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Dentoskeletal and Tongue Soft-Tissue Correlates: A Cephalometric Analysis of Rest Position

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The relationship between dentoskeletal and tongue soft-tissue variables has been quantified in a sample of 60 adult females with normal and anterior open-bite malocclusions. Three lateral rest-position head films were obtained for each subject. A principal component analysis reduced the data base and six significant canonical correlations were identified. The first canonical correlation ($r_1 = 0.962$) represented a size-related correlation factor between the two groups of variables. Subjects with characteristics of a short face syndrome and some evidence of overbite had tongue tips positioned below the lower occlusal plane ($r_2 = 0.929$). In contrast, skeletal open-bite subjects ($r_4 = 0.759$) revealed tongue tips ahead of and above the lower incisor teeth with the mandible in the rest position. Undererupted mandibular teeth ($r_5 = 0.666$) were associated with a reduced tongue height and an inferior epiglottis; short tongue length ($r_6 = 0.563$) correlated with a linear combination of upright central incisors, a small overjet, a low ANB angle, unerupted maxillary and mandibular teeth, and a steep occlusal plane. The multivariate statistical analysis extracted clinically significant associations between tongue soft-tissue and dentoskeletal variables. Tongue posture at rest in skeletal open-bite subjects appeared to be related to incisor position. (AM J ORTHOD **88**: 333-341, 1985.)

Numerous studies^{1,11-12,17,22} have evaluated the interaction between the volume and position of the tongue and craniofacial morphology. Genioglossus muscle activity reveals a lower threshold in response to jaw-opening in anterior open-bite subjects⁷; correlations with an open bite and unerupted upper and lower incisors have been documented.⁶ It appears that the lower threshold for the tongue musculature in open-bite subjects may reflect a predisposition to a forward tongue posture with mandibular rotations of 0.5 to 3.0 mm that

are within the range of normal freeway space.² Furthermore, it has been suggested⁷ that this forward tongue posture may be sufficient to prevent vertical eruption of the anterior teeth and thus result in an anterior open-bite malocclusion. On the basis of studies of tongue and lip pressure, previous reports^{13,14} have suggested that the pressures created at rest may have an influence on dental arch form and tooth position. However, a multivariate evaluation of the interaction between tongue soft-tissue variables at rest and dentoskeletal variables has not been completed.

The purpose of this study was to document the relationship between tongue muscle parameters at rest and craniofacial morphology in adult human subjects with normal and anterior open-bite malocclusions. In addition, the study was designed to reduce the number of cephalometric variables by a principal component analysis and to test, on the pooled data base, for significant canonical correlations. Clarification of the relationship between tongue posture and craniofacial morphology could permit the development of revised postulates regarding tongue malfunction and a better rationale for the treatment of open-bite malocclusions.

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Fig. 1. Anatomic points, contours, and planes used to identify tongue soft-tissue parameters. UPW, Upper pharyngeal wall; MPW, middle pharyngeal wall; LPW, lower pharyngeal wall; E, epiglottis; H, hyoid; TT, tongue tip; TGH, tongue height; TGL, tongue length; LOP, lower occlusal plane. For complete definitions, see METHODS.

METHODS

A sample of 60 adult females (mean age of 20.5 years; range of 18 years 3 months to 23 years 8 months) was selected from a data base of 6,896 university students screened at three Japanese academic institutions. The selected subjects all revealed Class I skeletal relationships as defined by traditional cephalometric and clinical criteria. Subjects with functional disturbances of the masticatory system were excluded, as were persons with histories of digit habits. The sample was equally divided into two groups of 30. The first group (30 out of a possible 118) exhibited normal occlusions with minor irregularities of individual teeth, whereas the second group (30 out of a possible 286) presented with skeletal open-bite malocclusions in accordance with the definition proposed by Subtelny and Sakuda.¹⁶ Patients for both groups were selected on the basis of their availability for subsequent clinical examinations.

Three lateral head films were obtained with the mandible in the rest position. All radiographs were taken by one operator and the same equipment was used throughout. The patients, seated in an upright position with the Frankfort horizontal plane parallel to the floor, were instructed to complete saliva swallows on command. At count "5" of 15, the subject was told to swallow and relax. At count 15, the first radiograph was obtained. A 10-second interval between the initiation of the swallow and the return of minimal electro-

myographic activity of the tongue musculature was used.^{19,24} A second radiograph was exposed in a similar manner after an interval of 5 minutes. The third film was obtained after a minimum of 7 days and identical postswallow criteria were followed.

The dorsum of the tongue was coated with a mixture of barium sulfate and carboxymethylcellulose⁵ to enhance the radiopacity of the tongue soft tissues. Furthermore, a lead marker with a diameter of 2.0 mm and a thickness of 100 μ m was attached to the midpoint of the tongue tip by means of cyanoacrylate tissue adhesive.¹¹ The tongue tip (or apex linguae) represents the midsagittal junction of the tongue dorsum and the inferior mucous membrane.²³

Tracings were constructed of the 180 lateral head films and selected contours and points were digitized. The coordinates of each point were computed with respect to a standard sella-nasion horizontal axis (registered at sella). A detailed analysis of the direct cephalometric data for this identical sample has been published independently.¹⁹

For the canonical correlation analysis, 29 specific variables were selected on the basis of their clinical relevance to the tongue/dentoskeletal interplay. Vertical positions of the maxillary and mandibular teeth were determined as linear measurements along perpendicular lines from the incisor tip and molar occlusal surface midpoints to the palatal (ANS-PNS) and mandibular (Go-Me) planes. Incisor inclination was measured in millimeters from the tip along perpendicular lines to the AP plane. In addition to traditional cephalometric variables, a number of tongue soft-tissue measurements were determined (Fig. 1). The X and Y coordinates of the deepest point of the epiglottis (E) and the center of the lead disc on the tongue tip (TT) were identified.

TGL (mm) = TONGUE LENGTH. Linear distance between E and TT.

TGH (mm) = TONGUE HEIGHT. Linear distance along the perpendicular bisector of the E-TT line to the tongue dorsum.

TT/LOP (mm) = TONGUE TIP RELATIVE TO LOWER OCCLUSAL PLANE. Linear distance between TT and the lower occlusal plane (a line between the midpoint of the occlusal surface of the mandibular molar and incisor tip) measured perpendicular to the LOP. If the TT was located below the LOP, a positive value was calculated.

TT-L1/LOP (mm) = TONGUE TIP RELATIVE TO LOWER INCISOR TIP. Linear distance between TT and a perpendicular line to LOP through the incisor tip. If the TT was located behind the perpendicular line, a positive value was recorded.

TTA (mm²) = TOTAL TONGUE AREA. An area defined by the limits of E, H, Me, TT, and the dorsum of the tongue.

Table I. Principal component analysis of variables

<i>Linear combination</i>	<i>Correlation coefficient</i>	<i>Proportion of variance explained by first P.C.(%)</i>
[U1/PP + U6/PP]	0.551	82.3
[L1/MP + L6/MP]	0.647	81.6
[SNMP + PPMP + GoA]	0.895 SNMP vs. PPMP 0.727 SNMP vs. GoA 0.784 PPMP vs. GoA	80.7
[UPW _x + MPW _x + LPW _x]	0.750 UPW _x vs. MPW _x 0.650 UPW _x vs. LPW _x 0.730 MPW _x vs. LPW _x	82.6

Four linear combinations accounted for more than 75% of the total variance. They were identified by means of a principal component analysis. The respective correlation coefficient and proportion of variance explained by each principal component are provided.

UTA (mm²) = UPPER TONGUE AREA. An area defined by the limits of E, TT, and the dorsum of the tongue.

TOA (mm²) = TOTAL ORAL AREA. An area defined by the limits of upper incisor tips, PNS, UPW, MPW, LPW, E, H, Me, and lower incisor tip.

AOA (mm²) = ANTERIOR ORAL AREA. An area defined by the limits of upper incisor tip, PNS, E, H, Me, and lower incisor tip.

HNS (°) = HYOID ANGLE. The angle formed between the SN plane and H point on the anterior curvature of the hyoid bone.

UPW (mm) = UPPER PHARYNGEAL WALL. A point on the posterior pharyngeal wall identified by an extension of the palatal (ANS-PNS) plane.

MPW (mm) = MIDDLE PHARYNGEAL WALL. A point on the posterior pharyngeal wall identified by an extension of the LOP.

LPW (mm) = LOWER PHARYNGEAL WALL. A point on the posterior pharyngeal wall identified by an extension of a line through E drawn parallel to the SN plane.

To facilitate the statistical analysis, the number of variables was reduced. A principal component analysis¹⁸ was applied to the 29 original variables and a new set of 23 variables (which included four linear combinations) was used for the multivariate analysis. Canonical correlation analysis^{8,18} was selected because the complexity of the interrelationships under study could not readily be examined by univariate means. Canonical correlations were determined for the data matrix of the pooled sample of 60 subjects. All original values in the raw data matrix were normalized to determine the principal components and the canonical correlations. A canonical correlation analysis is an appropriate tool to describe and summarize the dependence between dentoskeletal and tongue soft-tissue factors because the dependence between the two sets of variables can be summarized in the correlation between the pair of canonical variables.^{8,18} If none of the canonical variables are significant, there is no linear combination of vari-

ables in the first group that is significantly correlated with a linear combination of variables in the second group. If there is a lot of interdependency between the two groups of variables, several canonical variables may be needed to express this interdependency.⁸ Canonical variables can be interpreted by an evaluation of the canonical variable loadings that are the correlations of the original variables with the canonical variables. To keep the overall significance level at 5%, the significance level of each individual correlation must be adjusted to 5/m% where m is the number of correlations being considered.¹⁸ This stringent test was adopted to determine the significance level of the canonical variable loadings in the present study.

RESULTS

The original 29 variables were reduced to 23 by a principal component analysis. Four linear combinations were identified (Table I). In addition, the correlation coefficients between the original variables and the proportion of variance explained by the first principal components are provided. For example, the three variables of SNMP, PPMP, and GoA were replaced by a linear combination since the first principal component explained 80.7% of the total variance. The variables denoted by [] represent new linear combination variables; the remaining variables were not combined.

A multivariate analysis was completed to determine if canonical correlations between linear combinations of variables in the dentoskeletal and tongue soft-tissue groups could be identified. All original values in the raw data matrix were normalized in terms of standard scores to determine the principal components and canonical correlations. Separate canonical correlations were evaluated for the pooled sample of 60 subjects for the 11 dentoskeletal and 12 tongue soft-tissue variables. Six significant canonical correlations were identified (Table II). Bartlett's test indicated the number of the

Table II. Canonical correlations (and their significance) between the dentoskeletal and tongue soft-tissue variable groups

Eigenvalue	Canonical correlation	No. of eigenvalue	Bartlett's test for remaining eigenvalues		
			Chi-square	DF	Tail probability
0.926	0.962	1	388.47	110	0.0
0.864	0.929	2	263.36	90	0.0
0.675	0.823	3	167.73	72	0.0
0.576	0.759	4	113.76	56	0.00001
0.444	0.666	5	72.58	42	0.00235
0.317	0.563		44.43	30	0.04356

Table III. Canonical variable loadings for the dentoskeletal and tongue soft-tissue variables

Variable	Canonical variable loadings					
	1	2	3	4	5	6
<i>Dentoskeletal</i>						
1. SNA	0.776	0.283	-0.148	0.244	-0.255	-0.155
2. SNB	0.959	-0.004	-0.021	-0.007	-0.022	0.193
3. ANB	-0.355	0.423	-0.184	0.369	-0.341	-0.530
4. OJ	-0.305	0.244	0.260	0.541	0.092	-0.617
5. OB	0.013	0.729	0.142	-0.588	-0.072	0.025
6. [SNMP + PPMP + GoA]	-0.391	-0.534	0.198	0.473	0.187	-0.187
7. SNOP	-0.703	-0.307	-0.258	-0.112	-0.029	0.408
8. [U1/PP + U6/PP]	-0.360	-0.490	0.312	-0.223	-0.271	-0.460
9. U1/AP	-0.144	-0.246	-0.328	0.295	0.249	-0.644
10. [L1/MP + L6/MP]	-0.042	-0.372	0.049	-0.251	-0.549	-0.523
11. L1/AP	0.085	-0.642	-0.628	-0.151	0.325	-0.202
<i>Tongue soft-tissue</i>						
12. TT _x	0.831	0.142	0.088	0.283	-0.135	-0.198
13. TT _y	-0.265	-0.778	0.041	-0.342	-0.262	-0.137
14. TT/LOP	-0.158	0.509	0.005	-0.658	-0.228	-0.232
15. TT - L1/LOP	0.019	0.137	-0.284	-0.754	0.061	0.229
16. TGH	-0.227	-0.352	-0.357	0.001	-0.453	0.143
17. TGL	0.001	-0.094	-0.205	-0.013	-0.155	-0.924
18. TTA/TOA	-0.116	0.014	0.006	0.198	0.020	-0.025
19. UTA/AOA	-0.301	0.137	-0.268	0.225	-0.181	0.202
20. E _x	0.789	0.010	0.065	0.325	-0.076	0.434
21. E _y	0.037	-0.228	0.222	0.168	-0.659	-0.258
22. HNS	0.776	-0.103	0.137	0.365	-0.158	0.279
23. [UPW _x + MPW _x + LPW _x]	0.523	-0.145	-0.058	0.598	-0.187	0.463

Significant loadings larger than 0.384 (absolute values) are enclosed in boxes.

canonical variables necessary to express the dependency between the two sets of variables; that is, the smallest number of eigenvalues such that the test of the remaining eigenvalues was nonsignificant. Five canonical correlations were significant at the $\alpha = 0.01$ level of significance, whereas one canonical correlation was significant at the $\alpha = 0.05$ level.

Canonical variable loadings for the dentoskeletal and tongue soft-tissue variables are provided in Table III. Since 23 canonical variable loadings were considered concurrently, it was determined that the correlation

coefficient could be declared significant¹⁸ at an overall 5% level if its absolute value was larger than 0.384 (indicated by boxes). The decision to neglect canonical variable loadings smaller than 0.384 was adopted. The absolute values of the canonical variable loadings were interpreted as light ($0.384 \leq r < 0.5$), moderate ($0.5 \leq r < 0.7$), and heavy ($0.7 \leq r < 1.0$). Canonical variable loadings for the TTA/TOA and UTA/AOA variables were not found to be significant for any of the six canonical correlations.

The first canonical correlation (r_1) revealed a linear

Fig. 2. Diagrammatic representation of the variable loadings for the first canonical correlation.

Fig. 3. Diagrammatic representation of the variable loadings for the second canonical correlation.

combination of positively loaded SNA and SNB variables with negatively loaded [SNMP + PPMP + GoA] and SNOP values with a linear combination of positively-loaded TT_x, E_x, HNS, and [UPW_x + MPW_x + LPW_x] variables. Subjects with anteriorly positioned maxillae and mandibles, flat occlusal and mandibular planes, and acute gonial angles tended to reveal a more forward tongue tip, epiglottis, hyoid, and posterior pharyngeal wall. A diagrammatic representation of this craniofacial type is provided in Fig. 2. The eigenvalue for the first canonical correlation (Table II) indicated that approximately 93% of the variation in the first dentoskeletal variable could be accounted

for by an interdependence with the first tongue soft-tissue variable. In other words, 93% of the variation of the skeletal variables was related to the forward position of the tongue, hyoid, and posterior pharyngeal wall.

The second canonical variable demonstrated a heavy positive loading for OB, negative moderate loadings for L1/AP and [SNMP + PPMP + GoA], a light negative loading for [U1/PP + U6/PP], and a light positive loading for ANB (Fig. 3). The second canonical variable for the tongue variables revealed a heavy negative loading for TT_y and a moderate positive loading for TT/LOP. Subjects with a deep overbite, upright lower incisors, significant ANB, a flat mandibular

Fig. 4. Diagrammatic representation of the variable loadings for the fourth canonical correlation.

Fig. 5. Diagrammatic representation of the variable loadings for the fifth canonical correlation.

plane, and undererupted maxillary teeth tended to have tongue tips behind and below the incisal edge of the lower centrals. By definition, the association determined by the second canonical correlation was statistically independent from that of the first.

A moderate negative loading for L1/AP was found in the third canonical correlation but significant loadings at the 5% level could not be identified for any of the tongue soft-tissue variables (see Table III). The fourth canonical correlation, in contrast to the second, revealed a linear combination of a moderate negative loading for

OB, a moderate positive loading for OJ, and a light positive loading for [SNMP + PPMP + GoA], together with a linear combination of heavy negative TT-LI/LOP, moderate negative TT/LOP, and moderate positive [UPW_x + MPW_x + LPW_x] loadings. Approximately 58% of the variation in the dentoskeletal variables could be accounted for by an interdependence with the tongue soft-tissue variables. Anterior open-bite malocclusions with significant overjets, steep mandibular planes, and obtuse gonial angles were associated with forward pharyngeal walls and tongue tips ahead

Fig. 6. Diagrammatic representation of the variable loadings for the sixth canonical correlation.

of the lower incisors and above the occlusal plane. Fig. 4 reveals a diagrammatic representation of the fourth canonical variable loadings.

The eigenvalue for the fifth canonical correlation indicated that 44% of the variation in the [L1/MP + L6/MP] variable could be explained by an association with E_y and TGH variables (Table II). Subjects with undererupted mandibular incisors and molars tended to have a more inferiorly positioned epiglottis and a low tongue height (Fig. 5).

The sixth canonical correlation revealed the largest number of significant loadings at the 5% level. Approximately 32% of the variation in the six dentoskeletal variables could be explained by an association with the three tongue soft-tissue variables. A diagrammatic representation of the sixth canonical correlation is provided in Fig. 6. Negative loadings for UI/AP, OJ, ANB, [L1/MP + L6/MP], and [UI/PP + U6/PP], together with a positive loading for SNOP, were associated with a heavy negative loading for TGL and light positive loadings for [UPW_x + MPW_x + LPW_x] and E_x . A short tongue together with a forward pharyngeal wall and epiglottis were observed in conjunction with upright maxillary incisors, a small overjet and ANB, undererupted teeth, and a steep occlusal plane.

DISCUSSION

The principal component analysis reduced the number of cephalometric variables to a smaller set of composite variables with a minimum loss of information. The combination of original variables was designed so

that the first principal components could be easily interpreted from a biologic viewpoint. Linear combinations for mandibular plane angulation and gonial angle, incisor and molar eruption, and upper, middle and lower pharyngeal wall variables were identified. Canonical correlation analyses have been applied previously^{8,18} to evaluate the complexity of interrelationships between dentoskeletal structures. Prior to this report, a multivariate approach had not been undertaken with respect to the interdependence between dentoskeletal and tongue soft-tissue variables.

In confirmation of earlier reports^{6-9,13} that have identified the rest position of the mandible as an important determinant of muscle activity and tooth position, six significant canonical correlations were identified. Caution must be exercised in the interpretation of these results because, although the coexistence of certain variables can be established, direct cause-and-effect relationships cannot be proved. However, documentation of the interaction between specific variables does enhance our understanding of the possible interplay between tongue soft-tissue and dentoskeletal factors. To describe correlations accurately, interpretations must be given in light of the sample under study. Thus, the reverse correlations for the six canonical correlations in this report could also be statistically accurate.

The first canonical correlation documented dentoskeletal variables of a forward maxilla and mandible, flat occlusal and mandibular planes, and an acute gonial angle in conjunction with a forward tongue tip, epiglottis, hyoid, and posterior pharyngeal wall. Such variables could be related to geometric and/or size differ-

ences in the sample under study. A previous report¹² determined that the age factor must be considered in evaluations of tongue position because children have a higher dorsal tongue height than adults. It has also been established that tongue growth is essentially complete in females 18 years of age.¹ Although it was assumed that growth was complete for the subjects in this report, obvious differences in overall craniofacial dimensions could exist in a sample of 60 persons. A large face tends to have a more anteriorly placed tongue tip, epiglottis, hyoid, and pharyngeal wall; the first canonical correlation documents this geometric fact.

Subjects who revealed some degree of incisor overbite with the mandible in the rest position were identified by the second canonical correlation. They also had upright lower incisors, a flat mandibular plane, an acute gonial angle, undererupted maxillary incisors and molars, and a large ANB. These craniofacial characteristics are typical of the short-face syndrome.^{20,21} The tongue tip was located inferior to the lower occlusal plane. In summary, a person with some degree of overbite and a flat mandibular plane tends to reveal a tongue tip behind and below the incisal edge of the lower central incisor. The third canonical correlation ($r_3 = 0.883$) explained 67.5% of the variation in L1/AP by a linear combination of tongue soft-tissue variables, none of which were significant at the 5% level.

In direct contrast to the second, the fourth canonical correlation represents the traditional cephalometric criteria of a skeletal open-bite malocclusion.^{4,15,21} Subjects with an anterior open bite, a large overjet, a steep mandibular plane, and a large gonial angle reveal a tongue tip ahead of the incisal edge of the lower central incisor and above the lower occlusal plane. Similar forward tongue postures at rest have been identified in patients who exhibit a tongue thrust.¹¹ In addition, the fourth canonical correlation identified a more forward posterior pharyngeal wall. These craniofacial characteristics fit the previous postulate⁷ of a sequence of events that lead to the development of an anterior open-bite malocclusion. These might include an initial factor (probably related to airway maintenance) that induces a mandibular rotation, a forward tongue posture to maintain the airway, gradual elimination of the original interocclusal clearance, and the appearance of an open vertical dimension between the incisal edges of the maxillary and mandibular teeth. The fourth canonical correlation quantifies such an interaction between tongue posture at rest and incisor position. Predicated on this observation in open-bite subjects, treatment plans for the correction of these malocclusions should probably include some consideration of how to reduce the for-

ward tongue posture. Since the degree of tongue protrusion is related to the amount of mandibular rotation,⁷ attempts to effect a counter-clockwise rotation of the mandible should be initiated. Techniques such as the use of a high-pull headgear¹⁰ or a posterior bite block³ have been shown to prevent further eruption of, or indeed to intrude, the maxillary molars in growing patients. In adult patients the superior repositioning of the maxilla by surgical treatment¹⁵ could accomplish the same objective.

The fifth canonical correlation ($r_5 = 0.666$) defines a relationship between the amount of eruption of the mandibular incisor and molar teeth and the linear combination of an inferior epiglottis and a low tongue height. In other words, subjects with undererupted teeth in the mandibular arch tend to have a more inferiorly positioned tongue base and a reduced tongue height. This again may be a geometric relationship since a mandible with less vertical development could be associated with a tongue of proportionately less vertical height.

The final canonical correlation ($r_6 = 0.563$) identifies another relationship in the sample of 60 adult females. Subjects who had a short tongue length, a forward posterior pharyngeal wall, and a forward epiglottis also revealed upright maxillary central incisors, a small overjet, a low ANB, undererupted teeth, and a steep occlusal plane. The tongue tip was below and behind the mandibular central incisor even though a forward posterior pharyngeal wall could be identified and such subjects did not reveal any evidence of an anterior open-bite malocclusion. Thus, it appears that a short tongue at rest in conjunction with a forward epiglottis and posterior pharyngeal wall is not related to overbite. This interaction of factors is in direct contrast to the craniofacial type portrayed by the fourth canonical correlation.

Despite the obvious limitations of interpretation in any two-dimensional cephalometric study, the canonical correlations between dentoskeletal and tongue soft-tissue variables contribute to our understanding of the interaction between resting-tongue posture and the development of the occlusion. Furthermore, the factors quantified in this article provide insight with regard to the interdependency between the geometric arrangement of the tongue and associated dentoskeletal structures in nongrowing adult subjects.

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REFERENCES

1. Cohen AM, Vig PS: A serial growth study of the tongue and intermaxillary space. *Angle Orthod* **46**: 323-337, 1976.
2. Garnick J, Ramfjord SP: Rest position: An electromyographic and clinical investigation. *J Prosthet Dent* **12**: 895-911, 1962.
3. Harvold EP: The activator in interceptive orthodontics. St. Louis, 1974, The CV Mosby Co, p 164.
4. Isaacson JR, Isaacson RJ, Spiedel MT, Worms FW: Extreme variation in vertical growth and associated variation in skeletal and dental relations. *Angle Orthod* **41**: 219-229, 1971.
5. Jensen R: Anterior teeth relationship and speech: Studies using cineradiography synchronized with speech recording. *Acta Radiol [Suppl]* (Stockh) **276**: 1-69, 1968.
6. Lowe AA: Correlations between orofacial muscle activity and craniofacial morphology in a sample of control and anterior open-bite subjects. *AM J ORTHOD* **78**: 89-98, 1980.
7. Lowe AA, Johnson WD: Tongue and jaw muscle activity in response to mandibular rotations in a sample of normal and anterior open-bite subjects. *AM J ORTHOD* **76**: 565-576, 1979.
8. Lowe AA, Takada K: Associations between anterior temporal, masseter, and orbicularis oris muscle activity and craniofacial morphology in children. *AM J ORTHOD* **86**: 319-330, 1984.
9. Lowe AA, Takada K, Taylor L: Muscle activity during function and its correlation with craniofacial morphology in a sample of subjects with Class II, Division 1 malocclusions. *AM J ORTHOD* **84**: 204-211, 1983.
10. Nahoum HI: Vertical proportions: A guide for prognosis and treatment in anterior open-bite. *AM J ORTHOD* **72**: 128-146, 1977.
11. Ozeki S: Roentgeno-cephalometric and cinefluorographic study of tongue thrust. *J Jpn Orthod Soc* **32**: 1-22, 1973.
12. Peat JH: A cephalometric study of tongue position. *AM J ORTHOD* **54**: 339-361, 1968.
13. Proffit WR: Equilibrium theory revisited: Factors influencing position of the teeth. *Angle Orthod* **48**: 175-186, 1978.
14. Proffit WR, Norton LA: The tongue and oral morphology: Influences of tongue activity during speech and swallowing. *In* Speech and the dentofacial complex: the state of the art. American Speech and Hearing Association Reports **5**: 106-115, 1970.
15. Schendel SA, Eisenfeld J, Bell WH, Epker BN, Mishelevich DJ: The long face syndrome: Vertical maxillary excess. *AM J ORTHOD* **70**: 398-408, 1976.
16. Subtelny JD, Sakuda M: Open-bite: Diagnosis and treatment. *AM J ORTHOD* **50**: 337-358, 1964.
17. Takada K: Correlations between tongue volume and orofacial morphology in control and open-bite subjects. *J Osaka Univ Dent Sch* **26**: 328-358, 1981.
18. Takada K, Lowe AA, Freund V: Canonical correlations between masticatory muscle orientation and dentoskeletal morphology in children. *AM J ORTHOD* **86**: 331-341, 1984.
19. Takada K, Lowe AA, Yoshida K, Sakuda M: Tongue posture at rest: An electromyographic and cephalometric appraisal. *J Osaka Univ Dent Sch* (in press), 1985.
20. Takeuchi K: Vertical facial growth in anterior open-bite and deep-bite by means of lateral cephalometric roentgenograms. *J Osaka Univ Dent Sch* **23**: 17-41, 1978.
21. Trouten JC, Enlow DH, Rabine M, Phelps A, Swedlow D: Morphologic factors in open bite and deep bite. *Angle Orthod* **53**: 192-211, 1983.
22. Vig PS, Cohen A: The size of the tongue and the intermaxillary space. *Angle Orthod* **44**: 25-28, 1974.
23. Warwick R, Williams PL (editors): Gray's anatomy, ed 35, Philadelphia, 1973, WB Saunders, p 1238.
24. Yoshida K, Takada K, Adachi S, Sakuda M: EMG approach to assessing tongue activity using miniature surface electrodes. *J Dent Res* **61**: 1148-1152, 1982.