*Title Page

TITLE: Relationships between nasal resistance, adenoids, tonsils, and tongue posture and maxillofacial form in Class II and Class III children

Authors:

Tomonori Iwasaki 1) D.D.S., Ph.D, Associate Professor
Substantial contributions to conception and design, analysis and interpretation of data, drafting the article, revising it critically for important intellectual content, and final approval of the version to be published.

Hideo Sato 1) D.D.S., Ph.D, Lecture
Analysis and interpretation of data, revising it critically for important intellectual content, and final approval of the version to be published.

Hokuto Suga 1) D.D.S., Research Associate
Analysis and interpretation of data, revising it critically for important intellectual content, and final approval of the version to be published.

Yoshihiko Takemoto 1) D.D.S., Ph.D, Research Associate
Analysis and interpretation of data, revising it critically for important intellectual content, and final approval of the version to be published.

Emi Inada 1) D.D.S., Ph.D, Research Associate
Analysis and interpretation of data, revising it critically for important intellectual content, and final approval of the version to be published.

Issei Saitoh 2) D.D.S., Ph.D, Associate Professor
Analysis and interpretation of data, revising it critically for important intellectual content, and final approval of the

version to be published.

Eriko Kakuno 3) D.D.S.
Acquisition of data, revising it critically for important intellectual content, and final approval of the version to be published.

Ryuzo Kanomi 3) D.D.S., Ph.D
Acquisition of data, revising it critically for important intellectual content, and final approval of the version to be published.

Youichi Yamasaki 1) D.D.S., Ph.D, Professor and Chairman
Substantial contributions to conception and design, revising it critically for important intellectual content, and final approval of the version to be published.

Institutional affiliation:

1) Field of Developmental Medicine, Health Research Course, Graduate School of Medical and Dental Sciences, Kagoshima University
2) Division of Pediatric Dentistry, Department of Oral Health Science, Course of Oral Life Science, Graduate School of Medical and Dental Sciences, Niigata University
3) Kanomi Orthodontic Office

Corresponding Author:

Tomonori Iwasaki, D.D.S., Ph.D

Affiliation & Address:

Field of Developmental Medicine, Health Research Course, Graduate School of Medical and Dental Sciences, Kagoshima University,

8-35-1, Sakuragaoka Kagoshima-City, Kagoshima, 890-8544, Japan.

TEL: +81-99-275-6262

FAX: +81-99-275-6268

E-mail: yamame@dent. kagoshima-u.ac.jp

ACKNOWLEDGEMENTS

This work was supported by KAKENHI from Japan Society for the Promotion of Science (No. 25670878, 25870566, 25293420). We thank Professor Gaylord Throckmorton, Ph.D for reviewing this paper for English usage.

***Highlights (for review)**

Nasal resistance of the Class II group was significantly larger than that of the Class III group.

Nasal resistance of the Class II group was significantly correlated with low tongue posture, and significantly negatively correlated with intermolar width.

Tonsil size of the Class III group was significantly correlated with forward tongue posture and lower incisor anterior position.

Forward tongue posture of the Class III group was significantly correlated with mandibular protrusion.

The relationships of upper airway factors differed between Class II and Class III children.

TITLE: Relationships between nasal resistance, adenoids, tonsils, and tongue posture and maxillofacial form in Class II and Class III children

ABSTRACT:

Introduction: The purpose of this study was to clarify the relationships between upper airway factors (nasal resistance, adenoids, tonsils and tongue posture) and maxillofacial form in Class II and III children **Methods**: Sixty-four subjects (mean age, 9.3 years) with malocclusion were divided into Class II and Class III groups by ANB angle. Nasal resistance was calculated using computational fluid dynamics from cone-beam computed tomography (CBCT) data. Adenoids, tonsils and tongue posture were evaluated in CBCT images. The groups were compared using Mann-Whitney U-tests and Student t-tests. Spearman's rank test assessed the relationships between upper airway factors and maxillofacial form. **Results**: Nasal resistance of the Class II group was significantly larger than that of the Class III group ($P = 0.005$). Nasal resistance of the Class II group was significantly correlated with inferior tongue posture ($P < 0.001$), and negatively correlated with intermolar width ($P = 0.028$). Tonsil size of the Class III group was significantly correlated with anterior tongue posture ($P < 0.001$) and mandibular incisor anterior position ($P = 0.007$). Anterior tongue posture of the Class III group was significantly correlated with mandibular protrusion. **Conclusions**: The relationships of upper airway factors differed between Class II and Class III children.

(Word count 200/200)

INTRODUCTION

Maxillofacial form is influenced by both genetic and environmental factors.[1,2] According to Moss's theory of the functional matrix, bone growth takes place in response to function.[3] Therefore, nasal resistance, presence of adenoids, size of the tonsils, and tongue posture are thought to affect maxillofacial form.

A previous study[4] reported that changes in facial growth resulted from respiratory obstruction due to enlarged adenoids or tonsils. Nunes et al.[5] evaluated the association between dentition and lymphoid tissues of children. Obstruction of different parts of the upper airway, due to presence of adenoids and enlarged tonsils, were associated with different forms of malocclusion. Primozic et al. [6] reported that Class III subjects had a significantly inferior tongue posture compared to Class I subjects, and an inferior tongue posture has also been associated with increased mandibular arch width.

However, the specific influence of presence of adenoids and enlarged tonsils on maxillofacial form are not completely understood, because no studies have comprehensively investigated the various factors (nasal resistance, presence of adenoids, enlarged tonsils, and tongue posture) influencing maxillofacial form.

Recently it has become possible to evaluate both the ventilation state of the nasal airway by computational fluid dynamics (CFD) and the three-dimensional (3-D) form of the upper airway using cone-beam computed tomography (CBCT).[7] The purpose of this study was to use CFD and 3-D form analysis to comprehensively evaluate associations between each upper airway factor and maxillofacial form.

Material and Method

Sixty-four patients who attended a large private orthodontic office in ●●, ●● for orthodontic treatment participated in this retrospective study. The subjects were divided into two groups according to their point A–nasion–point B (ANB) angle: 1) Class II malocclusion patients (ANB > 5°), 2) Class III malocclusion patients (ANB < 1°). All subjects had a FMA angle between 25° and 33°, which is the normal value for Japanese children.[8] The Class II and Class III groups consisted of twelve boys and twenty-one girls (average age: 9.4 ± 1.1 years old) and nine boys and twenty-two girls (average age: 9.2 ± 1.5 years old), respectively. Due to the retrospective nature of this study, an exemption was granted in writing by the institutional review broad of ●● University, and the requirement of obtaining informed consent was waived (#280). Inclusion criteria for the study were (1) subjects between 7 and 12 years of age having, (2) CBCT data taken for diagnosis for non-routine orthodontic treatment with (3) a craniocervical inclination between 95° and 105°.[9]

Exclusion criteria were (1) previous orthodontic treatment, (2) craniofacial or growth abnormalities, (3) a history of treatment for tonsillectomy or adenoidectomy (4) systemic diseases, and (5) temporomandibular joint disorders.

During the CBCT examination each patient had been asked to not move his or her head or swallow, and to maintain centric occlusion with relaxed tongue and lip positions at the end of expiration. The CBCT equipment (Alphard 3030; Asahi Roentgen Ind. Co., Ltd., Kyoto, Japan) was set to a maximum of 80 kV, maximum of 2 mA, exposure time of 17 s, and voxel dimension of 0.39 mm.

Cephalometric analysis

Definitions of landmarks, reference planes, and cephalometric angular measurements were taken from cephalometric images reconstructed from the CBCT images (Fig. 1, Table I). Traditional measurements were used to determine the dentofacial angles and the positions of the maxilla and mandible.

Nasal resistance (Fig. 2)

The 3-D nasal airway was generated from the CBCT data manually by volume-rendering software (INTAGE Volume Editor®; Cybernet, Tokyo, Japan) .[7] Subsequently, using mesh-morphing software (DEP Mesh Works/Morpher®; IDAJ, Kobe, Japan), the 3-D model was converted to a smoothed model without losing the patient-specific pattern of the airway shape. CFD was used to evaluate the ventilation state of the nasal airway models.[7] The models were exported to fluid dynamics software (Phoenics®; CHAM-Japan, Tokyo, Japan) in stereolithographic format. The flow was assumed to consist of a Newtonian, homogeneous, and incompressible fluid. Elliptic-staggered equations and the continuity equation were used in the analysis.[10] CFD of the nasal airway models was analyzed under the following conditions: (1) volume of air flowing at a velocity of 200 cm^3/s, (2) the wall surface was not slippery, and (3) the simulations were repeated 1000 times to calculate mean values. Convergence was judged by monitoring the magnitude of the absolute residual sources of mass and momentum, normalized to the respective inlet fluxes. The iteration was continued until all residuals fell below 0.2%. The simulation estimated airflow pressure.

In our simulation, air flowed from the choanae horizontally and was exhaled through both external nares. Nasal resistance simulation conformed to postnasal rhinomanometry and was calculated from air mass flow and difference in pressure between the external nares and choanae according to Ohm's law. Our nasal resistance was calculated from CFD of the nasal airway alone (except for the adenoids, tonsils, and soft palate). Using rhinomanometry by means of the active anterior method, Crouse et al.[11] found that nasal resistance in healthy 9- to 10-year-old children ranges from 3.0 to 5.0 cm of water per liter per second; these values correspond to 0.3–0.5 $Pa/cm^3/s$.

In reference to this report, nasal obstruction was defined as resistance greater than 0.5 $Pa/cm^3/s$, which corresponds to 100 Pa in this study.

Measurement of the adenoids and tonsils

The distance in the mid-sagittal plane from the posterior outline of the soft palate to the closest point on the adenoid tissue from CBCT images (Fig. 3) was used to classify the relative size of the adenoids into 4 groups.[12] The narrowest distance between tonsils in the mid-coronal plane was used to classify the relative size of tonsils into 5 groups (Fig. 4).[13]

Cross-sectional and 3-D analysis

The volume-rendering software was used to create the 3-D images and to evaluate the cross-sections and volumes.[14] The cross-sections of the oropharyngeal airway (OA) and the hypopharyngeal airway (HA), and volumes of the pharyngeal airway and intraoral airway were measured (Fig. 5). The intraoral airway was defined as the space between the palate and tongue. In this study, if the space was positive, it indicated a inferior tongue posture. Horizontal tongue posture was determined by subtracting HA depth from OA depth (i.e., the OA-HA depth difference). A positive value indicated a anterior tongue posture. In addition, the maxillary and mandibular widths and upper and lower molar widths were measured (Fig. 6).

Statistics

Fisher's exact test clarified the distribution of nasal obstruction, adenoid size, tonsil size, and inferior tongue posture in the both groups. The Student t-test and Mann-Whitney U-test were used ($P < .05$) to detect significant differences in nasal resistance, airway sizes, and maxillomandibular width between the malocclusion groups. To test for cephalometric measurement differences between the malocclusion groups, t-tests were used ($P < .0029$), with the levels of significance corrected ($n = 17$) using the Bonferroni method for multiple comparisons. Spearman correlation coefficients were calculated to evaluate the relationships among nasal resistance, adenoid size, tonsil size, tongue position, airway sizes, and cephalometric values. Statistical significance was set at $P < 0.05$.

RESULTS

Incidence of adenoids, enlarged tonsils, and inferior tongue posture and nasal obstruction

The incidence of adenoid hypertrophy (grade 3 and 4) in Class II subjects was 15.2%. In contrast, the incidence of Class III subjects was 3.2%. The distribution of adenoid sizes between the two malocclusion groups (Table II) was statistically significant according to the Fisher's exact test ($P = 0.013$). The incidence of tonsil hypertrophy (grade 4 and 5) in Class II subjects was 21.2%. And the incidence of Class III subjects was 22.6%. The tonsil size distribution between the two groups

(Table III) did not differ significantly. The distribution of nasal obstruction in children with inferior tongue posture significantly differed between the two malocclusion groups (P = 0.022) (Table IV, Fig 7).

Class II vs Class III (Table V and VI)

Nasal resistance of the Class II group was significantly greater than that of the Class III group. Oral pharyngeal (OA) depth and hypopharyngeal (HA) depth of the Class III group were significantly larger than those of the Class II group. Airway length of the Class II group was significantly longer than that of the Class III group. Maxillary width (W_{max}) and the difference between maxillary and mandibular widths (W_{max}-W_{man}) of the Class II group were significantly larger than those of the Class III group. The maxillary and mandibular dental arch widths (W_{U6} and W_{L6}) of the Class III group were significantly larger than those of the Class II group. The A(x) and U1(x) lengths, and CV_1(y) and U1(y) heights of the Class II group were significantly larger than those of the Class III group, while the SNB angle and B(x), and Pog(x) lengths of the Class II group were significantly smaller than those of the Class III group.

Comparison of Class III inferior-tongue-posture children with and without nasal obstruction (Table VII and VIII)

Mandibular width (W_{man}) of the without-obstruction group was significantly larger than that of the obstruction group. The difference between maxillary and mandibular widths (W_{max}-W_{man}) of the obstruction group was significantly smaller than that of the without-obstruction group. The SNB angle of the without-obstruction group was significantly larger than that of the obstruction group.

Relationships between upper airway factors and maxillofacial form (Table IX and X)

The nasal resistance of the Class II group was significantly correlated with intraoral airway volume, HA width, airway length, and H(y) height, but nasal resistance was significantly negatively correlated with the interdental width difference (W_{U6}-W_{L6}). The nasal resistance of the Class III group was significantly correlated with CV_1(y) height and was significantly negative correlated with the OA-HA depth difference and OA depth.

Adenoid size of the Class II group was significantly correlated with the OA-HA depth difference and U1(x) length. Adenoid size of the Class II group was significantly negative correlated with OA width.

Tonsil size of the Class II group was significantly correlated with the OA-HA depth difference, but was significantly negatively correlated with OA width, OA-HA width difference, upper interdental width (W_{U6}), the W_{U6}-W_{L6} difference, and CV_1(y) height. Tonsil size of the Class III group was significantly correlated with the OA-HA depth difference, OA depth, and L1(x) length, but was significantly negatively correlated with OA width.

Intraoral airway volume of the Class II group was significantly correlated with HA width, and airway length, and H(y) length, and was significantly negatively correlated with the W_{U6}-W_{L6} difference. Intraoral airway volume of the Class III group was significantly correlated with FMA angle and B(x) and Pog(x) lengths.

The OA-HA depth difference of the Class II group was significantly correlated with OA depth, A(x) length, and U1(x) length, and was significantly negatively correlated with OA width, HA depth, HA width, W_{U6}, and the W_{U6}-W_{L6} difference. The OA-HA depth difference of the Class III group was significantly correlated with OA depth, L1(x) length, and B(x) length, and was significantly negatively correlated with OA width and HA width.

DISCUSSION

Previous studies[5,15-19] evaluated an association between the size of the adenoids, tonsils size, and tongue position and maxillofacial form in children with airway obstruction. However, nasal airway resistance can result not only from adenoids and enlarged tonsils but also from nasal airway shape and tongue position. Until recently, evaluation of nasal airway resistance for nasal airway alone has been difficult using only the morphology of the adenoids and tonsils. However, now the nasal airway can be evaluated using CFD.[20]

This study evaluated various factors of the nasal airway ventilation state, adenoids size, tonsils size, tongue posture (inferior and anterior), and airway form from a single set of CBCT data. The influence of these factors on maxillofacial form were comprehensively investigated. This study demonstrates that the relationships among upper airway factors (i.e., nasal obstruction, presence of adenoids, enlarged tonsils, and inferior and anterior tongue posture) and maxillofacial form differ between Class II and Class III children. Nasal obstruction and presence of adenoids were confirmed as upper airway features of Class II children. Relative constriction of the maxillary dentition correlated with nasal obstruction, enlarged tonsils, and a inferior and anterior tongue posture. The upper airway of Class III children is characterized by no nasal obstruction and a large pharyngeal airway diameter. Protrusion of the mandibular incisors was associated with enlarged tonsils and a anterior tongue posture.

Inferior tongue posture

Primozic, et al.[6] evaluated the distance from the palate to the tongue using cephalograms of severe Class III 19-year-olds. These cases had a wide mandibular dentition and inferior tongue posture. However, the state of the upper airway was not mentioned.

The intraoral airway volume of the Class II group was 1.07 cm^3 (Table V) compared to 0.70 cm^3 reported in a previous study of Class I children.[14] Nasal obstruction was detected in many of our Class II cases with inferior tongue posture (Fig. 7), suggesting that inferior tongue posture occurred with mouth breathing because the correlation was strong (Table IX, rs = 0.732, $P < 0.001$). Although mean intraoral airway volume in the Class III group (1.66 cm^3) was more than that of the Class II subjects (1.07cm^3) (Table V), this difference was not statistically significant. However, nasal obstruction was present in only half the Class III inferior-tongue-posture children, suggesting that in the cases without nasal obstruction a different factor, perhaps a wider and more anterior mandible may have allowed a inferior tongue posture (Fig7 and 8). Therefore, the inferior-tongueposture Class III children were compared between those with and those without nasal obstruction (Table VII and VIII). The result were that the SNB angle, $CV_1(x)$ length, and mandibular width (W_{man}) of the Class III children with inferior tongue posture but without nasal obstruction were larger than those of the Class III children with nasal obstruction. This suggests that Class III children without nasal obstruction have a wider mandible and enough posterior tongue space to allow a inferior tongue posture.

Anterior tongue posture

A more anterior tongue posture, indicated by a larger OA-HA depth difference, is associated with adenoid size, enlarged tonsils, and maxillary incisor and maxillary protrusion in the Class II group (Table IX). Presumably the enlarged adenoids and tonsils pushed the tongue forward, resulting in incisor and maxillary protrusion.

In the Class III group, an association of anterior tongue posture with enlarged tonsils was particularly strong (Table X, $r_s = 0.724$, $P < 0.001$). Franco, et al.[18] reported that having much of the oropharyngeal space occupied by enlarged tonsils might determine a anterior tongue posture, with the pressure of the tongue acting on the anterior portion of the mandible. Our results suggest that anterior tongue posture, by enlarged tonsils, pushed the mandibular incisor and mandible forward because the Class III group did not have nasal obstruction.

On the other hand, the association between enlarged tonsils and anterior tongue posture in the Class II group ($r_s = 0.429$) was relatively weaker than that in the Class III group ($r_s = 0.724$). Inferior tongue posture and a lower hyoid position are likely to occur when mouth breathing is caused by nasal obstruction and presence of adenoids in the Class II group. Therefore, anterior tongue pressure from enlarged tonsils in the Class II group may not be sufficient to prevent retrusion of the mandible.

Maxillofacial form

In previous studies, the mandible of Class II children with airway obstruction had a lower and more retruded position only in the presence of adenoids or adenoids and enlarged tonsils. Conversely, Class III children had protrusion of the mandible only in cases where enlarged tonsils were reported.[17,18]

A similar association[17,18] was not shown in the Class II group in our study (Table IX). Because the FMA of our subjects was limited to 25-33 degrees, it might be slightly more difficult to show a significant association. However, our finding of a lower hyoid bone when there was nasal obstruction and inferior tongue posture in the Class II group might indicate a tendency similar to previous studies.[17,18]

The FMA was not significantly associated with nasal resistance in the Class III group either. However, it did show an association with inferior tongue posture that was not related to nasal obstruction. This may indicate that inferior tongue posture influences the lower position of the mandible with or without nasal obstruction in Class III children.

Dental arch width

Pharyngeal airway obstruction by enlarged tonsils has been observed in many Class I, II, and III children with cross bite.[5] Caixeta, et al.[15] reported that dental arch width increased after adeno-tonsilectomy. Diouf, et al.[16] suggested that the maxillary dentition becomes constricted in cases of inferior tongue posture with airway obstruction.

In the Class II group of the present study nasal obstruction and a anterior tongue posture, along with enlarged tonsils and a inferior tongue posture, were associated with constriction of the maxillary dentition (Table IX). However, associations between maxillary dentition constriction and presence of adenoids, enlarged tonsils, and inferior and anterior tongue posture were not detected in the Class III group. This may be because the Class II group was more likely to have nasal obstruction than the Class III group (Table X).

Airway volume

Previous studies reported that the airway volume of Class III subjects is larger than that of Class I and II subjects.[21-23] The pharyngeal airway volume in these studies were measured from palatal plane to CV3 (third cervical vertebrae) or CV2 (second cervical vertebrae). However, our study measured another part, i.e., from palatal plane to tip of epiglottis plane. Our pharyngeal airway length (PNS-H(y)) of the Class II group was longer than that of Class III group while pharyngeal depth was shorter in Class II children. The effect of shorter depth combined with greater length resulted in the same volume between Class II and Class III children.

Limitations

The present study evaluated only the association between upper airway factors and maxillofacial form, and caution is advised with interpreting this as cause and effect. Long-term follow up data and randomized controlled trials will be required in the future. This evaluation of nasal obstruction was by CFD rather than direct measurement of airflow in the patients. Therefore, calibration of CFD with rhinomanometry, which is the standard method, should be undertaken.

Clinical implication (Fig. 8 and 9)

These results suggest the possibility that inferior tongue posture associated with nasal obstruction, and anterior tongue posture associated with enlarged tonsils causes an imbalance of the maxillomandibular dentition width in Class II children. Although caution is advised with interpreting this as cause and effect, the mandible may retreat to compensate for the narrow maxillary dentition. [24] Therefore, in Class II children that have relatively narrow maxillary dentition with nasal obstruction an improvement of nasal obstruction and tongue posture are necessary along with expansion of the maxillary dentition.

Maxillofacial form of Class III children is only slightly influenced by nasal obstruction and presence of adenoids. However, reduction of anterior tongue posture by tonsilectomy and elevation of inferior tongue posture are required when anterior tongue posture with enlarged tonsils and inferior tongue posture without nasal obstruction are detected. In cases of inferior tongue posture with nasal obstruction, elevation of inferior tongue posture by reducing nasal obstruction is necessary. We believe that improving these airway factors will contribute to satisfactory results of orthodontic and dentofacial orthopedic treatment and the stability of subsequent treatment.

Conclusion

The necessity of a comprehensive evaluation of the upper airway (nasal airway resistance, adenoids, tonsils, tongue) was shown to relate to the diagnosis of maxillofacial malocclusions. Class II morphology with nasal obstruction and a inferior tongue posture is related to a relatively narrow upper dentition. Class III morphology with enlarged tonsils with a anterior tongue posture might induce protrusion of the mandible.

References

1. Proffit WR. Equilibrium theory revisited: factors influencing position of the teeth. Angle Orthod 1978;48:175-186.
2. McNamara JA, Jr. Functional determinants of craniofacial size and shape. Eur J Orthod 1980;2:131-159.
3. Moss ML. The function matrix. In: Kraus BS, Riedel RA, editors. Vistas of Orthodontics. Philadelphia; 1962. p. PP85-98.
4. Linder-Aronson S. Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the denition. A biometric, rhino-manometric and cephalometro-radiographic study on children with and without adenoids. Acta Otolaryngol Suppl 1970;265:1-132.
5. Nunes WR, Jr., Di Francesco RC. Variation of patterns of malocclusion by site of pharyngeal obstruction in children. Arch Otolaryngol Head Neck Surg 2010;136:1116-1120.
6. Primozic J, Farcnik F, Perinetti G, Richmond S, Ovsenik M. The association of tongue posture with the dentoalveolar maxillary and mandibular morphology in Class III malocclusion: a controlled study. Eur J Orthod 2013;35:388-393.
7. Iwasaki T, Takemoto Y, Inada E, Sato H, Suga H, Saitoh I et al. The effect of rapid maxillary expansion on pharyngeal airway pressure during inspiration evaluated using computational fluid dynamics. Int J Pediatr Otorhinolaryngol 2014;78:1258-1264.

8. Deguchi T, Kitsugi A. Stability of changes associated with chin cup treatment. Angle Orthod 1996;66:139-145.
9. Muto T, Takeda S, Kanazawa M, Yamazaki A, Fujiwara Y, Mizoguchi I. The effect of head posture on the pharyngeal airway space (PAS). Int J Oral Maxillofac Surg 2002;31:579-583.
10. Gamiño B, Aguillón J. Numerical simulation of syngas combustion with a multi-spark ignition system in a diesel engine adapted to work at the Otto cycle. Fuel 2010;89:581-591.
11. Crouse U, Laine-Alava MT, Warren DW. Nasal impairment in prepubertal children. Am J Orthod Dentofacial Orthop 2000;118:69-74.
12. Major MP, Witmans M, El-Hakim H, Major PW, Flores-Mir C. Agreement between cone-beam computed tomography and nasoendoscopy evaluations of adenoid hypertrophy. Am J Orthod Dentofacial Orthop 2014;146:451-459.
13. Friedman M, Tanyeri H, La Rosa M, Landsberg R, Vaidyanathan K, Pieri S et al. Clinical predictors of obstructive sleep apnea. Laryngoscope 1999;109:1901-1907.
14. Iwasaki T, Hayasaki H, Takemoto Y, Kanomi R, Yamasaki Y. Oropharyngeal airway in children with Class III malocclusion evaluated by cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2009;136:318 e311-319; discussion 318-319.
15. Petraccone Caixeta AC, Andrade I, Jr., Bahia Junqueira Pereira T, Franco LP, Becker HM, Souki BQ. Dental arch dimensional changes after adenotonsillectomy in prepubertal children. Am J Orthod Dentofacial Orthop 2014;145:461-468.
16. Diouf JS, Ngom PI, Sonko O, Diop-Ba K, Badiane A, Diagne F. Influence of tonsillar grade on the dental arch measurements. Am J Orthod Dentofacial Orthop 2015;147:214-220.
17. Sousa JB, Anselmo-Lima WT, Valera FC, Gallego AJ, Matsumoto MA. Cephalometric assessment of the mandibular growth pattern in mouth-breathing children. Int J Pediatr Otorhinolaryngol 2005;69:311-317.
18. Franco LP, Souki BQ, Cheib PL, Abrao M, Pereira TB, Becker HM et al. Are distinct etiologies of upper airway obstruction in mouth-breathing children associated with different cephalometric patterns? Int J Pediatr Otorhinolaryngol 2015;79:223-228.
19. Baroni M, Ballanti F, Franchi L, Cozza P. Craniofacial features of subjects with adenoid, tonsillar, or adenotonsillar hypertrophy. Prog Orthod 2011;12:38-44.
20. Iwasaki T, Saitoh I, Takemoto Y, Inada E, Kanomi R, Hayasaki H et al. Improvement of nasal airway ventilation after rapid maxillary expansion evaluated with computational fluid dynamics. Am J Orthod Dentofacial Orthop 2012;141:269-278.
21. Grauer D, Cevidanes LS, Styner MA, Ackerman JL, Proffit WR. Pharyngeal airway volume and shape from cone-beam computed tomography: relationship to facial morphology. Am J Orthod Dentofacial Orthop 2009;136:805-814.
22. Oh KM, Hong JS, Kim YJ, Cevidanes LS, Park YH. Three-dimensional analysis of

pharyngeal airway form in children with anteroposterior facial patterns. Angle Orthod 2011;81:1075-1082.
23. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop 2011;139:e511-521.
24. Reichenbach E, Taatz K. Kieferorthopaedische Klinik und Therapie. Leipzig, Germany: JA Barth Verl; 1971.

FIGURE LEGENDS

Fig 1. Measurements of anteroposterior and vertical cephalometric landmark positions. Abbreviations: S, sella turcica; N, nasion; A, point A; U1, tip of the maxillary incisor; L1, tip of the mandibular incisor; B, point B; Pog, pogonion; H, hyoid; CV_1, the most anterior point of the anterior arch of the atlas; FH plane, Frankfort horizontal plane; VR plane, Vertical reference plane passing through S; ML plane, mandibular plane.

Fig 2. Example of a CFD analysis of the nasal airway: A, extraction of the nasal airway data; B, volume rendering and numeric simulation; C, evaluation of nasal airway ventilation state. C_p, choanae pressure; EN_p, external nasal pressure.

Fig 3. Measurement of relative adenoid size (Upper figures are in the mid-sagittal plane, Lower figures are a cross section of nasopharyngeal airway at its narrowest part). The distance from the posterior outline of the soft palate to the closest point on the adenoid tissue was measured (yellow arrows). A, Grade 1: less than 25% obstruction. B, Grade 2: 25% to 50% obstruction. C, Grade 3: 50% to 75% obstruction. D, Grade 4: more than 75% obstruction.

Fig 4. Measurement of relative tonsil size (Upper figures are in the coronal plane of the oropharyngeal airway's narrowest part, Lower figures are in the horizontal plane of the oropharyngeal airway's narrowest part): A, Grade 1: no hyperplasia of tonsil. B, Grade 2: tonsils extended one-quarter of the way to the midline (yellow arrow). C, Grade 3: tonsils extended half way to the midline (yellow arrow). D, Grade 4: tonsils extended three-quarters of the way to the midline (yellow arrow). E, Grade 5: tonsils completely obstruct the airway, also known as "kissing" tonsils (yellow arrow).

Fig 5. Measurements of airway volumes and cross-sections. A: landmarks and planes for the axial airway section. B: intraoral airway volume between the palate and tongue. C: pharyngeal airway volume between the PL and EB planes. D: cross-sectional area (CSA) of OA. E: CSA of HA. Abbreviations: PNS, posterior nasal spine; PL plane, a plane parallel to the hard palate passing through the PNS; TU, tip of the uvula; EB, base of epiglottis; EB plane, a plane parallel to the PL plane passing through the EB; OA, oropharyngeal airway cross-section was measured parallel to the PL plane at TU; HA, hypopharyngeal airway cross-section was measured along the PL plane passing through the EB; D, depth; W, width.

Fig 6. Measurements of the three-dimensional widths of maxillofacial form. Abbreviations: Max, the greatest depth point of concavity of the maxillary contour; W_{max}, maxillary width between the left and right Max; Go, gonion; W_{man}, mandibular width between the left and right Go; U6, most lingual point of upper first molar; $W_{U6,}$, maxillary dental arch width between the left and right U6; L6, most lingual point of upper first molar; W_{L6}; mandibular dental arch width between the left and right L6

Fig 7. Distribution of nasal resistance and intraoral airway in Class II and Class III children. White markers: Without nasal obstruction, Red markers: Nasal obstruction (more than 100 pa), Round markers: Without inferior tongue posture (intraoral airway volume = 0 cm3), Triangular markers: Inferior tongue posture, Fisher's exact test clarified the distribution of inferior-tongue-posture children (blue area) between Class II and Class III (P = 0.022).

Fig 8. Distribution of nasal obstruction, presence of adenoids, enlarged tonsils, inferior tongue posture and large mandible among the subjects.

The black cells correspond to presence of each factor. Nsal obstruction; the resistance greater than 0.5 Pa/cm3/s, Adenoids; grade 3 or 4, Enlarged tonsils; Grade 4 or 5, Inferior tongue posture; the space between the palate and tongue was positive, Large mandible; either mandibular width or B(x) values were more than 1 S.D. larger than all subjects.

Fig. 9 Examples of nasal airway ventilation state using CFD (upper figure) and adenoids, tonsils (outlined in black), and tongue posture (light yellow area) in Class II and III children (lower figure). A; A Class II case with nasal obstruction (upper figure, more than 100 Pa) and enlarged tonsils (yellow arrow). The tongue posture (large red arrow) and the hyoid bone (light blue arrow) are low in spite of enlarged tonsils for nasal obstruction. However, the anteriorly directed pressure on the mandibular incisor and mandible by anterior displacement of the tongue by an enlarged tonsil is small (blue arrow) because the hyoid bone is low. B; A Class III case without nasal obstruction (upper figure, less than 100 Pa) and with enlarged tonsil (yellow arrow). The tongue was inferior without nasal obstruction, but the tongue was pushed forward (large red arrow) by the enlarged tonsils. The influences on the mandible and mandibular incisor of the anterior tongue posture are large (blue arrow) because the hyoid bone is not low. C; A Class III case without nasal obstruction (upper figure, less than 100 Pa) and with small tonsils (yellow arrow). Tongue posture was unaffected by the nasal airway and tonsils. The reason for the inferior tongue may be due to increased mandibular size and no low hyoid bone.

Figure 1

Click here to download high resolution image

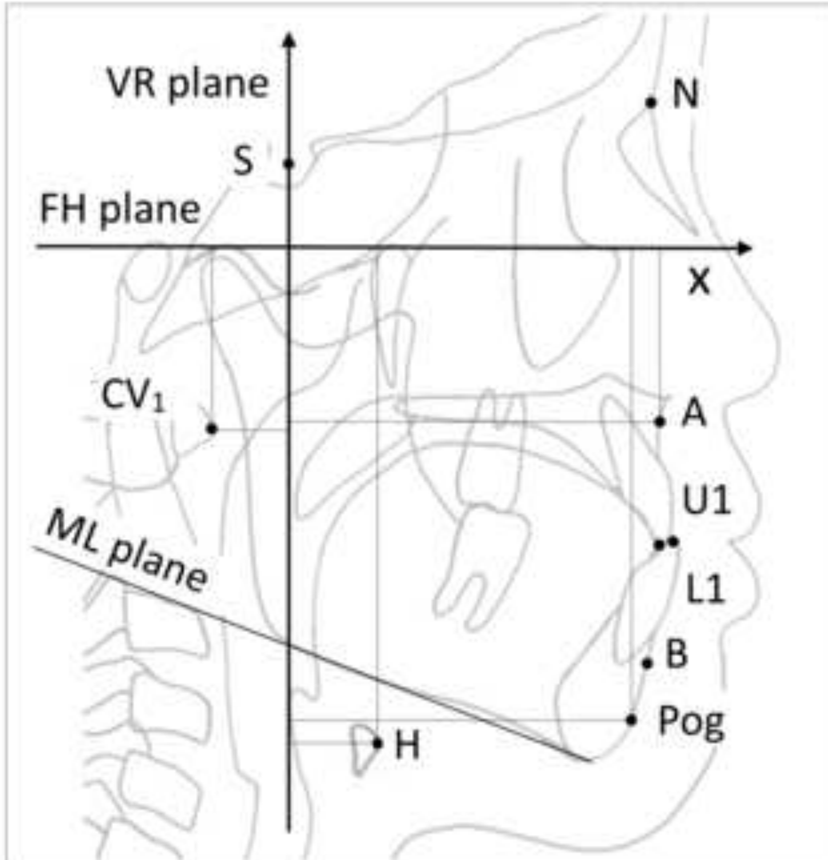

Figure 2
Click here to download high resolution image

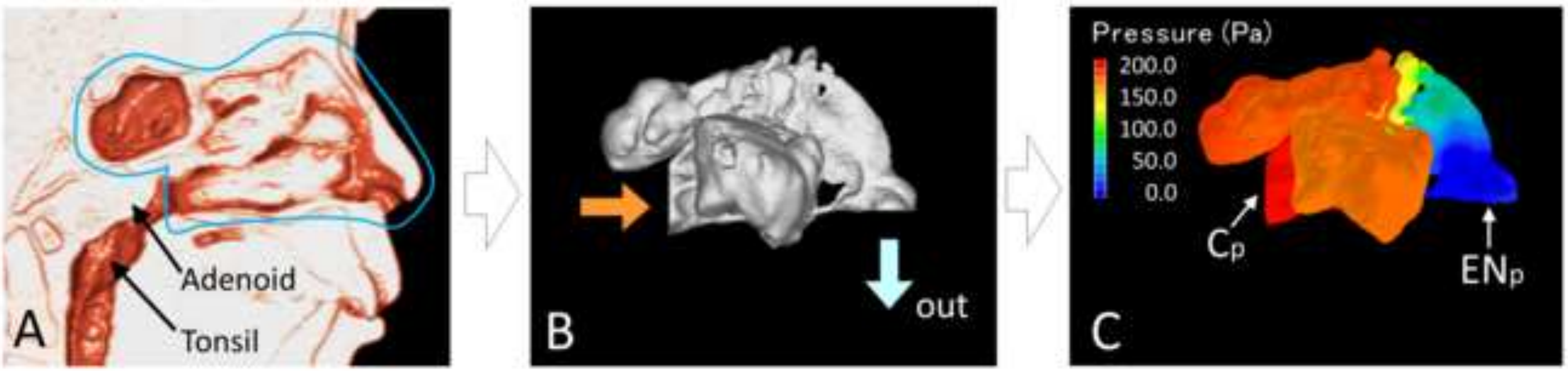

Figure 3
Click here to download high resolution image

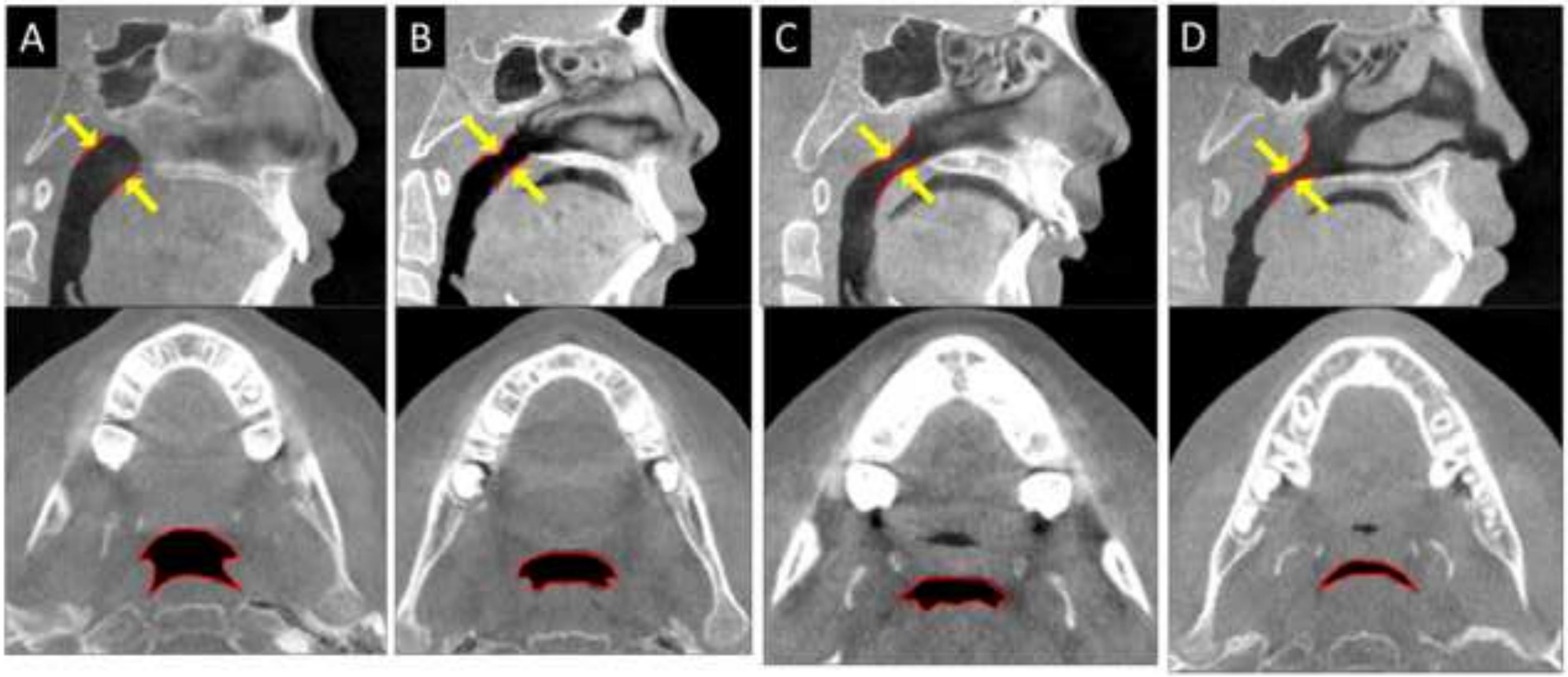

Figure 4
Click here to download high resolution image

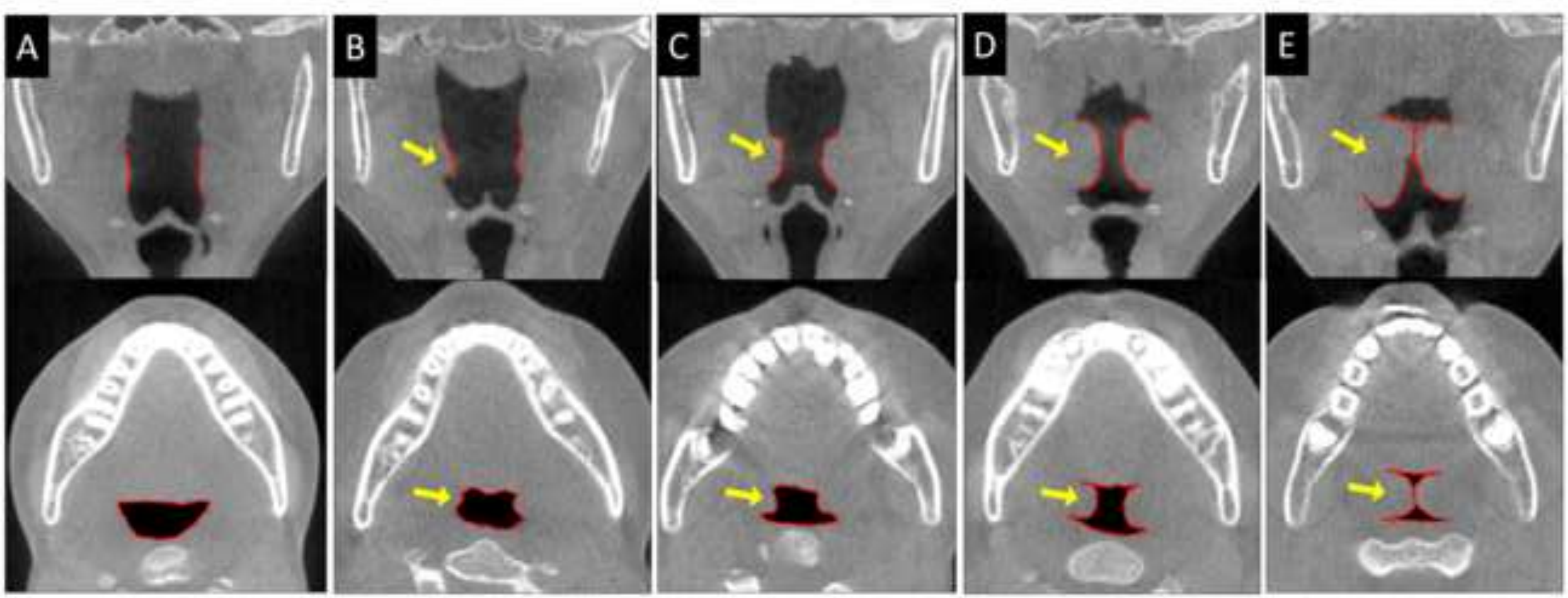

Figure 5

Click here to download high resolution image

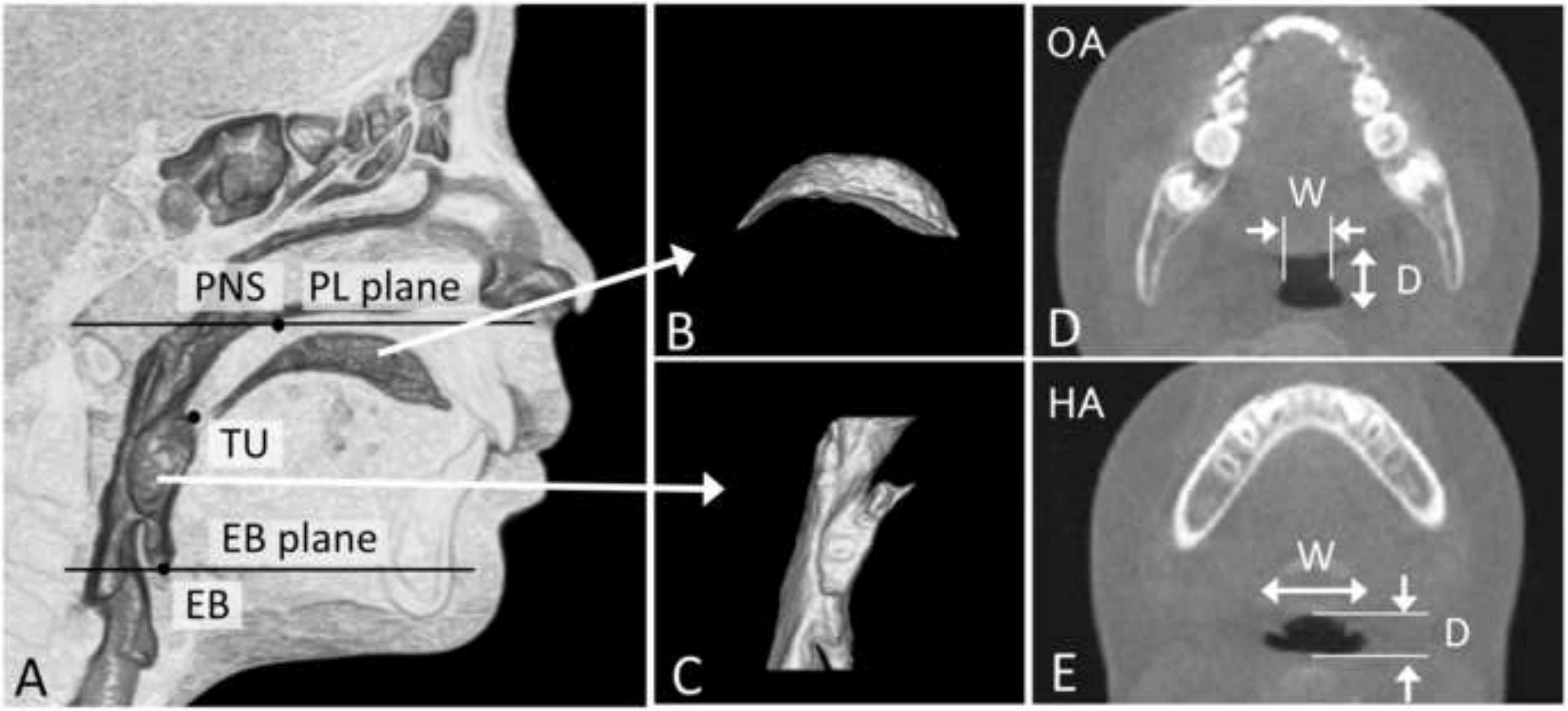

Figure 6
Click here to download high resolution image

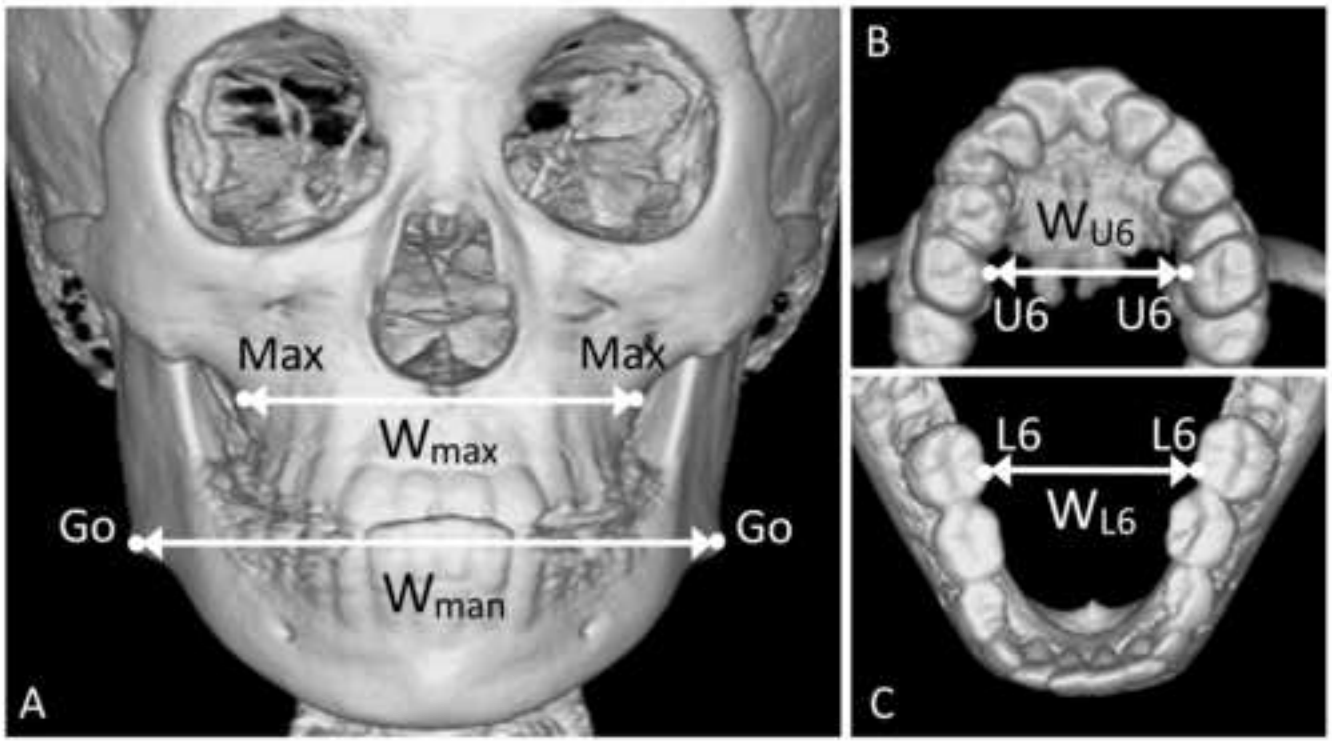

Figure 7
Click here to download high resolution image

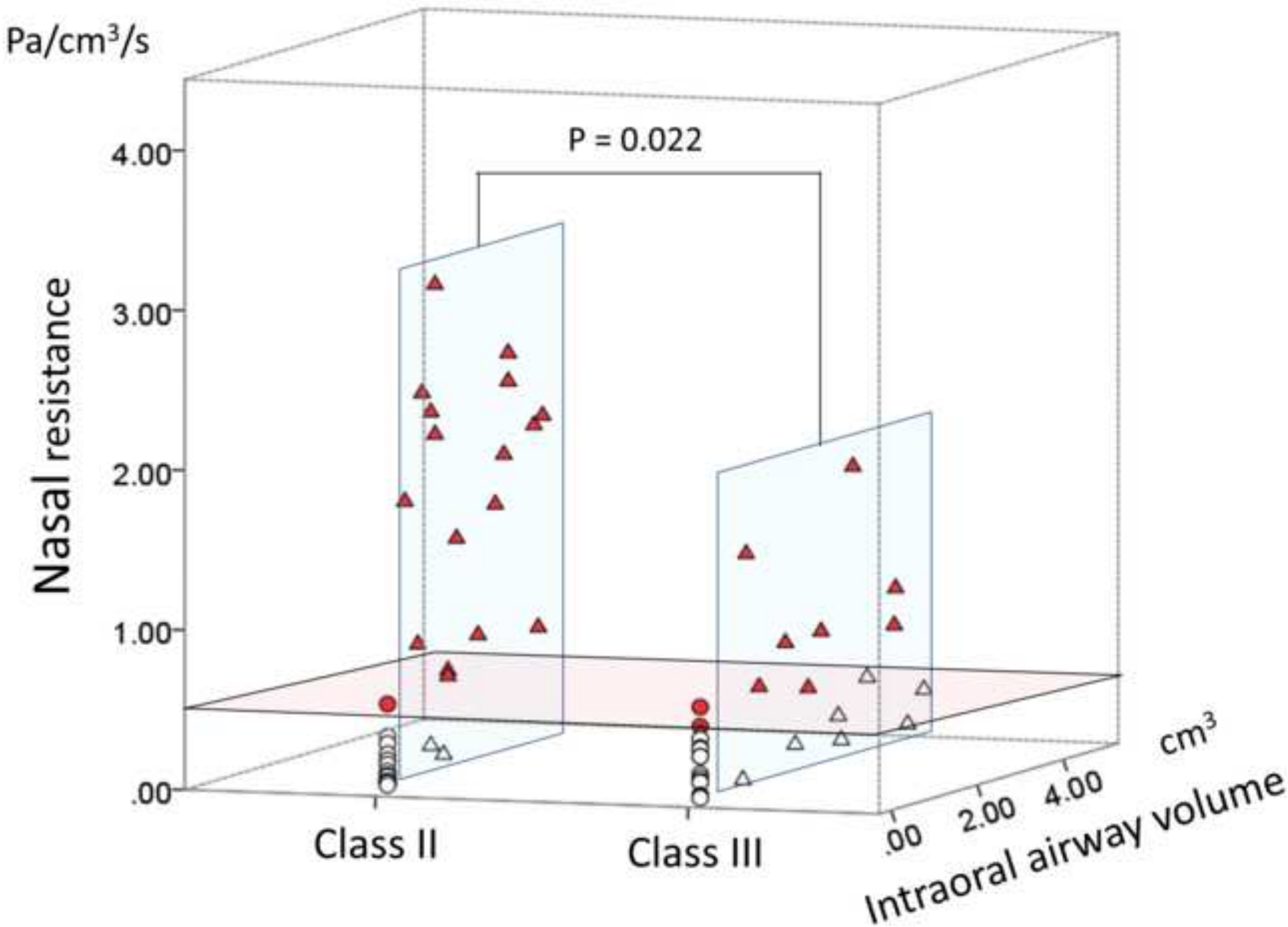

Figure 8

Click here to download high resolution image

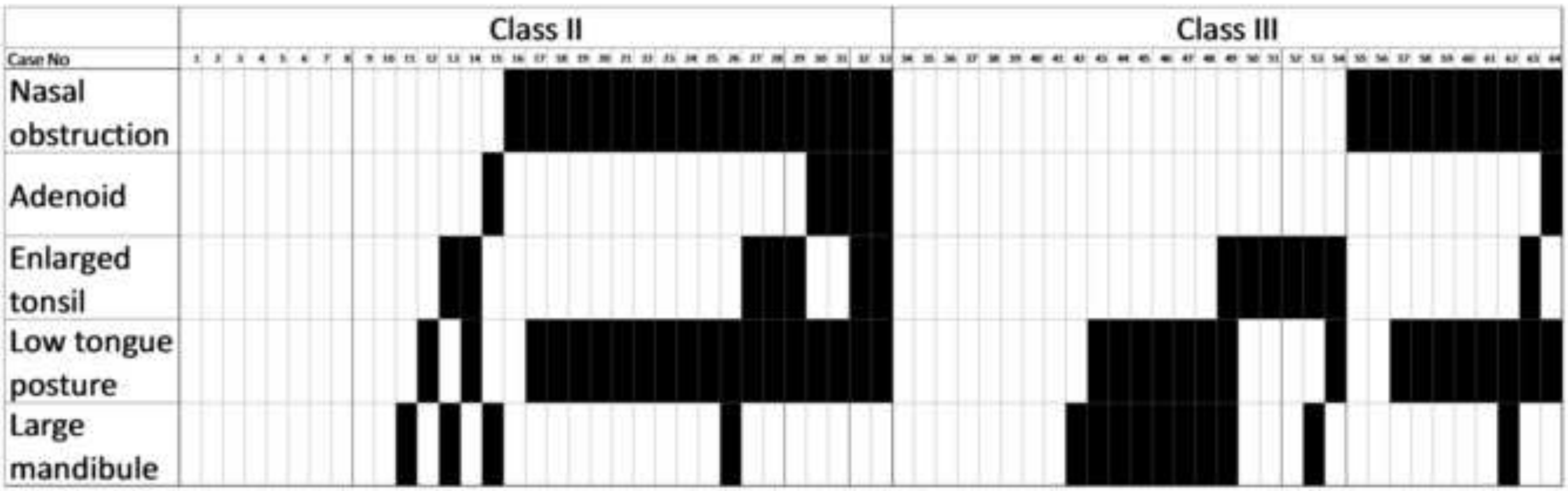

Figure 9
Click here to download high resolution image

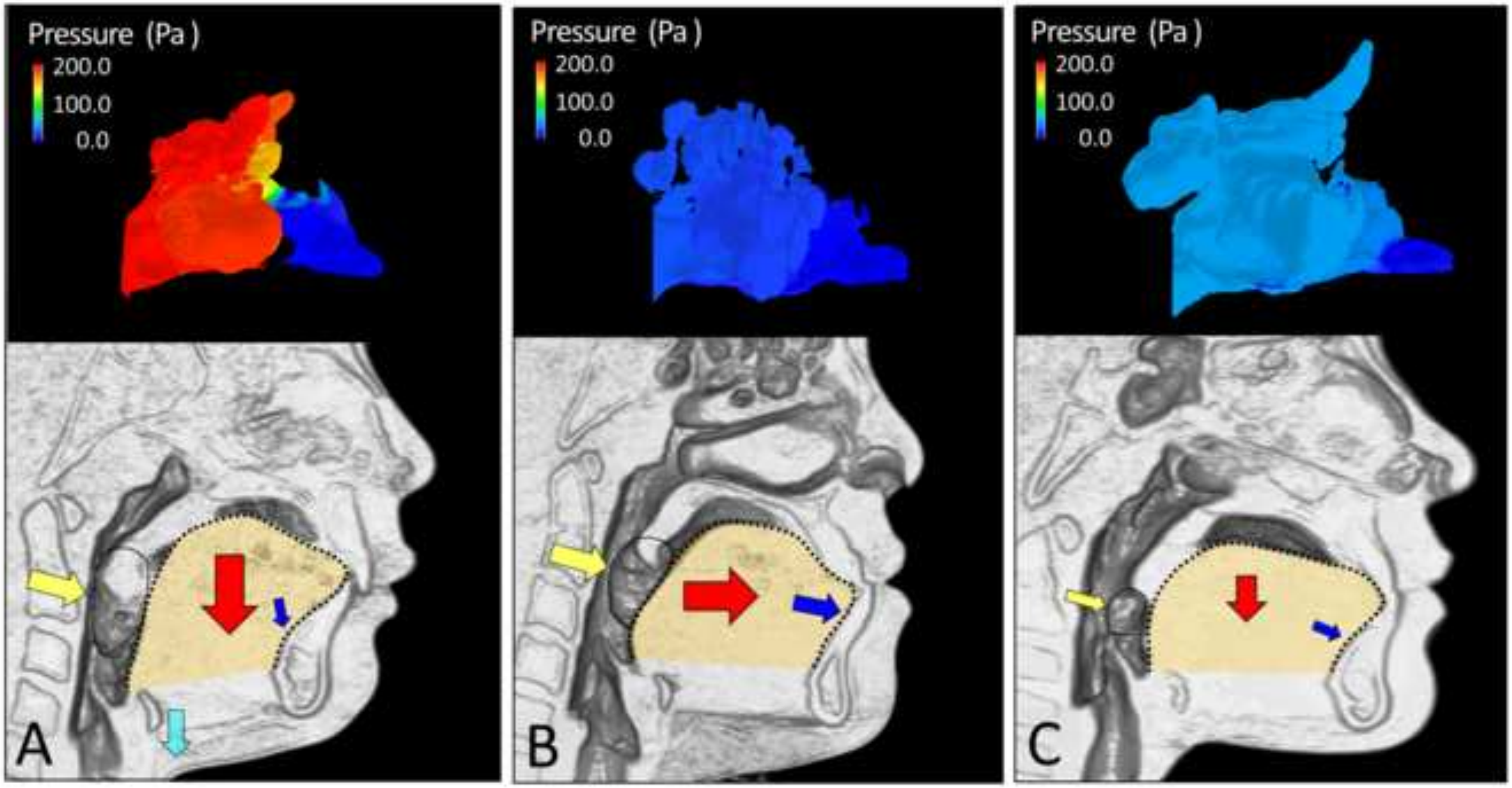

Table I

Table I Abbreviations in this study

Abbreviation	Definition
N	Nasion: the intersection between the internal and nasofrontal sutures in the midsagittal plane
S	Sella turcica: the midpoint of the sella turcica
PNS	Posterior nasal spine
A	Point A: the deepest midline point of the premaxilla between the anterior nasal spine and prosthion
U1	Tip of the upper incisor
L1	Tip of the lower incisor
B	Point B: the posterior point of the concavity between infradentale and pogonion
Pog	Pogonion: the most anterior point of the bony chin
Go	Gonion: the midpoint of the curvature of the angle of the mandible
H	Hyoidale: the most superoanterior point of the hyoid
CV_1	The most anterior point of the anterior arch of the atlas
TU	Tip of uvula
EB	Base of epiglottis
Max	The deepest point of concavity of the maxillary contour
U6	Most lingual point of upper first molar
L6	Most lingual point of lower first molar
FH plane	Frankfort horizontal plane
VR plane	Vertical reference plane passing through S
ML plane	Mandibular plane
PL plane	The horizontal plane parallel to the hard palate and passing through the PNS
EB plane	Plane parallel to the PL plane passing through the EB
OA	Oropharyngeal airway cross-section was measured parallel to the PL plane at TU
HA	Hypopharyngeal airway cross-section was measured along the PL plane passing through the EB
D	Depth
W	Width
W_{max}	Maxillary width between the left and right Max
W_{man}	Mandibular width between the left and right Go
W_{U6}	Maxillary dental arch width between the left and right U6
W_{L6}	Mandibular dental arch width between the left and right L6

Table II

Table II. Subject distributions based on adenoid size

	Grade 1	Grade 2	Grade 3	Grade 4	Fisher' s exact test P
Class II (n = 33)	19	9	3	2	0.013*
Class III (n = 31)	28	2	1	0	

*Statistically significant P <0.05

Table III

Table III. Subject distributions based on tonsil size

	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Fisher' s exact test P
Class II (n = 33)	3	14	9	5	2	0.379
Class III (n = 31)	1	8	15	6	1	

Table IV

Table IV. Subject distributions based on nasal obstruction

		Non–obstruction	Obstruction	Fisher' s exact test P
Without inferior~~low~~ tongue posture	Class II	13	1	1.000
	Class III	13	2	
With ~~low~~ inferior tongue posture	Class II	2	17	0.022*
	Class III	8	8	

*Statistically significant P <0.05

Table V

Table V Comparison of Class II and Class III children

	Class II (n = 33)		Class III (n = 31)		
	Mean	SD	Mean	SD	P
Nasal resistance (Pa/cm^3/s)	0.99	0.96	0.44	0.42	0.005**
Pharyngeal airway volume (cm^3)	9.98	2.69	9.61	2.53	0.574
Intraoral airway volume (cm^3)	1.07	1.21	1.66	1.93	0.151
OA depth (mm)	12.69	2.33	15.53	4.05	0.001**
OA width (mm)	14.03	6.41	16.61	4.63	0.071
HA depth (mm)	13.95	2.29	15.70	2.46	0.005**
HA width (mm)	27.76	3.36	28.85	5.71	0.352
OA-HA depth difference (mm)	−1.27	1.98	−0.17	3.80	0.149
OA-HA width difference (mm)	−13.73	6.48	−12.24	5.68	0.333
Airway length (mm)	49.48	3.62	45.45	2.85	< 0.001*
W_{max} (mm)	61.36	2.84	58.31	3.04	< 0.001**
W_{man} (mm)	85.56	4.92	85.29	4.83	0.829
W_{max}−W_{man} difference (mm)	−24.20	3.90	−26.99	4.28	0.008**
W_{U6} (mm)	32.87	2.06	34.09	1.97	0.018*
W_{L6} (mm)	32.45	2.04	33.54	2.06	0.038*
W_{U6}−W_{L6} difference (mm)	0.42	1.62	0.55	2.04	0.767

**Statistically significant at P < 0.01

* Statistically significant at P < 0.05

Table VI

Table VI　Comparison of Class II and Class III children

	Class II (n = 33)		Class III (n = 31)		
	Mean	SD	Mean	SD	P
SNA (degree)	81.11	2.93	80.06	1.69	0.085
SNB (degree)	73.38	2.98	80.60	2.26	< 0.001*
A(x) (mm)	60.93	2.37	58.23	3.51	< 0.001*
U1(x) (mm)	67.45	3.53	61.70	3.95	< 0.001*
L1(x) (mm)	61.72	3.82	62.79	4.02	0.278
B(x) (mm)	54.55	3.78	58.72	3.95	< 0.001*
Pog(x) (mm)	54.11	4.03	58.78	4.40	< 0.001*
H(x) (mm)	14.77	4.21	15.83	5.11	0.369
CV_1(x) (mm)	−9.94	2.77	−9.99	2.48	0.937
CV_1(y) (mm)	26.95	3.70	21.80	3.98	0.001*
H(y) (mm)	69.36	3.63	66.73	5.05	0.019
A(y) (mm)	25.53	2.61	24.19	2.99	0.060
U1(y) (mm)	44.68	3.09	41.89	3.43	< 0.001*
L1(y) (mm)	40.56	3.16	39.52	3.57	0.222
B(y) (mm)	58.36	3.32	59.08	4.70	0.482
Pog(y) (mm)	68.99	3.68	67.81	4.73	0.268

* Statistically significant at P < 0.0029

Table VII

Table VII　Comparison of Class III children with ~~low~~inferior tongue posture with and without nasal obstruction

	without obstruction (n = 8)		with obstruction (n = 8)		
	Mean	SD	Mean	SD	P
Nasal resistance (Pa/cm^3/s)	0.21	0.14	0.99	0.44	0.001*
Pharyngeal airway volume (cm^3)	10.22	2.76	8.74	2.87	0.310
Intraoral airway volume (cm^3)	3.63	1.53	2.79	1.33	0.264
OA depth (mm)	16.63	4.85	15.20	5.35	0.584
OA width (mm)	16.24	4.92	16.21	5.21	0.991
HA depth (mm)	14.96	3.00	15.64	3.13	0.665
HA width (mm)	29.57	5.90	27.34	8.96	0.565
OA-HA depth difference (mm)	1.67	6.02	-0.44	3.12	0.393
OA-HA width difference (mm)	-13.33	4.20	-11.12	6.46	0.432
Airway length (mm)	45.25	3.12	46.45	2.37	0.403
W_{max} (mm)	58.01	2.68	58.91	3.81	0.593
W_{man} (mm)	89.28	4.55	83.73	4.95	0.035*
W_{max}-W_{man} difference (mm)	-31.26	4.14	-24.81	3.89	0.006**
W_{U6} (mm)	34.68	2.31	33.16	1.81	0.167
W_{L6} (mm)	34.18	2.21	32.49	1.70	0.109
W_{U6}-W_{L6} difference (mm)	0.50	1.90	0.68	1.28	0.832

**Statistically significant at $P < 0.01$

* Statistically significant at $P < 0.05$

Table VIII

Table VIII Comparison of Class III children with ~~low~~inferior tongue posture with and without nasal obstruction

	without obstruction (n = 8)		with obstruction (n = 8)		
	Mean	SD	Mean	SD	P
SNA (degree)	80.31	1.33	79.19	0.37	0.051
SNB (degree)	81.81	1.56	79.25	0.93	0.001*
A(x) (mm)	58.10	3.56	60.25	4.00	0.275
U1(x) (mm)	61.35	3.43	64.12	4.43	0.184
L1(x) (mm)	64.35	4.15	63.72	4.34	0.771
B(x) (mm)	60.47	3.33	59.69	4.42	0.696
Pog(x) (mm)	60.93	3.46	59.76	4.63	0.576
H(x) (mm)	14.63	4.88	16.21	5.93	0.571
CV_1(x) (mm)	−11.33	1.06	−8.43	2.78	0.022
CV_1(y) (mm)	21.96	2.42	24.47	3.35	0.108
H(y) (mm)	67.51	6.36	67.91	4.63	0.887
A(y) (mm)	24.94	3.98	24.28	3.56	0.729
U1(y) (mm)	42.81	4.88	42.52	2.97	0.887
L1(y) (mm)	39.71	5.15	40.19	3.21	0.825
B(y) (mm)	60.08	6.24	60.46	4.56	0.891
Pog(y) (mm)	69.03	5.93	68.94	4.67	0.975

* Statistically significant at $P < 0.0029$

Table IX

Table IX Spearman rank correlation coefficients and P values between upper airway and maxillofacial form in Class II children

	Nasal resistance			Adenoid size			Tonsil size			Intraoral airway volume			OA–HA depth difference		
	r_s	P		r_s	P		r_s	P		r_s	P		r_s	P	
Intraoral airway volume	0.732	< 0.001	**												
OA depth													0.430	0.012	*
OA width				−0.396	0.022	*	−0.676	< 0.001	**				−0.491	0.004	**
HA depth													−0.391	0.024	*
HA width	0.412	0.017	*							0.373	0.033	*	−0.349	0.047	*
OA–HA depth difference				0.362	0.039	*	0.429	0.013	*						
OA–HA width difference							−0.626	0.000	**						
Airway length	0.442	0.010								0.434	0.012				
W_{U6}							−0.382	0.028	*				−0.355	0.042	*
W_{U6}–W_{L6} difference	−0.383	0.028	*				−0.350	0.046	*	−0.503	0.003	**	−0.408	0.018	*
A(x)													0.368	0.035	*
U1(X)				0.463	0.007	**							0.417	0.016	*
CV_1(y)							−0.404	0.020	*						
H(y)	0.387	0.026	*							0.402	0.020	*			

**Statistically significant at P < 0.01

* Statistically significant at P < 0.05

Not shown rank and values were not statistically significant

Table X

Table X Spearman rank correlation coefficients and P values between upper airway and maxillofacial form in Class III children

	Nasal Resistance			Adenoid size			Tonsil size			Intraoral airway volume			OA–HA depth difference		
	r_s	P		r_s	P		r_s	P		r_s	P		r_s	P	
OA–HA depth difference	−0.362	0.046	*				0.724	< 0.001	**						
OA depth	−0.381	0.035	*				0.698	< 0.001	**				0.765	< 0.001	**
OA width							−0.632	< 0.001	**				−0.593	< 0.001	**
HA width													−0.534	0.002	**
L1(x)							0.474	0.007	**				0.533	0.002	**
B(x)										0.385	0.033	*	0.387	0.032	*
Pog(x)										0.389	0.030	*			
$CV_1(y)$	0.496	0.005	**												

**Statistically significant at P < 0.01

* Statistically significant at P < 0.05

Not shown rank and values were not statistically significant