corresponding to tonsil, P_{max}: maximum negative pressure, RA: retropalatal airway, ΔRA: Pressure changes in RA where adenoids and palatine tonsil influence.

Figure 1

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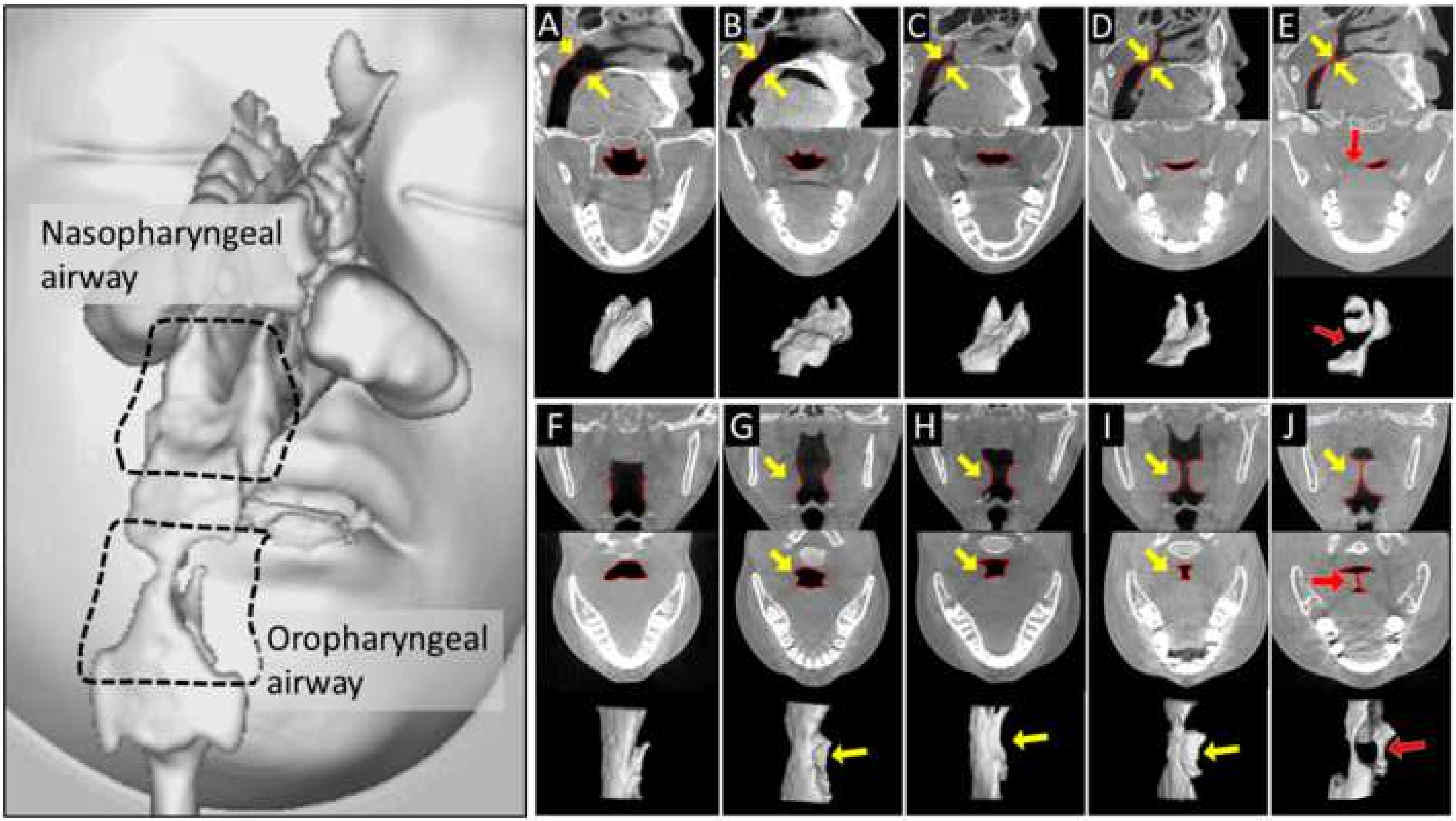
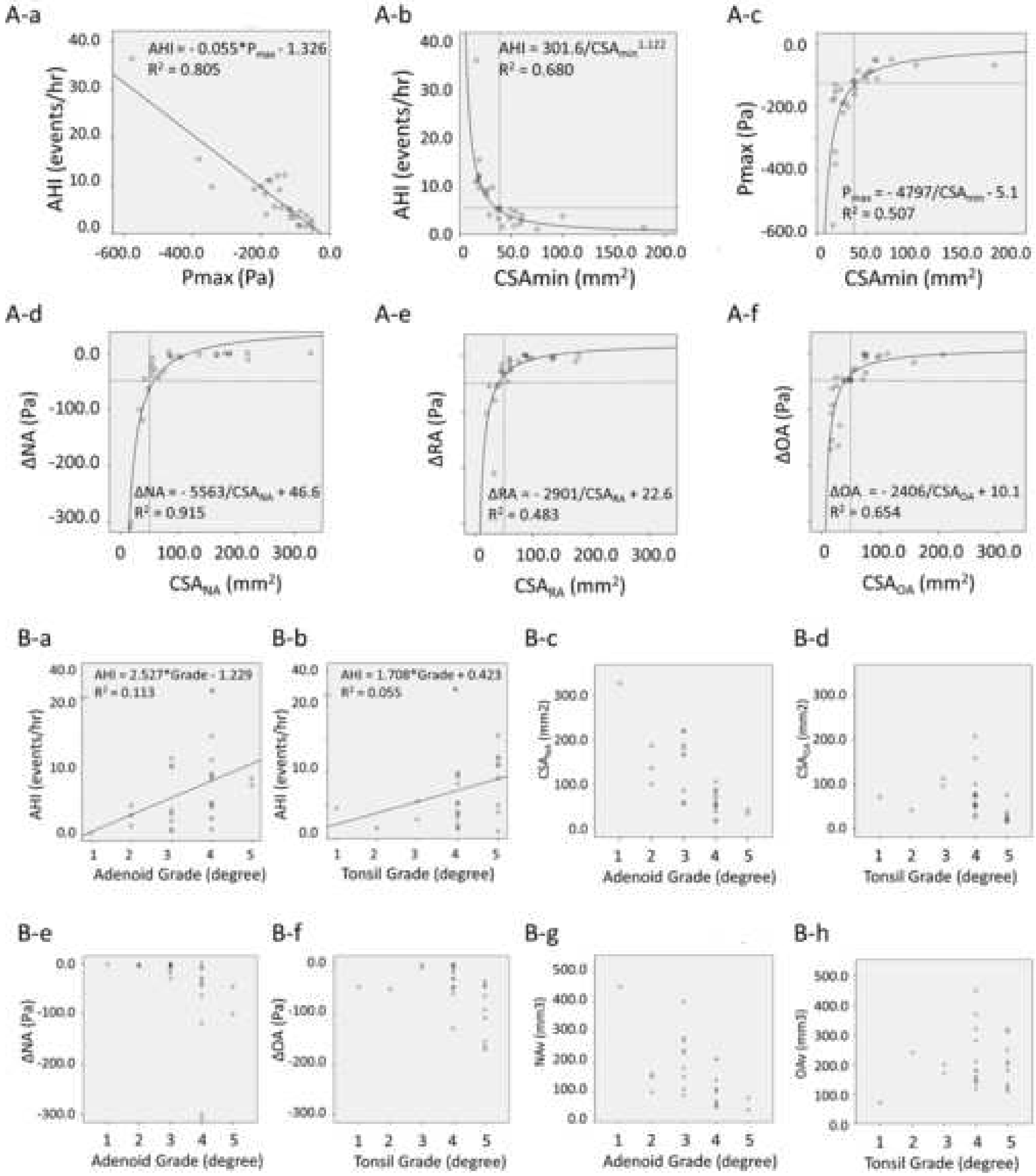


Figure 2



A-a
AHI = - 0.055*Pmax - 1.326
R² = 0.805
AHI (events/hr)
Pmax (Pa)
A-b
AHI = 301.6/CSAmin 1.122
R² = 0.680
AHI (events/hr)
CSAmin (mm²)
A-c
Pmax = - 4797/CSAmin - 5.1
R² = 0.507
Pmax (Pa)
CSAmin (mm²)
A-d
ΔNA = - 5563/CSANA + 46.6
R² = 0.915
ΔNA (Pa)
CSANA (mm²)
A-e
ΔRA = - 2901/CSARA + 22.6
R² = 0.483
ΔRA (Pa)
CSARA (mm²)
A-f
ΔOA = - 2406/CSAOA + 10.1
R² = 0.654
ΔOA (Pa)
CSAOA (mm²)
B-a
AHI = 2.527*Grade - 1.229
R² = 0.113
AHI (events/hr)
Adenoid Grade (degree)
B-b
AHI = 1.708*Grade + 0.423
R² = 0.055
AHI (events/hr)
Tonsil Grade (degree)
B-c
Adenoid Grade (degree)
B-d
Tonsil Grade (degree)
B-e
ΔNA (Pa)
Adenoid Grade (degree)
B-f
ΔOA (Pa)
Tonsil Grade (degree)
B-g
NAV (mm3)
Adenoid Grade (degree)
B-h
OAV (mm3)
Tonsil Grade (degree)

Table 1 Morphologic and functional variable of the upper airway and correlation coefficient to AHI.

n = 27

	Min	Max	mean	SD	AHI Correlation coefficents	AHI P
age	3. 70	13. 10	6. 62	2. 26		
Ht (cm)	91. 90	153. 40	116. 88	16. 35		
Bw (Kg)	12. 10	54. 00	24. 01	10. 74		
BMI (Kg/mm2)	12. 60	23. 10	16. 80	2. 95		
Percentiles BMI(%ile)	0. 10	98. 20	54. 23	34. 83		
AHI (events/hr)	1. 10	36. 30	7. 38	7. 00		
Max pressure (Pa) †	-576. 00	-50. 00	-159. 30	114. 87	-. 838**	0. 000
ΔNA (Pa) †	-310. 00	2. 00	-43. 49	81. 39	-0. 220	0. 271
ΔRA (Pa) †	-210. 00	1. 00	-30. 24	44. 59	-0. 301	0. 127
ΔOA (Pa) †	-170. 90	-0. 70	-51. 87	51. 90	-. 838**	0. 000
Adenoid grade (degree) †	1. 00	5. 00	3. 41	0. 93	.427*	0.026
Tonsil grade (degree) †	1. 00	5. 00	4. 07	0. 96	.399*	0.039
NAv (mm3)*	0. 40	4. 50	1. 54	1. 05	-0.148	0.461
RAv (mm3)*	0. 70	4. 50	2. 05	0. 88	-0.106	0.600
OAv (mm3)*	0. 30	6. 70	2. 15	1. 39	-0.131	0.514
PAv (mm3)*	1. 70	10. 40	4. 21	1. 78	-0.082	0.685
CSA_{NA} (mm2)*	16. 30	327. 90	106. 24	76. 40	-.384*	0.048
CSA_{RA} (mm2)*	19. 80	178. 90	74. 62	43. 31	-.442*	0.021
CSA_{OA} (mm2)*	15. 80	208. 00	61. 45	45. 03	0.054	0.788
CSAmin (mm2)*	15. 80	178. 90	44. 14	33. 79	-.485*	0.010

AHI = aponea hyponea index, Pmax; maximum negative pressure, CSA; cross sectional area, CSAmin; minimum CSA, ΔNA; Pressure changes in NA corresponding to adenoids part, ΔRA; Pressure changes in RA where adenoids and palatine tonsil influence, respectively, ΔOA; Pressure changes in OA corresponding to tonsil part, CSA_{NA}; CSA of NA, CSA_{RA}; CSA of RA, CSA_{OA}; CSA of OA, NA; nasopharyngeal airway, RA; reropalatal airway, OA; oropharyngeal airway, NAv; NA volume, RAv; RA volume, OAv; OA volume. PAv; Pharyngeal airway volume.

Table 2

Table 2 Relationship between cross-sectional area and pressure drop.

	Max pressure (Pa)	ΔNA (Pa)	ΔRA (Pa)	ΔOA (Pa)
CSAmin (mm2)	.849**	0.306	.544**	.550**
	0.000	0.121	0.003	0.003
CSA_{NA} (mm2)	.503**	.853**	0.275	-0.189
	0.008	0.000	0.165	0.345
CSA_{RA} (mm2)	.558**	0.290	.842**	.493**
	0.002	0.143	0.000	0.009
CSA_{OA} (mm2)	.431*	-0.223	.414*	.865**
	0.025	0.264	0.032	0.000
PAv (mm3)	0.225	.509**	0.134	-0.123
	0.258	0.007	0.504	0.540
NAv (mm3)	0.234	.743**	0.046	-.439*
	0.240	0.000	0.819	0.022
RAv (cm3)	0.183	.435*	0.099	-0.149
	0.361	0.023	0.623	0.458
OAv (cm3)	0.140	0.200	0.029	0.056
	0.486	0.318	0.885	0.780

CSA = cross-sectional area, Max = maximum value, Min = minimum value, ΔNA = differences of the pharyngeal airway pressure, between choana and pharynx airway at the palatal plane, ΔRA = difference of the pharynx airway pressure, between the palatal plane and tip of the soft palate, ΔOA = difference of the pharynx airway pressure between tip of the soft palate and the epiglottis bottom, NA = nasopharyngeal airway, RA = retropalatal airway, OA = oropharyngeal airway, CSA_{NA}; CSA of NA, CSA_{RA}; CSA of RA, CSA_{OA};CSA of OA,NAv; NA volume, RAv; RA volume, OAv; OA volume. PAv; Pharyngeal airway volume.