Airway adequacy, head posture, and craniofacial morphology

Solow

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Previous studies of different samples have demonstrated associations between craniocervical angulation and craniofacial morphology, between airway obstruction by adenoids and craniofacial morphology, and between airway obstruction and craniocervical angulation. A hypothesis to account for the different sets of associations was suggested by Solow and Kreiborg in 1977. In the present study, the three sets of associations were examined in a single group of nonpathologic subjects with no history of airway obstruction. Cephalometric radiographs taken in the natural head position and rhinomanometric recordings were obtained from twenty-four children 7 to 9 years of age. Correlations were calculated between twenty-seven morphologic, eight postural, and two airway variables. A large craniocervical angle was, on the average, seen in connection with small mandibular dimensions, mandibular retrognathism, and a large mandibular inclination. Obstructed nasopharyngeal airways (defined as a small pm-ad 2 radiographic distance and a large nasal respiratory resistance, NRR, determined rhinomanometrically) were, on the average, seen in connection with a large craniocervical angle and with small mandibular dimensions, mandibular retrognathism, a large mandibular inclination, and retroclination of the upper incisors. The observed correlations were in agreement with the predicted pattern of associations between craniofacial morphology, craniocervical angulation, and airway resistance, thus suggesting the simultaneous presence of such associations in the sample of nonpathologic subjects with no history of airway obstruction.

Key words: Airway resistance, craniocervical posture, craniofacial development

Recent years have witnessed a renewed interest in the interaction between form and function in the craniofacial region. Two physiologic factors have received particular attention with regard to their possible relation to craniofacial development, namely, (1) the adequacy of the nasopharyngeal airway and (2) the postural relations of the head and the cervical column.

Direct measurement of the adequacy of the nasopharyngeal airway can be performed by rhinomanometry,[1] a measuring technique based on a concept devised in principle at the turn of the century.[2, 3] This technique has gained more widespread use in the last decade after the development of modern pressure transducers and miniaturized electronic technology.

The relationship between *airway adequacy* and type of malocclusion was studied in orthodontic patients by Watson, Warren, and Fischer[4] and Rasmus and Jacobs.[5] They found no association between rhinomanometric measures of airway adequacy and type of malocclusion or craniofacial morphology. In 1970, however, Linder-Aronson[6] demonstrated that the craniofacial morphology of children with upper airway obstruction due to enlarged adenoids differed systematically from that of a matched control group. Among the morphologic characteristics of the adenoid children were a reduced facial prognathism and a larger mandibular plane inclination in relation to the anterior cranial base and the palatal plane.

In follow-up studies after adenoidectomy, Linder-Aronson[7, 8] found that, with the continued facial growth, the average craniofacial morphology of the adenoid children approached that of the control group. This reversibility of the differences in morphology suggests that the differences had been caused by the adenoid obstruction of the airway. The precise nature of this causal mechanism was not known, but Linder-Aronson suggested that a lowered position of the tongue played a significant role.

A relationship between rhinomanometric measures of airway adequacy and craniofacial morphology in adenoid subjects has since been shown by Bushey[9] and Jonas, Mann, and Schlenter.[10] Sosa, Graber, and Muller[11] and Mottl and Pfister[12] found craniofacial morphology related to radiographic measures of nasopharyngeal airway adequacy. Respiratory obstruction in patients with cleft lip and palate was shown by Drett-

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ner,[13] Warren, Duany, and Fisher,[14] and Warren, Trier, and Bevin.[15] Improved nasal airflow in orthodontic patients after rapid maxillary expansion was demonstrated by Hershey, Stewart, and Warren[16] and by Loreille and Béry.[17]

A relationship between *head posture* and craniofacial morphology was suggested in 1926 by Schwartz,[18, 19] who attributed the development of Class II malocclusion to hyperextension of the head relative to the cervical column during sleep. Gresham and Smithels[20] noted a vertical development of the face and a larger prevalence of Class II malocclusion in subjects with "poor neck posture," and Björk[21] observed a raised head position and facial retrognathism in subjects with a flat cranial base angle.

A detailed correlation study of head posture and craniofacial morphology was made by Solow and Tallgren,[22, 23] who noticed a systematic set of associations between morphologic and postural variables. Among the postural variables, the position of the head in relation to the cervical column (that is, the craniocervical angulation) showed more correlation with morphology than the conventional measure of head posture, the position of the head in relation to the true vertical. Among the morphologic characteristics of subjects with a large craniocervical angulation were a reduced facial prognathism, a large mandibular plane inclination, and a large lower anterior facial height.

The findings were supported by Thompson,[24] and similar findings were made by Opdebeek and associates,[25] Marcotte,[26] and Treuenfels.[27]

The similarity of the morphologic characteristics of subjects with obstructed airway due to adenoids and subjects with a large craniocervical angulation led Solow and Kreiborg[28] to propose a hypothesis to account for the association between head posture, craniofacial morphology, and airway obstruction.

A chain of interactions was suggested involving (1) change in airway adequacy, (2) neuromuscular feedback, (3) change in craniocervical angulation, (4) passive stretching of the soft-tissue layer covering the face and neck, (5) morphologic change, and (6) change in airway adequacy.

In principle, any link in this sequence could be the site of a primary affliction triggering a chain reaction. As examples of triggering factors were suggested (1) adenoid tissues, perennial allergic conditions, (2) disturbances in the visual, proprioceptive, utricular, or semicircular canal systems, (3) cervical spine anomalies, (4) scar tissues, and (5) sutural growth disorders, condylar growth disorders, or a discrepancy between the vertical components of condylar and cervical vertebral growth.

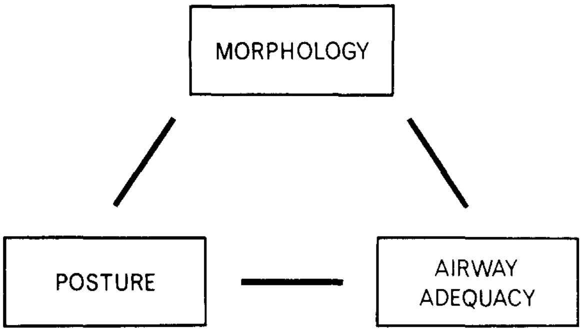

Fig. 1. Simplified theoretical model for developmental relationships between craniofacial morphology, craniocervical posture, and airway adequacy.

An immediate prediction of the hypothesis was that an increased craniocervical angulation would be expected in children with airway obstruction due to adenoids. This was independently tested by Solow and Greve[29] and by Woodside and Linder-Aronson.[30] Solow and Greve[29] examined twenty-four children hospitalized for adenoidectomy. A positive correlation was found between craniocervical angulation and nasal respiratory resistance, which is a measure of airway obstruction. Two months after adenoidectomy there was a 2° reduction in craniocervical angulation and in the position of the head in relation to the true vertical.

Woodside and Linder-Aronson[30] examined a group of sixteen children before adenoidectomy and four months postsurgically and compared these to a matched control group of sixteen children. Presurgically, the position of the head in relation to the true vertical was about 2° higher in the adenoid children than in the controls. Postsurgically, this difference had disappeared.

Both studies thus confirmed the prediction of the hypothesis. A similar relationship between adenoidal obstruction of the airways and head posture before and after adenoidectomy had previously been reported by Ricketts.[31]

A relationship between head posture and airway adequacy was demonstrated experimentally by the use of a nose clip by Vig, Showfety, and Philips,[32] whereas Weber, Preston, and Wright,[33] in another experimental study, could not demonstrate such an association.

The relationship between the three factors discussed above (craniofacial morphology, craniocervical posture, and airway adequacy) is illustrated in Fig. 1. The three sets of associations between these three factors have been demonstrated in different samples, some of which represent various pathologic conditions.

It was the aim of the present investigation to examine whether the predicted association between (1)

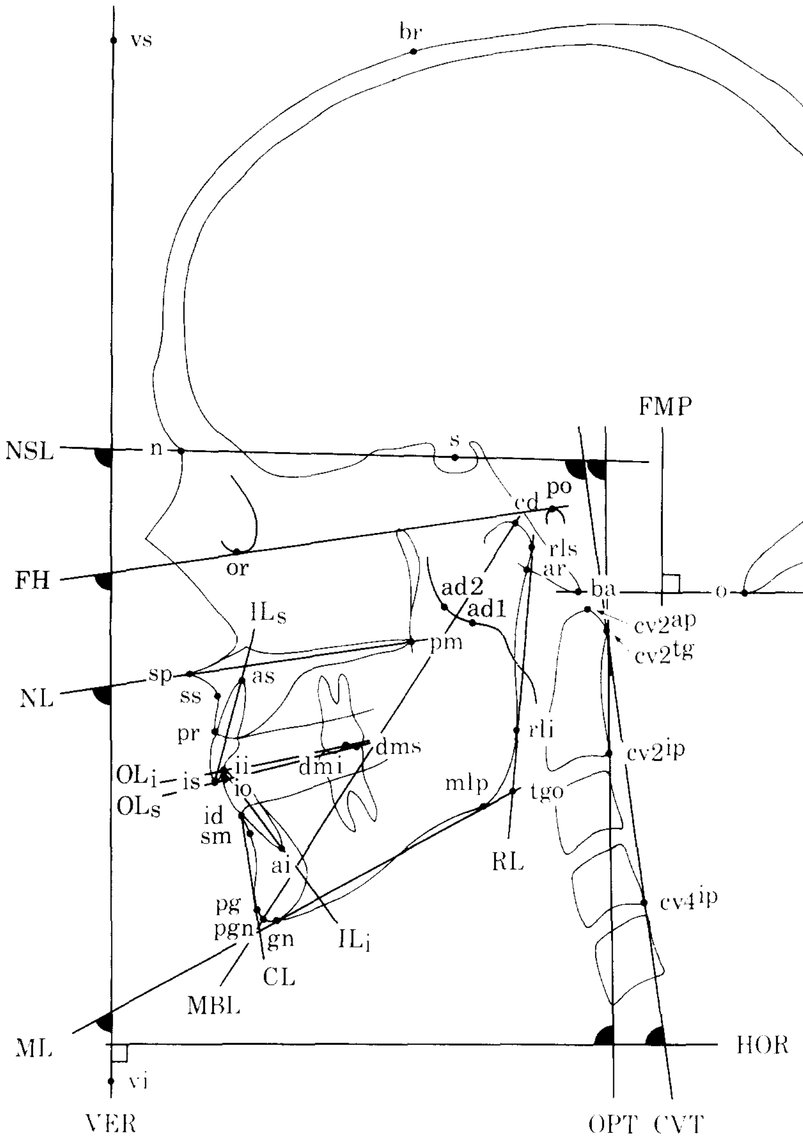

Fig. 2. Reference points and lines. Some postural angles are indicated.

posture and morphology, (2) morphology and airway adequacy, and (3) airway adequacy and craniocervical posture could be demonstrated in a single sample of nonpathologic subjects with no history of airway obstruction.

MATERIAL AND METHODS

The sample comprised twenty-four children (twelve boys and twelve girls) admitted to the Farum Community Orthodontic Clinic for treatment of various malocclusions. The age range was 7.6 to 9.4 years, with a mean of 8.6 years.

Lateral and posteroanterior cephalometric radiographs were obtained in a Dana Cephalix cephalometer with a Lumex head holder and a Philips Rotapractix x-ray source.

The lateral cephalometric radiographs were exposed in the natural head position (mirror position[34, 35]) with the subjects standing in orthoposition, a position defined by Molhave[36] as the intention position from standing to walking. The true vertical was indicated on the films (*VER*, Fig. 2) with an 0.5 mm weighted lead wire mounted on the head holder. Exposure data were 80 kV and 32 mAs for the lateral films and 86 kV and 40 mAs for the posteroanterior films. A ratio 8 grid and high-speed intensifying screens were used. The radiographs were taken by dental auxiliaries as described by Siersbæk-Nielsen and Solow.[35] Thirty-eight reference points (Fig. 2) marked directly on the films were digitized. The data were checked by superimposition of each film on a computer-generated plot of the digitized points.

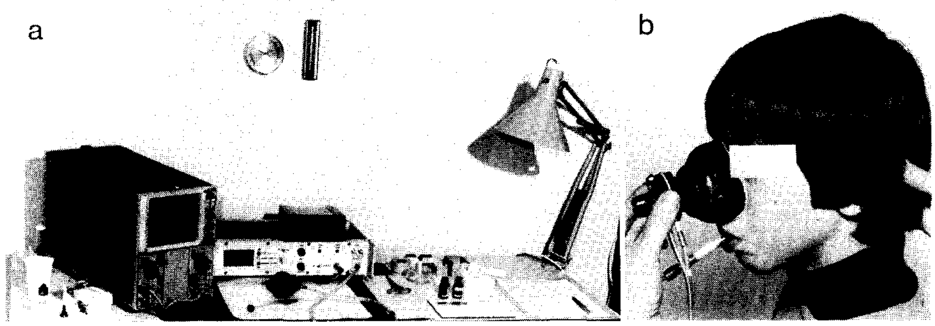

Fig. 3. Rhinomanometric recording. **A,** Equipment. **B,** Recording procedure. (For details, see Solow & Greve.[37])

In addition to normal orthodontic diagnostic material comprising casts, facial and intraoral photographs, and the cephalometric radiographs described above, nasal respiratory resistance (NRR) was determined by rhinomanometric recordings.[37] The recording of NRR requires sophisticated instrumentation but is harmless and noninvasive to the patient, who breathes normally through a nose mask connected to a flowmeter while holding in the mouth a tube connected to a pressure gauge (Fig. 3).

The respiratory resistance was determined by a nasal resistance meter (Mercury Electronics NR1, Glasgow, Scotland), supplemented by a storage screen oscilloscope. To avoid air slippage, the rim of the nose mask was lined individually for each subject with an impression material. NRR (cm H_2O/ 1/sec) was determined by posterior rhinomanometry as pressure drop over the nose (cm H_2O) divided by airflow through the nose (liters per second) at a flow rate of 0.2 liter per second. For each subject the mean of four series of four recordings (that is, sixteen recordings) was used in order to reduce the effect of random fluctuations. The recordings were made in January and February. Nose drops (Neosynephrine), were given in both nostrils. This reduces the variability due to possible temporary congestion of the nasal mucosa and also serves to emphasize the contribution of the pharyngeal component to the total nasopharyngeal respiratory resistance. The subjects were acclimatized at least 1 hour in the clinic before the recording.

The parents of the children were questioned regarding previous nasal allergic conditions or airway obstructions due to adenoids. No such conditions were reported.

VARIABLES STUDIED

For the sake of compactness of presentation, only two craniofacial reference lines (NSL and FH) were used in the present study to express the position of the head in relation to the true vertical and to the cervical column. The position of the head to the true vertical was expressed by the variables NSL/VER and FH/VER, the craniocervical angulation by the variables NSL/OPT, FH/OPT, NSL/CVT, FH/CVT and the cervical inclination by the variables OPT/HOR and CVT/HOR.

The adequacy of the nasopharyngeal airway was expressed by the rhinomanometric measure of nasal respiratory resistance, NRR, and by the radiographic dimension pm-ad 2, which is an approximate measure of the narrowest part of the nasopharyngeal airway.

Craniofacial morphology was expressed by twenty-seven linear and angular dimensions representing cranial base, maxilla, mandible, total face, jaw relations, nasopharynx, and dentoalveolar relations.

Method errors for postural, morphologic, and airway variables have been reported by Solow and Tallgren[22, 34] and Solow and Greve.[37]

STATISTICAL METHOD

The association between the three groups of variables was expressed by correlation coefficients. With the present sample size of twenty-four subjects, the conventional 5% level of significance is $r = 0.41$. However, since most of the biologic sources of variability were represented by several variables, associations expressed by groups of correlations of similar magnitude were considered to be of interest, even if the coefficients taken individually did not reach the 5% level of significance. It was decided, therefore, to include in the analysis also correlations significant at the $p \leq 0.1$ level in the findings, bearing in mind in the interpretations the larger probability of a type I error.

The statistical analyses were performed by the SAS statistical program package[38] at the Northern Europe University Computer Centre (NEUCC) in Copenhagen.

RESULTS

The variables were tested for possible sex differences by t tests. No differences were found significant

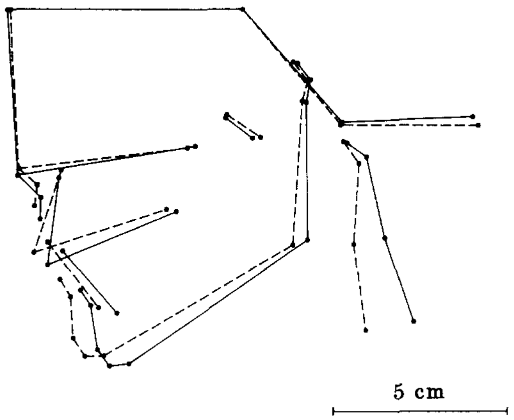

Fig. 4. Craniofacial morphology related to craniocervical angulation. Mean facial diagrams for the ten children with the largest (——) and the ten children with the smallest (----) craniocervical angles (NSL/OPT). Diagrams were superimposed on horizontal nasion-sella line, registered on sella point, for comparison of craniofacial morphology. Note difference in prognathism and in mandibular size and inclination.

at the 1% level. In the following analysis, therefore, male and female data were pooled. Descriptive statistics for the pooled sample are given in Table I.

Head posture and craniofacial morphology

The correlations between the craniofacial morphologic variables and the postural variables are given in Table II.

In most instances the correlations of the postural angles, NSL/VER, NSL/OPT, and NSL/CVT, were similar to those of the angles FH/VER, FH/OPT, and FH/CVT. However, because of the topographic effect of a common reference line, the correlations of the morphologic variables involving the NSL reference line with the postural variables NSL/VER, NSL/OPT, and NSL/CVT were usually numerically somewhat larger than those with the corresponding variables FH/VER, FH/OPT, and FH/CVT.

The pattern of associations largely followed that observed in the previous study on young male adults.[22] A large craniocervical angle, on the average, was seen in connection with small maxillary and mandibular posterior heights (s-pm, ar-tgo), a small mandibular prognathism (s-n-pg), a small nasopharyngeal space (pm-s-ba), a large sagittal jaw relation (ss-n-pg), and large inclinations of the maxillary and mandibular bases in relation to the anterior cranial base (NSL/NL, NSL/MBL).

The pattern of associations is illustrated by a comparison of mean facial diagrams for the ten subjects with the largest and the ten subjects with the smallest craniocervical angulations (Fig. 4). The differences in average craniofacial morphology of the two posturally extreme groups are similar to those found in a previous study[22] of 120 male adults (Fig. 5).

Table I. Variables studied

	Mean	*SD*
Cranial base		
1. n-s (mm)	67.11	3.29
2. s-ba (mm)	42.50	2.28
3. n-s-ba (°)	131.67	2.56
Maxilla		
4. ss-pm (mm)	45.48	2.31
5. n-sp (mm)	46.63	2.72
6. s-pm (mm)	42.18	2.74
7. s-n-ss (°)	80.57	2.74
8. NSL/NL (°)	8.03	3.19
Mandible		
9. pgn-cd (mm)	102.48	4.34
10. pg-tgo (mm)	68.20	2.49
11. ar-tgo (mm)	40.60	2.93
12. s-n-pg (°)	77.03	2.94
13. NSL/ML (°)	32.03	4.26
14. NSL/MBL (°)	55.94	2.86
15. ML/RL (°)	125.51	5.65
Facial height		
16. n-gn (mm)	104.35	4.86
17. sp-gn (mm)	60.29	4.43
18. s-tgo (mm)	68.66	3.69
Jaw relations		
19. ss-n-pg (°)	3.54	2.56
20. NL/ML (°)	24.00	5.07
Nasopharynx		
21. pm-s-ba (°)	62.13	2.53
Dentoalveolar		
22. IL_s/NL (°)	110.10	8.30
23. sp-is (mm)	25.72	2.22
24. IL_i/ML (°)	97.29	4.75
25. ii-gn (mm)	36.96	1.91
Occlusion		
26. oj (mm)	5.56	2.22
27. ob (mm)	2.51	2.34
Craniovertical		
28. NSL/VER (°)	98.55	3.57
29. FH/VER (°)	90.00	2.98
Craniocervical		
30. NSL/OPT (°)	94.04	10.30
31. NSL/CVT (°)	98.27	8.87
32. FH/OPT (°)	85.49	9.64
33. FH/CVT (°)	89.72	8.35
Cervical inclination		
34. OPT/HOR (°)	94.51	9.20
35. CVT/HOR (°)	90.28	7.80
Airway		
36. pm-ad 2 (mm)	13.16	3.24
37. NRR (cm H_2O/1/sec)	2.05	0.63

n = 24.

Table II. Correlations between airway adequacy, head and cervical posture, and craniofacial morphology

	Craniovertical		*Craniocervical*				*Cervical inclin.*		*Airway*	
	NSL/VER	*FH/VER*	*NSL/OPT*	*NSL/CVT*	*FH/OPT*	*FH/CVT*	*OPT/HOR*	*CVT/HOR*	*pm-ad 2*	*NRR*
Cranial base										
1. n-s (mm)	.08	.03	−.03	.05	−.06	.02	.07	−.02	.08	−.20
2. s-ba (mm)	−.03	.20	−.21	−.16	−.16	−.09	.23	.17	.35†	−.24
3. n-s-ba (°)	.49*	.19	.01	−.07	−.12	−.22	.18	.30	.16	−.04
Maxilla										
4. ss-pm (mm)	.31	.08	.35†	.34	.28	−.26	−.27	−.24	−.01	−.09
5. n-sp (mm)	.31	.06	.13	.13	.04	.03	−.03	−.01	−.06	−.27
6. s-pm (mm)	−.46*	−.47*	−.47*	−.43*	−.48*	−.43*	.35†	.28	.20	−.21
7. s-n-ss (°)	−.57**	−.57**	−.21	−.25	−.19	−.23	.01	.03	.27	−.09
8. NSL/NL (°)	.51*	.35†	.44*	.42*	.39†	.36†	−.30	−.25	−.18	−.07
Mandible										
9. pgn-cd (mm)	−.18	−.18	−.33	−.31	−.34	−.32	.30	.27	.36†	−.36†
10. pg-tgo (mm)	−.04	−.01	−.27	−.28	−.28	−.29	.29	.30	.42*	−.31
11. ar-tgo (mm)	−.25	−.17	−.42*	−.47*	−.41*	−.45*	.38†	.42*	.26	−.35†
12. s-n-pg (°)	−.67***	−.42*	−.57**	−.59**	−.49*	−.49*	.38†	.36†	.55**	−.32†
13. NSL/ML (°)	.36†	.11	.34	.34	.26	.25	−.24	−.23	−.20	.29
14. NSL/MBL (°)	.43*	.17	.42*	.39†	.34	.29	−.30	−.25	−.49*	.35†
15. ML/RL (°)	−.14	−.21	−.08	−.03	−.10	−.05	.04	−.03	.13	−.08
Facial height										
16. n-gn (mm)	.24	.12	.17	.18	.14	.14	−.10	−.10	−.17	−.02
17. sp-gn (mm)	.13	.05	.22	.22	.20	.19	−.20	−.19	−.21	.16
18. s-tgo (mm)	−.20	−.02	−.15	−.16	−.09	−.09	.09	.09	−.06	−.32
Jaw relations										
19. ss-n-pg (°)	.16	−.14	.44*	.40†	.36†	.31	−.43*	−.39†	−.34	.27
20. NL/ML (°)	−.02	−.13	.01	.02	−.03	−.01	−.01	−.03	−.06	.28
Nasopharynx										
21. pm-s-ba (°)	−.18	−.31	−.34	−.36†	−.39†	−.41*	.31	.32	.47*	−.21
Dentoalveolar										
22. IL_s/NL (°)	−.19	−.01	−.38†	−.35†	−.34	−.29	.35†	.31	.39†	−.63***
23. sp-is (mm)	.32	.09	.38†	.36†	.31	.28	−.30	−.26	−.39†	.36†
24. IL_i/ML (°)	−.08	.00	−.16	−.11	−.14	−.07	.15	.08	.27	−.19
25. ii-gn (mm)	.07	−.08	.02	.02	−.03	−.03	.01	.01	−.16	.07
Occlusion										
26. oj (mm)	.40†	.23	.12	.14	.05	.06	.02	.02	−.07	−.14
27. ob (mm)	.21	−.03	.02	.00	−.06	−.10	.06	.10	−.14	.13
Airway										
36. pm-ad 2 (mm)	−.30	−.19	−.65***	−.61**	−.64***	−.59**	.61**	.56**	—	−.30
37. NRR	.39†	.33	.24	.23	.21	.19	−.12	−.08	−.30	—

†$p<0.1$.
*$p<0.05$.
**$p<0.01$.
***$p<0.001$.

Airway adequacy and craniofacial morphology

The associations between the craniofacial morphologic dimensions and the two measures of airway adequacy, the radiographically determined distance, pm-ad 2, and the rhinomanometrically determined measure of nasal respiratory resistance, NRR, are given in Table II.

An obstructed airway (that is, a small pm-ad 2 distance and a large NRR) was, on the average, seen in connection with small linear dimensions of the mandible (pgn-cd, pg-tgo, ar-tgo), a small mandibular prognathism (s-n-pg), a large mandibular inclination (NSL/MBL), a small nasopharyngeal space (pm-s-ba), and retroclination of the upper incisors (IL_s/NL).

No significant associations were found with maxillary size, maxillary prognathism, or maxillary inclination.

The pattern of associations is illustrated by mean facial diagrams of ten subjects with the largest and ten subjects with the smallest nasal respiratory resistance (Fig. 6).

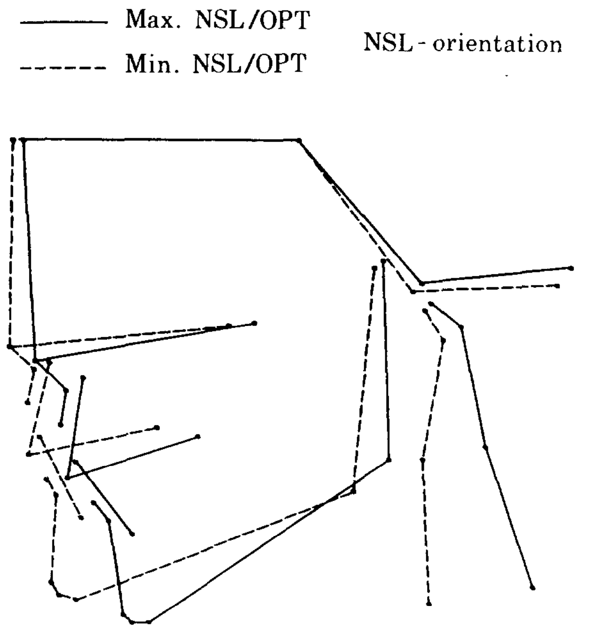

Fig. 5. Superimposed mean facial diagrams from previous study of 120 adult males.[22] Mean diagrams for ten subjects with largest (——) and ten subjects with smallest (----) craniocervical angles (NSL/OPT). Superimposition as in Fig. 4.

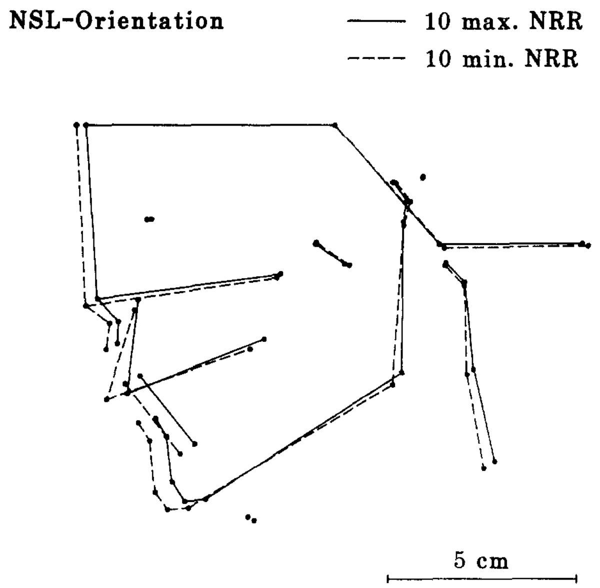

Fig. 6. Craniofacial morphology related to nasal respiratory resistance. Mean facial diagrams for the ten subjects with the highest (——) and the ten subjects with the lowest (----) nasal respiratory resistance (NRR), superimposed as in Fig. 4. Note difference in prognathism and in mandibular size and inclination in the high- and low-resistance groups. None of the children studied had clinical signs of respiratory obstruction.

Head posture and airway adequacy

The correlations between the postural variables and the measures of airway adequacy are given in Table II.

Nasal respiratory resistance (NRR) showed low positive but generally not significant correlations with the postural variables.

The radiographic measure of airway obstruction, on the other hand, showed marked correlations with the craniocervical angulation and with cervical inclination. A small distance pm-ad 2 was, on the average, seen in connection with a large craniocervical angle and a forward inclination of the cervical column, whereas a large distance pm-ad 2 was seen in connection with a small craniocervical angulation and a backward inclination of the cervical column. These associations are illustrated in Fig. 7, which shows cephalometric radiographs of subjects NF 12 (pm-ad 2 = 19.0 mm, NSL/OPT = 81.4°) and NF 01 (pm-ad 2 = 7.2 mm, NSL/OPT = 107.3°) recorded in the natural head position.

DISCUSSION

Head posture and craniofacial morphology

The analysis of the correlations between craniofacial morphology and the position of the head and the cervical column in relation to each other and to the true vertical or horizontal confirmed the presence of a comprehensive pattern of correlations.

In general, the correlations between posture and morphology involved two or three of the three groups of postural angles, and the craniocervical angulation was consistently one of the groups involved. The analysis thus supported the previous observations[22] that, of the postural variables, those expressing the craniocervical angulation generally show the most consistent correlations with craniofacial morphology.

Despite the small sample size, the observed correlations were in agreement with those described by Solow and Tallgren.[22] In particular, positive and negative correlations in the range of 0.3 to 0.4 indicated that a large craniocervical angle, on the average, was seen in connection with small linear mandibular dimensions, mandibular retrognathism, and a large inclination of the mandible in relation to the anterior cranial base.

Correlation coefficients of 0.3 to 0.4 obviously are of little predictive value. Their presence, however, supports the contention that there exists a growth-coordinating mechanism which relates mandibular development to craniocervical angulation.

The graphic comparison of the craniofacial morphology in the subjects with the largest and smallest craniocervical angulations showed the same type of dif-

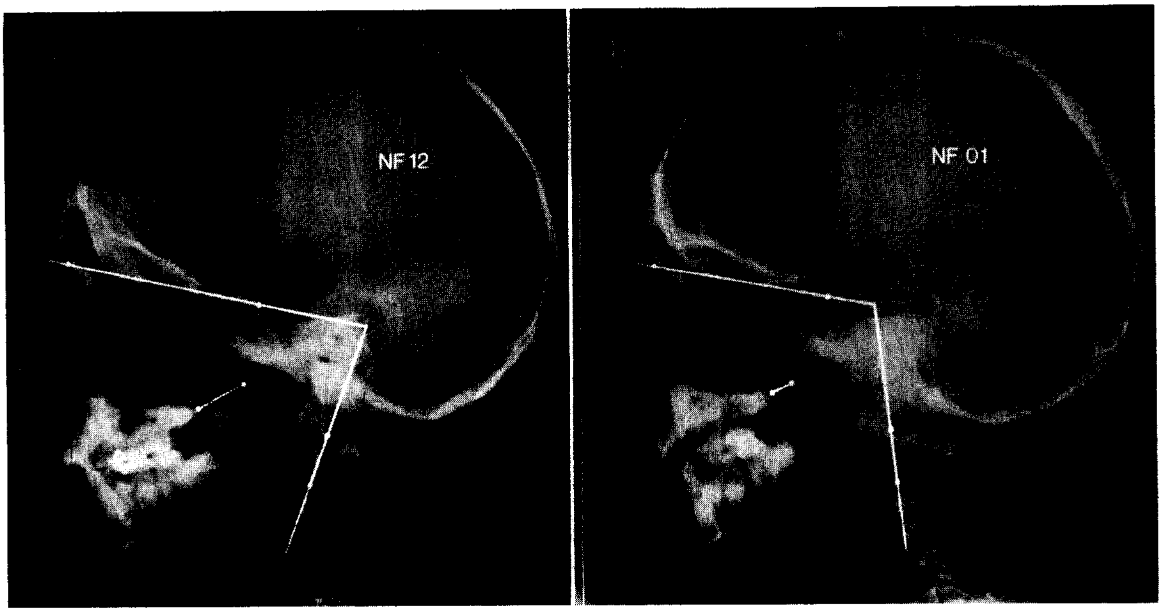

Fig. 7. Respiratory obstruction and craniocervical angulation as judged from cephalometric radiographs of subjects recorded in the natural head position. **A,** Subject NF 12 showing good sagittal extent of nasopharyngeal passage (pm-ad 2 = 19.0 mm) and small craniocervical angle (NSL/OPT = 81.4°). **B,** Subject NF 01 showing relatively narrow sagittal extent of nasopharyngeal passage (pm-ad 2 = 7.2 mm) and large craniocervical angle (NSL/OPT = 107.3°).

ferences that had been demonstrated in a previous study of young male adults, but the differences were smaller in magnitude. This may be due to the differences in sample size in the two studies. The difference between extreme centiles of a sample are directly related to the sample size, since the probability of including relatively extreme variants increases with the sample size.

Airway adequacy and craniofacial morphology

The correlations between the variables screening craniofacial morphology and the two measures of airway adequacy (pm-ad 2 and NRR) revealed an interesting pattern of associations. Airway adequacy was related to the size and position of the mandible, but no associations were found with the corresponding maxillary variables.

In the previous study of head posture and craniofacial morphology in young male adults[22] it was noticed that graphically the average morphologic differences between the two posturally extreme groups with large and small craniocervical angulations bore a striking resemblance to the well-known morphologic differences observed between subjects with large and small mandibular plane inclinations. This was interpreted to indicate that craniocervical angulation might be specifically related to mandibular growth. The present observation of a specific relationship between airway adequacy and mandibular size and position expands this interpretation and suggests that mandibular development is related to both airway adequacy and craniocervical angulation.

It is important to notice, however, that correlation analysis alone does not indicate the nature of the causal mechanisms at work. The causal factor could be airway adequacy, craniocervical angulation, mandibular development, or some other factor not included in the study.

Head posture and airway adequacy

The results of the analysis of the associations between the postural variables and the measures of airway adequacy were different for the radiographically and the rhinomanometrically determined measures of airway adequacy. The radiographically determined measure of the free airway between the maxilla and the adenoid tissue (pm-ad 2) showed remarkably strong correlations with the craniocervical angulation ($r = -0.6$) and with the cervical inclination ($r = 0.6$). Insofar as this distance can be interpreted as a true measure of airway adequacy, the correlations indicate a strong relationship between airway adequacy and craniocervical angulation.

The directly rhinomanometrically determined respiratory resistance, on the other hand, showed correlations of only 0.2 with craniocervical angulation and 0.3

to 0.4 with the position of head in relation to the true vertical. These correlations are in agreement with those found in a previous study of head posture and airway adequacy in children hospitalized for adenoidectomy.[29]

The difference between the correlations displayed by the two types of measure of airway adequacy is of some interest for the interpretation of studies of airway adequacy. The lower correlations displayed by NRR could be due to the technical difficulties of performing this measurement and the ensuing relatively large method error.[37]

On the other hand, it should be noticed that the sagittal radiographic measure estimates only the pharyngeal component of the resistance, whereas the rhinomanometric measure comprises both the nasal and the pharyngeal components. In a sample such as the present one, with no history of adenoid airway obstruction, the pharyngeal component of the resistance would be expected to be relatively low and the difference between the two types of measurement thus particularly noticeable.

Despite the difference in the two types of measure of airway adequacy, all the correlations indicated that, on the average, obstruction or reduced adequacy of the nasopharyngeal airway was associated with a larger craniocervical and craniovertical angulation. This is in agreement with the findings of Solow and Greve,[29] Woodside and Linder-Aronson,[30] and Vig, Showferty, and Philips[32] in adenoid children and in experimental subjects.

CONCLUSION

In conclusion, it may be stated that in the present study of normal children from an orthodontic clinic with no symptoms of upper airway obstruction, predicted associations were found between craniofacial morphology, craniocervical angulation, and upper airway adequacy. The correlations were moderate but indicate the presence of a general control mechanism in craniofacial development.

In view of the moderate sample size and its cross-sectional nature, the investigation should be considered a pilot study. Future studies of a longitudinal type are required to analyze the detailed nature of the mechanism at work.

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