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Association of lip posture and the dimensions of the tonsils and sagittal airway with facial morphology

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The classic clinical observation that Class II division I anomalies are frequently associated with mouth breathing has up to the present day produced abundant literature, however without reaching a consensus among the diverging opinions."

These words of Korkhaus[1] are as true today as they were when he wrote them in 1939. Korkhaus also observed that mouthbreathing often was associated with enlarged adenoids or tonsils or both. The assumption was that hypertrophy of the lymphatic structures of Waldeyer's ring caused mouthbreathing and ultimately resulted in a narrow dental arch, a skeletal Class II malocclusion, and a longer face overall.

Lymphoid tissue and facial form

In his landmark study, Linder-Aronson[2] established the relationship between the presence of adenoid tissue and the following features: retrusion of the maxilla and mandible relative to the cranial base, narrow dental arches, (tendency to) crossbite, retroclination of the maxillary and mandibular incisors, short mandibular dental arches, increased facial height, and a low tongue position. In a later study, Linder-Aronson[3] reported spontaneous realignment of the maxillary and mandibular incisors following adenoidectomy, suggesting a direct relationship between the magnitude of adenoid tissue and craniofacial form.

Abstract

The specific contribution of enlarged tonsils or adenoids to craniofacial growth remains unknown, and there is no agreement in the literature as to the significance of lip posture. This study assessed the separate associations of lip posture, sagittal airway size, and tonsil size with selected cephalometric measures. Clinical and cephalometric data of 207 children who presented for evaluation of tonsil and/or adenoid problems were evaluated. Multiple linear regression was used to assess the linear relationship between each of the three parameters and the cephalometric dependent variables. Open lip posture, reduced sagittal airway, and large tonsils were each associated statistically with a characteristic but different skeletal configuration. This association was proportional. Specifically, a more open lip posture was associated with a more backwardly rotated face and larger lower facial height. Reduced sagittal airway size was associated with *en bloc* backward relocation of the maxilla and mandible. Because the sella-nasion dimension shortened proportionally, the SNA and SNB angles were not affected. Larger tonsils were associated with more forward relocation and rotation of the maxilla and mandible and increased SNA and SNB angles. Because each of the three parameters was associated proportionally with a different craniofacial morphology, it is concluded that lip posture, sagittal airway size, and tonsil size represent three different and unrelated phenomena with respect to their effects on craniofacial growth and form.

Key Words

Airway • Adenoids • Tonsils • Cephalometry • Craniofacial growth • Pharynx • Vertical dimension

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Table 1
Cephalometric measures

Cranial base
Anterior cranial base length (mm): sella to nasion (S-N)
Posterior cranial base length (mm): sella to articulare (S-Ar)
Cranial base angle (deg): articulare-sella-nasion (ArSN)
Vertical dimensions
Total anterior face height (mm): nasion to menton (N-Me)
Upper anterior face height (mm): nasion to anterior nasal spine (N-ANS)
Lower anterior face height (mm): anterior nasal spine to menton (ANS-Me)
Upper posterior face height (mm): sella to posterior nasal spine (S-PNS)
Lower posterior face height (mm): articulare to gonion (Ar-Go)
Frankfort horizontal-sella nasion plane angle (deg): (FH-SN)
Frankfort horizontal-palatal plane angle (deg): (FHPP)
Frankfort horizontal-occlusal plane angle (deg): (FHOP)
Frankfort horizontal-mandibular plane angle (deg): (FHMP)
Maxillary dimensions
Articulare to A-point (mm) (Ar-A)
Bony pharynx (mm): articulare to posterior nasal spine (Ar-PNS)
Sella-nasion-A-point angle (deg) (SNA)
Mandibular dimensions
Mandibular length (mm): articulare to gnathion (Ar-Gn)
Corpus length (mm): gonion to pogonion (Go-Pg)
Gonial angle (deg): articulare-gonion-menton (ArGoMe)
Sella-nasion-B-point angle (deg) (SNB)
A-point-nasion-B-point angle (deg) (ANB)
Maxillary dentoalveolar region
Upper incisor edge to palatal plane (mm) (UIE-PP)
Upper incisor to Frankfort horizontal plane (deg) (UI-FH)
Maxillary molar vertical position (mm): upper first molar mesiobuccal cusp tip to palatal plane (UM-PP)
Maxillary molar horizontal position (mm): upper first molar mesiobuccal cusp tip to articulare (UM-Ar)
Mandibular dentoalveolar region
Lower incisor edge to mandibular plane (mm) (LIE-MP)
Mandibular incisor inclination (deg): lower incisor to mandibular plane (LI-MP)
Mandibular molar vertical position (mm): lower first molar mesiobuccal cusp tip to mandibular plane (LM-MP)
Mandibular molar horizontal position (mm): lower first molar mesiobuccal cusp tip to articulare (LM-Ar)
Overjet (mm)
Overbite (mm)

Similar observations have been noted by other investigators.[4-7] For example, in children with enlarged adenoids, the mandibular plane angle is increased,[4-6] and the tongue occupies a more downward and forward position in the oral cavity.[5-7] Additionally, the clivus often has a more forward inclination relative to the cranial base.[4] Other researchers have noted an enlarged cranial base angle and a low dorsal arch of the first cervical vertebra in children with enlarged adenoids.[8] Solow et al.[9] examined a sample of 24 children before adenoidectomy and found a large craniocervical angle, increased nasal respiratory resistance, and a decreased size of the passage between the adenoid tissue and choanae. Postadenoidectomy, the craniocervical angle was reduced. A large craniocervical angle has also been observed in children with enlarged tonsils.[7] Only one study[10] failed to document any relationship between adenoid tissue size and craniofacial form.

Airway parameters and facial form

Results of studies of the relationship between airway parameters and facial form are conflicting.[2,9,12-17] Some investigators[2,9,13] postulated a direct relationship between increased airway resistance and enlarged adenoid tissue. In these studies airway resistance was measured indirectly from lateral cephalometric radiographs. Woodside and coworkers,[12] in a sample of 60 children, assessed nasal obstruction by posterior rhinomanometry immediately preadenoidectomy and 5 years postadenoidectomy. These workers found that during the 5-year study period, mandibular growth was greater in children who had undergone adenoidectomy than in a control group; however, there was no difference in maxillary growth. Conversely, studies comparing dentofacial form with breathing patterns demonstrate inconclusive results.[15-17] In one study, Ung and coworkers [17] found that over a 24-hour period subjects varied in their mode of breathing. In addition, nasal airway resistance and nasal power were not correlated with either dental or skeletal variables.

Lip posture also has been used as a parameter to assess airway resistance indirectly. The suggestion is that individuals who have a more open lip posture also have increased nasal airway resistance. Previous studies have demonstrated that children who have a more open lip posture also have larger mandibular and palatal plane angles,[18] decreased maxillary growth,[19] and increased lower anterior face height.[20] In addition, there have been reports of an association between craniocervical posture and airway size,

but the results of these studies are inconclusive.[21-22] Finally, a review of the literature[23] failed to support a relationship between obstructed nasorespiratory function and long-face syndrome, and a recent review of 125 articles concluded that "scientific evidence prompts us to moderate our clinical expectations...when we therapeutically attempt to alter a LFS [long face syndrome] patient's breathing mode."[24]

Studies based on population data have demonstrated that the volume of the airway can be computed very accurately by means of three-dimensional CT scans;[25,26] however, three-dimensional norms are not available. In addition, genetic factors seem to have a considerable influence on the size of the pharyngeal soft tissue airway space.[27] The thickness of the pharyngeal soft tissue does not follow Scammon's curve[28] but appears to be largest at 5 years and decreases to 10 years.

From the literature reviewed, the nature of the specific contribution of either enlarged tonsils or adenoids to craniofacial growth remains unknown. In addition, there is no agreement in the literature as to the significance of lip posture in craniofacial growth and development. This study assesses the separate association of three parameters—lip posture, sagittal airway size, and tonsil size—with selected cephalometric measures.

Materials and methods

The sample population was taken from a previous study of indications for tonsillectomy and adenoidectomy at the Children's Hospital of Pittsburgh.[32-36] The children presented for consideration of tonsillectomy and/or adenoidectomy. For this study, the final sample of children was selected based on the following criteria: no history of tonsillectomy or adenoidectomy; complete clinical records; technically adequate lateral cephalograms; visibility of the tonsils on lateral cephalograms; and the absence of respiratory infections at the time of clinical examination. In all instances, the gender and age of the children were known. In addition, cephalograms were obtained between 1975 and 1984, and only one cephalogram per child was used. In the end, 207 Caucasian children aged 3 to 13 years were included in this study.

Data on lip posture were obtained at the time of clinical examination. The amount of lip separation was evaluated, with the child distracted or in repose, using a 4-point scale (none=1, mild=2, moderate=3, severe=4); lip separation was evaluated only in children who were free of respiratory infection. Both the sagittal airway size and tonsil size were measured from a lateral cephalogram taken during the same appointment. Sagittal airway size was measured as the isthmus between the most superior posterior aspect of the upper half of the soft palate to the closest point on the posterior pharyngeal wall. This isthmus is smaller when the adenoids are large, and vice versa.[9,13,28,32] Tonsil size was measured as the maximum width of the tonsil shadow close to the gonial angle and parallel to the Frankfort horizontal plane.

Table 2
Independent variables for children selected from the Pittsburg study (N=207)

Independant variable	Range	Mean	S.D.
Gender (female/male)	44% / 56%		
Age (yrs.)	3 - 13	7.13	2.00
Lip posture (scale value)	1 - 4	2.01	0.90
Sagittal airway size (mm)	0.00 - 15.20	4.60	2.90
Tonsil size (mm)	5.60 - 22.90	13.90	3.50

The lateral cephalometric radiographs were traced by one investigator (JAM) and checked for accuracy of landmark determination by another. The radiographs were then digitized. The specific dimensions measured in this study are outlined in Table 1. Dimensions were chosen without intentionally being redundant. In order to facilitate interpretation, the cephalometric measures are presented in two components: skeletal and dental. The skeletal measures are further grouped into cranial base, vertical, maxillary, and mandibular dimensions (Table 1).

Statistical analysis

Means and standard deviations were computed for each independent variable (Table 2), as well as Pearson product moment correlation coefficients, to assess multicollinearity. Individual regression analyses were performed with gender, age, lip posture, sagittal airway size, and tonsil size as the independent variables and the cephalometric measures as the dependent variables. The level of significance was set at $\alpha \leq 0.05$.

Explanation of regression analysis

The multiple linear regression model weighs, in multidimensional space, the contribution of each independent variable to the explained variance in the dependent variable, after adjusting for all other independent variables. The model retains a beta-weight and a significance level for each independent variable. The beta-weight gives the change of a given dependent or cephalometric variable for each unit change of an independent variable. This change is propor-

Table 3
Associations of gender, age, lip posture, sagittal airway size, and tonsil size with selected cephalometric measures of dentofacial form

Measure	Gender	Age	Lip posture	Sagittal airway size	Tonsil size	R-square
Cranial base						
S-N (mm)	2.6	0.8	ns	0.3	ns	0.40
S-Ar (mm)	1.7	0.9	ns	ns	ns	0.36
ArSN (°)	ns	ns	ns	ns	ns	0.03
Vertical						
N-Me (mm)	2.5	2.6	2.7	ns	ns	0.60
N-ANS (mm)	ns	1.4	0.5	ns	ns	0.55
ANS-Me (mm)	1.9	1.1	2.4	ns	-0.2	0.43
S-PNS (mm)	1.5	1.0	ns	0.2	0.1	0.46
Ar-Go (mm)	0.9	0.9	ns	0.2	0.2	0.36
FH-SN (°)	ns	ns	ns	ns	ns	0.03
FH-PP (°)	ns	ns	0.7	ns	ns	0.04
FH-OP (°)	ns	ns	ns	ns	ns	0.06
FH-MP (°)	ns	ns	2.4	-0.3	-0.3	0.28
Maxillary						
Ar-A (mm)	3.4	1.1	ns	0.4	0.3	0.44
Ar-PNS (mm)	2.0	0.5	ns	0.2	0.2	0.32
SNA(°)	ns	-0.3	ns	ns	0.1	0.08
Mandibular						
Ar-Gn (mm)	2.8	2.2	ns	0.4	0.3	0.56
Go-Pg (mm)	1.5	1.7	ns	0.3	ns	0.49
ArGoMe (°)	ns	-0.6	1.5	ns	ns	0.12
SNB (°)	ns	ns	-0.7	ns	0.2	0.11
ANB (°)	ns	-0.2	ns	ns	ns	0.06
Maxillary dentoalveolar						
UIE-PP (mm)	1.1	0.8	1.0	ns	ns	0.35
UI-FH (°)	ns	ns	ns	ns	ns	0.18
UM-PP (mm)	ns	0.7	0.6	ns	ns	0.34
UM-Ar (mm)	2.0	1.5	ns	0.4	0.2	0.44
Mandibular dentoalveolar						
LIE-MP (mm)	1.5	0.9	0.8	ns	ns	0.34
LI-MP (°)	ns	ns	-2.6	0.6	ns	0.23
LM-MP (mm)	1.0	0.4	ns	ns	ns	0.15
LM-Ar (mm)	2.0	1.6	ns	0.4	0.3	0.50
Overjet (mm)	ns	ns	ns	ns	ns	0.05
Overbite (mm)	ns	ns	ns	ns	ns	0.10

* Nonstandardized beta-weights
** All values shown were significant at p<=0.05; ns denotes not significant

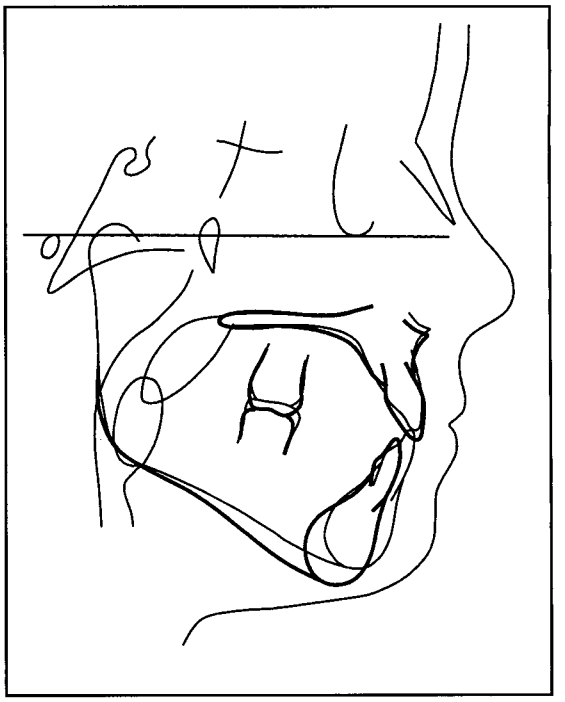

Figure 1

tional. For example, the range for lip posture was 1 for closed lips to 4 for extremely open lips (Table 2). This range implies that the beta-weight for a given cephalometric measure in children with severe open lips was 4 times the beta-weight for children with closed lips. The range for sagittal airway size was 0 to 15.2 mm (Table 2). This implies that the beta-weight for a given cephalometric measure in children with maximum sagittal airway was 15.2 times the beta-weight in children with a minimum sagittal airway. Finally, the range for tonsil size was 5.6 to 22.9 mm. Therefore, the beta-weight for a given cephalometric measure in children with maximum tonsil size was 17.3 times the beta-weight in children with minimum tonsil size. The significant beta-weights for the parameters lip posture, sagittal airway size, and tonsil size were integrated and interpreted as three distinct morphological forms for each parameter.

Results

Table 2 shows the mean values and ranges for the demographic and independent variables: gender, age, lip posture, sagittal airway size, and tonsil size. Gender breakdown of the sample was 44% female, 56% male. The average age of the subjects was 7.1 years, with a range of 3 to 13 years. Sagittal airway size ranged from 0.0 to 15.2 mm, and tonsil width ranged from 5.60 to 22.9 mm. Three of the correlation coefficients among the independent variables were significantly different from zero; however, the magnitudes of

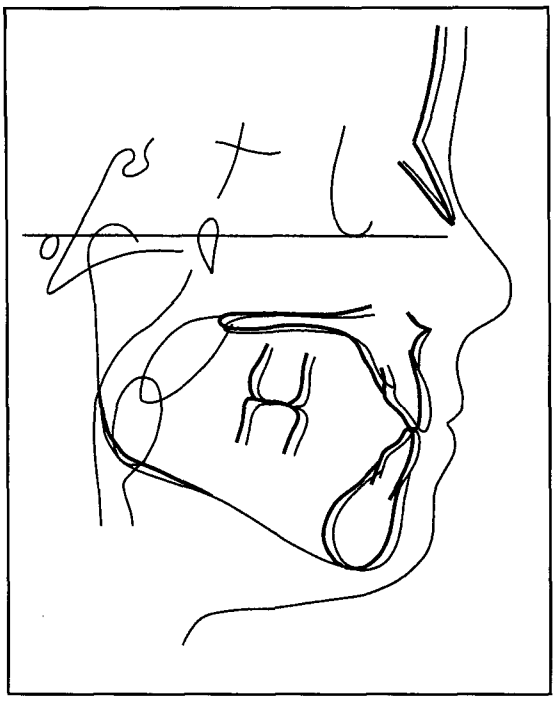

Figure 2

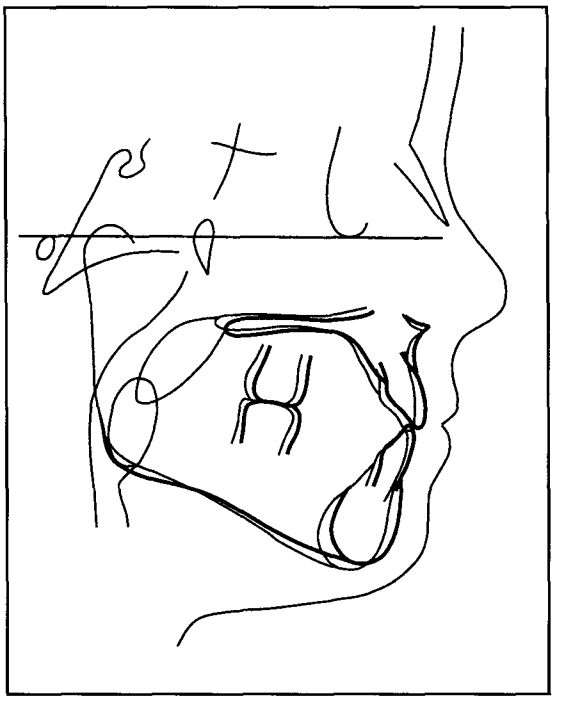

Figure 3

Figure 1
Open lip posture was associated with features seen in the characteristic backward-rotating growth pattern, a retrognathic face, and enlarged lower facial height. This figure is made by incorporating the significant mean differences for lip posture in an arbitrarily chosen tracing and provides a general picture rather than a quantitative representation of the data.

Figure 2
The skeletal pattern associated with a reduced sagittal airway (or larger adenoids) was characterized by features of less horizontal growth of the whole face. This figure is made by incorporating the significant mean differences for the sagittal airway in an arbitrarily chosen tracing and provides a general picture rather than a quantitative representation of the data.

Figure 3
The skeletal pattern associated with larger tonsils was characterized by increased posterior but decreased lower anterior facial height, and a prognathic face. These features suggest more horizontal growth. This figure is made by incorporating the significant mean differences for tonsils in an arbitrarily chosen tracing and provides a general picture rather than a quantitative representation of the data.

these differences were small and the effects of multicollinearity were judged to be small.

Table 3 shows the associations (beta-weights) between the independent (demographic and clinical) variables and the various cephalometric dependent variables together with the respective coefficients of explained variance (*R*-square) as determined by multiple regression analysis. The median of the explained variances was 0.32. For 10 of the 34 variables, the explained variance was more than 0.40. The highest value (0.60) was noted for total anterior facial height (N-Me).

Results of the analysis for lip posture, sagittal airway size, and tonsil size are discussed separately below. Figures 1 through 3 were constructed by calculating the value of each dependent variable using the mean of values for each independent variable. These figures provide an easy visual representation of the differences among the dependent variables for each of the three parameters, lip posture, sagittal airway size, and tonsil size.

Lip posture (Table 3 and Figure 1)

Skeletal

A more open lip posture was associated with an increase in total facial height (N-Me), lower anterior facial height (ANS-Me), palatal plane angle (FH-PP), mandibular plane angle (FH-MP), and gonial angle (Ar-Go-Me); however, the chin was more retrognathic (Np-Pg).

Dental

A more open lip posture was associated with an increase in the vertical position of the maxillary molars and incisors relative to the palatal plane (UM-PP and UI-PP) and mandibular incisors relative to the mandibular plane (LIE-MP); however, there was a decrease in the mandibular incisor inclination relative to the mandibular plane (LI-MP).

Sagittal airway size (Table 3 and Figure 2)

Skeletal

An increase in the size of the sagittal airway was associated with increases in anterior cranial base length (S-N), posterior facial height (S-PNS and Ar-Go), midfacial length (Ar-A), bony pharynx (Ar-PNS), mandibular length (Ar-Gn), and mandibular corpus length (Go-Pg); however, there was a decrease in the mandibular plane angle.

Dental

An increase in the size of the sagittal airway was associated with increases in the distances of the maxillary and mandibular first molars to articulare (UM-Ar and LM-Ar) and an increase in the degree of mandibular incisor proclination relative to the mandibular plane (LI-MP).

Tonsil size (Table 3 and Figure 3)

Skeletal

An increase in the size of the tonsils was associated with increases in posterior facial height (S-PNS and Ar-Go) and the dimensions determining the depth of the midface and mandible (Ar-A, Ar-PNS, SNA, Ar-Gn, and SNB); however, there was a decrease in lower anterior facial height (ANS-Me) and the mandibular plane angle (FH-MP).

Dental

An increase in the size of the tonsils was associated with an increase in the dimensions of the maxillary and mandibular first molar horizontal positions (UM-Ar and LM-Ar).

Discussion

To our knowledge, this study is unique in that it is the first attempt to separate the associations of craniofacial morphology among the parameters of lip posture, sagittal airway size, and tonsil size. The results of this study demonstrate that these three parameters are associated with coherent but different skeletal configurations and suggest facial skeletal adaptations to specific environmental stimuli.

The significant beta-weights can be interpreted as the amount of change in a dependent variable relative to each unit change in an independent variable. For example, consider the beta-weights for the bony pharynx (Ar-PNS, Table 3). The explained variance for this dependent variable was 44%. On average in this study population, the bony pharynx was 2.0 mm larger in males than in females (females were coded as zero, males were coded as one), and there was an estimated increase in the size of the bony pharynx of 0.5 mm per year of age (the unit value equals years). For each millimeter increase in sagittal airway size and tonsil size, the bony pharynx was larger by 0.2 mm; however, there was no association between lip posture and the size of the bony pharynx. Notably, in this study the magnitude of the associations among the size of the bony pharynx, gender (2 mm), and growth (0.5 mm/yr.) are comparable with the values reported in the literature.[35]

The skeletal pattern associated with lip posture (Table 3 and Figure 1) appeared unrelated to that associated with both sagittal airway size and tonsil size. A more open lip posture was associated with a downward and backward rotation of the maxilla and mandible, a more obtuse gonial angle, a retruded mandible with retroclined incisors, extruded maxillary molars and maxillary and mandibular incisors, and an elongated total facial height caused mainly by a larger lower anterior facial height. These features of a more open lip posture were indicative of a backward rotating growth pattern.

The skeletal pattern associated with sagittal airway size (Table 3 and Figure 2) must be interpreted differently. Clinically, a zero value for sagittal airway size represents an abnormal condition, while a large value is more representative of a normal condition. Thus, the skeletal pattern associated with the more abnormal condition of reduction in sagittal airway size due to enlarged adenoids was characterized by an *en bloc* backward rotation of the maxilla and mandible (including the dental arches) relative to the cranial base and by a shorter mandibular body. The sella-nasion dimension varied proportionally such that the SNA and SNB angles were not affected. Also, anterior cranial base rotated in a similar manner.

The skeletal pattern associated with greater tonsil size (Table 4 and Figure 3) appeared to be the opposite, in many respects, of the pattern associated with a reduction in sagittal airway size. Larger tonsil size was characterized by a forward relocation of the maxilla and mandible relative to the cranial base, and by a wider bony pharynx. Because the sella-nasion dimension was not enlarged, the SNA and SNB angles were larger. Thus, a characteristic for both sagittal airway and tonsil size was a coherent pattern of maxillary and mandibular relocation relative to the cranial base; however, these relocations occurred in opposite directions.

Finally, two important caveats must be noted concerning our findings and the conclusions they suggest. First, a cephalogram produces a two-dimensional image of the convoluted and anatomically irregular three-dimensional nasal airway morphology.[24,25] Second, the children we studied constituted a selected population of severely affected patients. Accordingly, our findings must be viewed as approximations and our conclusions tentative. Also, these findings must be considered specific to the population studied and not necessarily generalizable to other groups of children.

Conclusions

This study suggests specific but different craniofacial morphological associations for lip posture, sagittal airway, and tonsils.

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References

1. Korkhaus G. Biomechanische Gebiss- und Kieferorthopädie (Orthodontie). In: Brun C, ed. Handbuch der Zahnheilkunde. Vierter Band. Gebiss-, Kiefer- und Gesichtsorthopädie. München: Bergmann, 1939; 140-742.
2. Linder-Aronson S. Adenoids. Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the dentition. Acta Oto-laryngol suppl 265, 1970.
3. Linder-Aronson S. Effects of adenoidectomy on dentition and nasopharynx. Am J Orthod 1974;65:1-15.
4. Koski K, Lähdemäki P. Adaptation of the mandible in children with adenoids. Am J Orthod 1975;68:660-665.
5. Adamidis IP, Spyropoulos MN. The effects of lymphadenoid hypertrophy on the position of the tongue, the mandible and the hyoid bone. Eur J Orthod 1983;5:287-294.
6. Tarvonen P-L, Koski K. Craniofacial skeleton of 7-year-old children with enlarged adenoids. Am J Orthod Dentofac Orthop 1987;91:300-304.
7. Behlfelt K, Linder-Aronson S, Neander P. Posture of the head, the hyoid bone, and the tongue in children with and without enlarged tonsils. Eur J Orthod 1990;12:458-467.
8. Huggare J, Kylamarkula S. Morphology of the first cervical vertebra in children with enlarged adenoids. Eur J Orthod 1985;7:93-96.
9. Solow B, Siersbaek-Nielsen S, Greve E. Airway adequacy, head posture and craniofacial morphology. Am J Orthod 1984;86:214-223.
10. Sosa FA, Graber TM, Muller TP. Postpharyngeal lymphoid tissue in Angle Class I and Class II malocclusions. Am J Orthod 1982;81:299-309.
11. Linder-Aronson S. Naso-respiratory function and craniofacial growth. In: McNamara JA Jr., ed. Naso-respiratory function and craniofacial growth. Monograph 9, Craniofacial Growth Series, Ann Arbor: Center for Human Growth and Development, University of Michigan, 1979; 121-147.
12. Woodside DG, Linder-Aronson S, Lundström A, McWilliam J. Mandibular and maxillary growth after changed mode of breathing. Am J Orthod Dentofac Orthop 1991;100:1-18.
13. Dunn GF, Green LJ, Cunat JJ. Relationships between variation of mandibular morphology and variation of nasopharyngeal airway size in monozygotic twins. Angle Orthod 1973;43:129-135.
14. Handelman CS, Osborne G. Growth of the nasopharynx and adenoid development from one to eighteen years. Angle Orthod 1976;46:243-259.
15. Diamond O. Tonsils and adenoids: why the dilemma? Am J Orthod 1980;78:495-503.
16. Vig PS. Respiratory mode and morphological types: some thoughts and preliminary conclusions. In: McNamara JA Jr., ed. Naso-respiratory function and craniofacial growth. Monograph 9, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1979;233-250.
17. Ung N, Koenig J, Shapiro PA, Shapiro G, Trask G. A quantitative assessment of respiratory patterns and effects on dentofacial development. Am J Orthod Dentofac Orthop 1990;98:523-532.
18. Fricke B, Gebert HJ, Grabowski R, Hasund A, Sergl HS. Nasal airway, lip competence, and craniofacial morphology. Eur J Orthod 1993;15:297-304.
19. Gross AM, Kellum GD, Franz D, Michas K, Walker M, Foster M, Bishop FW. A longitudinal evaluation of open mouth posture and maxillary arch width in children. Angle Orthod 1994;64:419-424.
20. Hartgerink DV, Vig PS. Lower anterior face height and lip incompentence do not predict nasal airway obstruction. Angle Orthod 1989;59:17.
21. Weber ZJ, Preston CB, Wright PG. Resistance to

nasal airflow related to changes in head posture. Am J Orthod 1981;80:536-545.
22. Wenzel A, Hendriksen J, Melsen B. Nasal respiratory resistance and head posture: Effect of intranasal cortico-steroid in children with asthma and perennial rhinitis. Am J Orthod 1983;84:422-426.
23. O'Ryan FS, Gallagher DM, Labanc JP, Epker BN. The relation between nasorespiratory function and dentofacial morphology: A review. Am J Orthod 1982;82:403-410.
24. Tourne LPM. The long face syndrome and impairment of the nasopharyngeal airway. Angle Orthod 1990;60:167-176.
25. Montgomery WM, Vig PS, Staab van E, Matteson SR. Computed tomography: A three-dimensional study of the nasal airway. Am J Orthod 1979;76:363-375.
26. Lowe AA. The tongue and airway. Otolaryngologic Clinics of North America 1990;23:677-698.
27. Billing H, Leighton BC, Linder-Aronson S, Lundström A, McWilliam J. The development of the pharyngeal space and lymphoid tissue on the posterior nasopharyngeal wall. Eur J Orthod 1988;10:106-110.
28. Linder-Aronson S, Leighton BC. A longitudinal study of the development of the posterior nasopharyngeal wall between 3 and 16 years of age. Eur J Orthod 1983;5:47-58.
29. Preston CB. Preliterate environment and the nasopharynx. Am J Orthod 1979;76:646-656.
30. Bluestone CD. The role of tonsils and adenoids in the obstruction of respiration. In: McNamara JA Jr., ed. Naso-respiratory function and craniofacial growth. Monograph 9, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1979; 251-273.
31. Paradise JL. Clinical trials of tonsillectomy and adenoidectomy: Limitations of existing studies and a current effort to evaluate efficacy. South Med J 1976;69:1049-1053.
32. McNamara JA Jr. Influence of respiratory pattern on craniofacial growth. Angle Orthod 1981;51:269-300.
33. Smillie KW. An introduction to regression and correlation. London: Academic Press, 1966
34. Riolo ML, Moyers RE, McNamara JA Jr, Hunter WS. An atlas of craniofacial growth. Monograph 2, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1974.
35. Linder-Aronson S, Woodside DG. The growth in sagittal depth of the bony nasopharynx in relation to some other facial variables. In: McNamara JA Jr., ed. Naso-respiratory function and craniofacial growth. Monograph 9, Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, University of Michigan, 1979; 27-40.