Dr. Vargervik

Morphologic response to changes in neuromuscular patterns experimentally induced by altered modes of respiration

Karin Vargervik, D.D.S., Arthur J. Miller, Ph.D., George Chierici, D.D.S., Egil Harvold, D.D.S., Ph.D., LL.D., and Britta S. Tomer, D.D.S.
San Francisco, Calif.

The present experiment was designed to test whether specific recordable changes in the neuromuscular system could be associated with specific alterations in soft- and hard-tissue morphology in the craniofacial region. The effect of experimentally induced neuromuscular changes on the craniofacial skeleton and dentition of eight rhesus monkeys was studied. The neuromuscular changes were triggered by complete nasal airway obstruction and the need for an oral airway. Alterations were also triggered 2 years later by removal of the obstruction and the return to nasal breathing. Changes in neuromuscular recruitment patterns resulted in changed function and posture of the mandible, tongue, and upper lip. There was considerable variation among the animals. Statistically significant morphologic effects of the induced changes were documented in several of the measured variables after the 2-year experimental period. The anterior face height increased more in the experimental animals than in the control animals; the occlusal and mandibular plane angles measured to the sella-nasion line increased; and anterior crossbites and malposition of teeth occurred. During the postexperimental period some of these changes were reversed. Alterations in soft-tissue morphology were also observed during both experimental periods. There was considerable variation in morphologic response among the animals. It was concluded that the marked individual variations in skeletal morphology and dentition resulting from the procedures were due to the variation in nature and degree of neuromuscular and soft-tissue adaptations in response to the altered function. The recorded neuromuscular recruitment patterns could not be directly related to specific changes in morphology.

Key words: Oral respiration, neuromuscular recruitment, soft-tissue adaptation, skeletal adaptation

The effects of mouth breathing on craniofacial morphology and development of dental malocclusions have come into focus in the orthodontic literature during the last few years. Although this is an old issue, a cause-and-effect relationship has been difficult to establish. It has been demonstrated by many investigators, however, that altered function can affect the development of form.[1-17] In most of these studies the alterations in function have been produced by deletion of parts of the neuromuscular system rather than by alterations of normal functions within intact systems.

In our laboratory several experimental studies on the development of dental malocclusions and on the characteristics of neuromuscular activity which affects the skeletal and dentoalveolar morphology have been conducted.[18-28] In these in vivo studies, changes in orofacial functions have been induced while the neuromuscular and skeletal systems were left intact. The neuromuscular changes have been triggered by different methods: (1) placing a bone in a new position relative to the musculature by (a) medial displacement of one side of the maxilla in experimentally produced clefts,[21, 22] (b) placement of a palatal wedge to displace the tongue and the mandible,[18-20] (c) use of a functional appliance to hold the mandible down and forward in children with Class II dental malocclusions[29-31]; (2) changing muscle activity by muscle detachment[32]; and (3) changing muscle activity by inducement of oral respiration.[20, 23-28]

It has been established that changing position of a bone relative to its attached and surrounding musculature results in remodeling of surface areas as well as of the internal architecture of the bone. It has also been shown that experimentally induced changes in neuromuscular activity can result in altered skeletal morphology.

In previous experiments it was shown that induced dependency on oral respiration in rhesus monkeys resulted in different types of skeletal, dental, and soft-tissue morphology.[20, 23-26] The malocclusions that developed included anterior crossbite, increased overjet, canine crossbite, and dual bite. The soft-tissue changes

---

From the Craniofacial Center, University of California San Francisco.
This study was supported by grant DE 05558 from the National Institute of Dental Research.

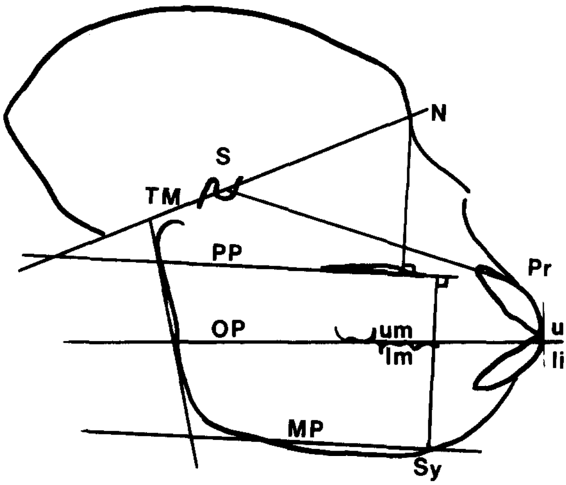

Fig. 1. Cephalometric points, landmarks, lines, and planes used in this study. Skeletal: Sella-nasion (S-N), sella-prosthion (S-Pr), maxillary unit (TM-Pr), mandibular unit (TM-Sy), upper face height = perpendicular from nasion to palatal plane (N-PP), lower face height = perpendicular from Sy to palatal plane (PP-Sy), total anterior face height (N-Sy), palatal plane angle (SN-PP), occlusal plane angle (SN-OP), mandibular plane angle (SN-MP), ramus angle (SN-RM), gonial angle (MP-RM). Dental: Distance between the maxillary incisal edge and a tangent to the mesial surface of the maxillary first molar (ui-um), corresponding measurement in the mandible (li-lm), and the distance between the maxillary and mandibular incisor edges measured along the occlusal plane (ui-li).

included notching of the upper lip and various types of grooves and shape changes of the tongue. It is postulated that the variations in morphologic response are due to differences in muscle recruitment associated with the change in mode of respiration.

Previous observations indicated that the characteristic morphologic changes of the lip and tongue disappeared within a short period of time when nasal breathing was restored.[26] It could therefore be expected that the neuromuscular patterns that were induced by oral respiration and that presumably caused the alteration in soft-tissue morphology and adaptive motor behavior would change after removal of the stimulus. Consequently, it was also expected that the skeletal morphology that resulted from the adaptation to oral respiration would again be affected by the new postexperimental neuromuscular recruitment patterns. If these patterns returned to pre-experimental levels, the skeletal and dental changes might be reversed.

The present experiment was designed to determine whether these distinctions could be made during adaptation to oral respiration and during adaptation to restored nasal breathing. The data from the first year of adaptation to mouth breathing in these animals were included in a previous publication.[26]

METHOD

In ten rhesus monkeys the nasal airway was obstructed by placement of hollow, cone-shaped, soft silicone plugs attached with a ligature to the nasal septum as described in previous publications.[20, 26] The nose plugs prevented inspiration of air but did allow small amounts of expiratory air to pass when the nares were dilated. Two of the animals were subsequently taken out of the study because of difficulties in keeping the nose plugs in place throughout the 2 years of the experiment. Ten animals (later reduced to eight) of comparable ages were designated as controls and were paired with the experimental animals according to sex and age (±5 months). There were one pair of females and seven pairs of male animals. Three pairs were older, ranging in age from 2 years 6 months to 3 years 7 months. The younger four pairs ranged from 1 year 3 months to 1 year 11 months. The control animals were followed by the same protocol of procedures and records as the experimental animals with the exception of the nose blockage. The experimental period varied from 18 to 31 months, and the postexperimental period from 20 to 29 months (Table III).

The procedure for obtaining electromyographic recordings (EMG) has been described in detail previously.[24, 25, 27] The recording technique was designed to distinguish between changes in continuous discharge (tonic) and rhythmic discharge (phasic), synchronous with a primary respiratory muscle. Recordings with intramuscular electrodes were obtained from two suprahyoid muscles (digastric and geniohyoid); two tongue muscle areas (genioglossus and dorsal tongue fibers); five areas around the lips and nares (floor of the nose, horizontal fibers of the superior and inferior orbicularis oris, lateral lip area, an area between the upper lip and nose, that is, lip-elevator region); four other facial muscles (buccinator, zygomaticus, mentalis, platysma); three jaw elevator muscles (medial pterygoid, masseter, temporalis); and the lateral pterygoid muscles.

Rhythmicity in the recorded muscles was correlated with the EMG activity from an intercostal muscle (second interspace) or the diaphragm. The onset and duration of rhythmic pattern of each muscle were compared by rectifying and integrating each EMG signal through a parallel resistor-capacitor circuit to obtain an envelope of EMG activity. Each integration was averaged for forty trials for each muscle. Continuous discharge (tonicity) was assessed by rectifying and integrating the EMG signal through a circuit that would reset at a predetermined voltage and by analyzing the number of resets.

The cephalometric landmarks, angles, and dimensions used are similar to those described previously,[19]

Table I. Electromyographic records obtained before placement of nose plugs (before), at the end of the experimental period (during), and 1 year after the nose plugs were removed (after)

		Geniohyoid			*Digastric*			*Lip elevator*			*Genioglossus*			*Dorsal tongue*		
		Before	*During*	*After*	*Before*	*During*	*After*	*Before*	*During*	*After*	*Before*	*During*	*After*	*Before*	*During*	*After*
1	3	0	R	0	0	R	0	0	R	T	0	RT	T	0	R	0
	8,108	T	0	T	0	0	0	0	R	T	T	RT	T	0	RT	0
	16,328	0	RT	0	0	0	0	R	R	0	RT	R	0	0	R	0
	16,495	0	RT	T	—	R	0	—	R	T	—	R	T	—	R	T
2	1	T	T	T	0	T	T	R	RT	0	T	T	T	0	0	0
	7,926	—	T	T	—	0	T	—	R	RT	—	T	T	—	—	0
	16,440	0	T	T	0	0	0	0	T	T	0	T	0	0	0	0
	16,504	—	T	T	—	0	T	—	0	T	—	T	T	—	0	0

0 = No recorded activity; T = tonic discharge; R = rhythmic discharge; — = no recording.

Table II. Observed behavior of the upper lip, tongue, and mandible in each of the experimental animals during recording sessions before (1), during (2), and after (3) nasal airway obstruction

	Upper lip									*Tongue*									*Mandible*					
	Apart consistently			*Raised rhythmically*			*Triangular*			*Protruded rhythmically*			*Midline groove*			*Flattened and/or pointed*			*Low consistently*			*Lowered rhythmically*		
	1	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*	*1*	*2*	*3*
3	–	+	–	–	+	–	–	–	–	–	–	–	–	+	–	–	+	–	–	+	+	–	–	–
8,108	+	+	+	–	+	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	+	–	–	–
16,328	+	+	+	+	+	–	–	–	–	–	+	–	–	–	–	–	+	–	+	+	+	–	–	–
16,495	0	+	+	0	+	–	0	+	+	0	–	–	–	–	–	–	+	–	0	+	+	0	–	–
1	–	+	+	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	+	+	–	–	–
7,926	0	+	+	0	–	–	0	–	–	0	–	–	–	+	–	–	–	–	0	+	+	0	–	–
16,440	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–
16,504	0	+	+	0	–	–	–	–	–	0	–	–	–	+	–	–	–	–	0	+	+	0	–	–

+ = Positive finding; – = negative finding, 0 = no record.

but with some additions (Fig. 1). During the periods of the recording sessions at which the EMG data were taped for analysis, records were made of certain behavioral characteristics of the upper lip, tongue, and lower jaw. Photographs were used to assess the morphologic changes in the tongue and lips.

DATA ANALYSIS

The experimental and control animals were initially paired, but during the postexperimental period the procedures were not carried out on the animals as pairs (that is, EMG recordings or radiographs on the same day for both animals in a pair). It was therefore decided to perform group rather than pair comparisons in the analysis of the data.

Student's t test was used to compare the control and experimental groups at three stages: (1) start of the experiment, (2) end of the experimental period, and (3) end of the postexperimental period. There was no significant intergroup age difference at the start of the experiment or at the end of the postexperimental period. However, there was an intergroup difference in the duration of the experimental period (T = −1.8, prob. > /T/0.09), and of the postexperimental period (T = 5.2, prob. > /T/0.001) (Table III). In order to reduce the effect that the differences in observation intervals could be expected to have on growth changes, the rate of change was calculated for each day of the two periods and multiplied by 365 to approximate the changes occurring in one year. The data from this averaging method reflect the overall changes during the experimental periods but obscure time-related variations.

Four of the experimental animals demonstrated rhythmic activity in the suprahyoid, perinasal, and tongue muscles during the period of mouth breathing. These animals were examined separately with regard to soft-tissue changes as well as skeletal response (Subgroup 1). The animals that did not demonstrate consistent rhythmicity in these muscles are presented in Sub-

Table III. Group comparison of age and of cephalometric linear and angular measurements obtained from radiographs at the start of the experiment (1), at the end of the experimental period (2), and at the end of the postexperimental period (3)

	1					*2*				
	Control		*Experimental*			*Control*		*Experimental*		
Variables	*X*	*SD*	*X*	*SD*	*T*	*X*	*SD*	*X*	*SD*	*T*
Age	805	325	822	296	−0.11	1370	383	1491	321	−0.68
Skeletal										
S-N (mm)	44.9	3.2	44.0	1.5	0.70	47.7	2.2	46.5	1.5	1.29
S-Pr (mm)	58.1	6.6	57.1	2.8	0.40	66.5	6.5	66.5	4.8	0.00
TM-Pr (mm)	64.9	8.8	62.8	4.6	0.60	75.1	8.3	74.3	7.1	0.23
TM-Sy (mm)	62.0	8.6	57.8	5.6	1.17	71.1	8.2	71.3	6.2	−0.05
N-PP (mm)	33.0	2.5	33.6	2.7	−0.43	35.5	2.9	38.3	2.7	−1.94
PP-Sy (mm)	29.9	3.6	27.8	1.8	1.38	34.6	3.9	33.8	1.9	0.57
N-Sy (mm)	63.3	6.2	62.0	4.3	0.46	70.3	6.9	73.3	4.7	−1.00
SN-PP (degrees)	26.6	2.2	30.8	3.7	−2.75*	25.7	3.3	31.3	3.4	−3.34*
SN-OP (degrees)	23.6	3.6	25.6	1.9	−1.29	21.7	2.9	27.5	3.4	−3.71*
SN-MP (degrees)	23.6	3.9	25.9	3.8	−1.16	23.0	2.1	27.0	3.4	−2.86*
SN-RM (degrees)	104.5	2.5	107.2	2.4	−2.17*	104.8	4.7	106.7	3.0	−0.95
Gonial angle (degrees)	97.8	4.6	98.5	4.5	−0.30	97.8	3.8	100.5	3.5	−1.46
Dental										
UI-UM (mm)	30.2	2.8	29.7	2.3	0.39	31.9	3.0	30.6	3.0	0.89
LI-LM (mm)	27.3	2.9	26.9	2.7	0.27	28.8	2.7	28.6	2.4	0.19
UI-LI (mm)	1.1	0.8	1.6	0.5	−1.33	1.31	0.8	−0.1	1.3	2.70*

*Significant at the 0.05 level.

group 2. In view of the fact that group comparisons may obscure pertinent information, the various data are presented for each individual animal.

RESULTS

After placement of the nose plugs, rhythmicity in EMG discharge was demonstrated in four of the animals in the following muscles: geniohyoid, digastric, genioglossus, dorsal tongue fibers, and lip elevator region (Table I, Subgroup 1). After nasal respiration was restored, the rhythmicity disappeared except in the lip-elevator region of one animal. Tonic EMG discharge was found consistently in the geniohyoid and genioglossus muscles of the nonrhythmic animals (Table I, Subgroup 2).

During the experimental period all of the experimental animals kept their lips separated constantly. Half of the group (Subgroup 1) demonstrated rhythmic raising of the upper lip and in two animals, one in each subgroup, the upper lip developed a triangular shape (Table II). All rhythmic movements disappeared shortly after the nasal respiration had been restored. Five of the eight animals continued to keep the lips separated, and seven of them maintained the low mandibular posture while they were in the EMG recording chair.

The results of the analysis of the actual linear and angular cephalometric measurements at the three experimental stages are shown in Table III. For most of the variables there was no significant difference between the two groups at the start. The exceptions were a steeper palatal plane measured to SN in the experimental group and a larger angle between the posterior border of the mandibular ramus measured to SN.

The data obtained at the time of removal of the nose plugs show significant anterior downward tipping of the palatal, occlusal, and mandibular planes as measured to the sella-nasion line. At the end of the 2-year postexperimental period the two groups were not significantly different with regard to the measured variables, with the exception of the distance from sella to nasion, a dimension that is not expected to be influenced by the experimental procedures. The intergroup difference in the duration of the two experimental periods (shorter for the controls during the first interval and longer during the second) was expected to affect the linear measurements of size during these periods. The method of analyzing adjusted rates of change was therefore used (Tables IV and V). The data on the rate of change during the experimental period of nasal airway obstruction demonstrated a significant increase in anterior downward tipping of the occlusal plane relative to SN in the experimental animals (SN-OP). The distance from nasion to the

3				
Control		*Experimental*		
X	*SD*	*X*	*SD*	*T*
2314	367	2282	336	.18
52.4	1.8	50.2	2.1	2.33*
77.6	5.8	77.6	6.7	0.02
88.8	5.5	88.4	8.6	0.10
85.1	5.0	84.7	7.9	0.13
39.9	2.5	40.5	2.6	−0.49
40.8	3.7	38.9	1.8	1.32
81.8	5.2	80.4	4.6	0.56
24.9	3.1	28.1	4.0	−1.81
22.1	2.4	24.0	5.1	−0.98
24.6	3.1	25.8	5.0	−0.60
102.6	10.0	106.0	4.3	−0.88
99.1	4.3	99.6	4.5	−0.25
35.1	3.3	34.6	4.9	0.27
31.1	3.1	30.6	3.2	0.28
1.9	1.4	1.8	2.3	0.13

palatal plane (N-PP), as well as the distance from nasion to the mandibular symphysis (N-Sy), representing anterior face height, increased significantly more in the experimental animals than in the control animals. The horizontal distance between the incisal edges of the upper and lower incisors decreased significantly in the experimental animals, indicating a tendency to reduction of overjet or development of anterior crossbite (Table VI). The adjusted rates of increase were also calculated with SN as a covariate to reduce the effect of size differences among the animals. The changes that were significantly different when this analysis was used are shown in Table V.

During the postexperimental follow-up period, the angular changes that had taken place during the experimental period were reversed. The angle between the palatal plane and SN (SN-PP), between the occlusal plane and SN (SN-OP), and between the mandibular plane and SN (SN-NP) decreased significantly in the experimental animals (Tables IV and V). The rate of face height increase was not statistically different between the two groups during the postexperimental follow-up period (Tables IV and V).

The adjusted rates of change in the skeletal and dental measurements, which were significantly affected by the experimental procedure, are presented for each experimental animal together with the mean values and standard deviations for the control group (Figs. 2 to 7). The four experimental animals listed first (Subgroup 1) demonstrated EMG rhythmicity in the suprahyoid, tongue, and lip-elevator muscles during the experimental period.

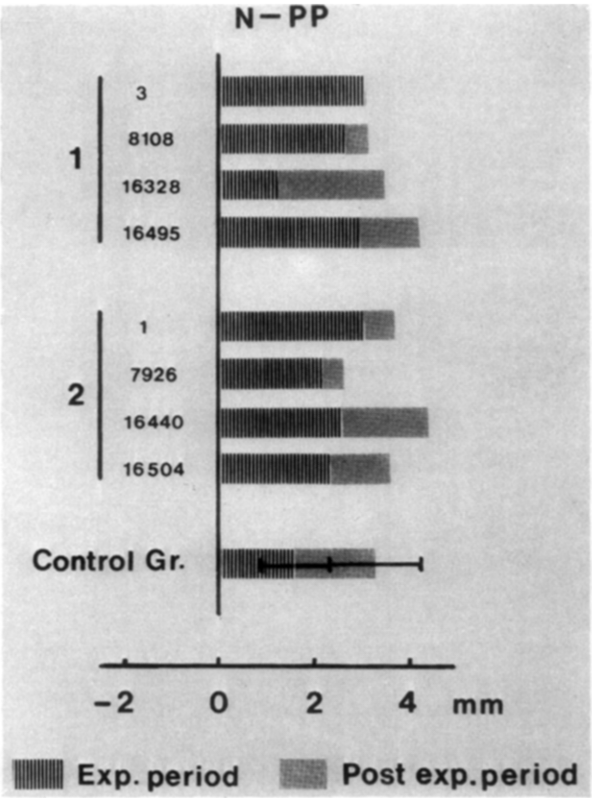

Fig. 2. Adjusted rate of increase in the upper face height (nasion to palatal plane) during the experimental and postexperimental periods for each of the experimental animals. For the control group, the mean rate of increase ± one standard deviation is indicated.

All animals had normal dental occlusions at the start of the experiment, with the exception of one that demonstrated considerable wear of the upper and lower incisors with a resultant anterior open bite. At the time the nose plugs were removed, seven of the animals had a reduction of the maxillary incisor overjet and five of them developed an anterior crossbite. During the postexperimental period there was a trend toward improvement of the incisor relationships. In three animals some degree of anterior crossbite persisted, and in two animals excessive overjet developed (Table VI).

DISCUSSION

The data demonstrate that the experimentally produced mouth breathing caused changes in EMG discharge patterns and in certain skeletal and dental dimensions and relationships. The return to nasal breathing resulted in changes in the same parameters. The docu-

Table IV. Adjusted rates of change for the linear and angular measurements obtained on lateral head films of eight control and eight experimental animals during the experimental period of nasal airway obstruction and during the postexperimental observation period (mean values ± one standard deviation and T values are shown)

	Experimental period					*Postexperimental period*				
	Control		*Experimental*			*Control*		*Experimental*		
	X	*SD*	*X*	*SD*	*T*	*X*	*SD*	*X*	*SD*	*T*
Skeletal										
S-N (mm)	1.9	1.1	1.3	0.5	1.34	1.8	0.8	1.7	0.8	0.23
S-Pr (mm)	5.4	1.9	5.1	1.3	0.40	4.3	2.2	5.2	2.3	−0.79
TM-Pr (mm)	6.7	1.7	6.3	1.7	0.45	5.3	3.0	6.6	2.8	−0.94
TM-Sy (mm)	5.9	2.1	7.4	1.3	−1.75	5.4	2.9	6.2	2.4	−0.61
N-PP (mm)	1.6	0.9	2.4	0.6	−2.33*	1.7	1.0	1.0	0.8	1.44
PP-Sy (mm)	3.2	1.9	3.2	0.6	−0.10	2.4	1.4	2.4	0.8	0.04
N-Sy (mm)	4.6	1.5	6.1	0.8	−2.48*	4.4	2.5	3.3	1.3	1.14
SN-PP degrees	−0.5	1.6	0.2	1.9	−0.81	−0.3	0.6	−1.5	1.3	2.48*
SN-OP (degrees)	−1.2	1.9	1.0	1.4	−2.57*	0.1	0.5	−1.7	1.7	2.98*
SN-MP (degrees)	−0.3	2.2	0.6	1.1	−0.99	0.6	0.7	−0.6	1.1	2.64*
SN-RM (degrees)	0.3	2.5	−0.2	1.3	0.52	−0.8	3.0	−0.4	1.3	−0.42
Gonial angle (degrees)	0.04	1.3	1.1	1.8	−1.33	0.5	1.2	−0.4	0.7	1.74
Dental										
UI-UM (mm)	1.1	0.4	0.5	1.1	1.44	1.2	1.0	1.9	1.6	−0.95
LI-LM (mm)	1.0	0.8	0.9	0.8	0.27	0.9	0.9	1.0	1.0	−0.24
UI-LI (mm)	0.1	0.2	−0.9	0.8	3.41*	0.2	0.3	0.9	0.7	−2.65*

*Statistically significant at the 0.05 level.

Table V. Measurements significantly different in the two groups when S-N was used as co-variate

	Experimental period		*Postexperimental period*	
Variables	*F*	*Prob. > F*	*F*	*Prob. > F*
Skeletal				
TM-Pr (mm)			4.77	0.048+
TM-Sy (mm)	12.33	0.004+		
N-PP (mm)	13.90	0.002+		
N-Sy (mm)	12.48	0.003+		
SN-PP degrees			6.42	0.025−
SN-OP (degrees)	8.06	0.014+	10.82	0.006−
SN-MP (degrees)	4.69	0.049+	7.09	0.020−
Dental				
UI-LI (mm)	10.68	0.006−	9.21	0.010+

+ = Significantly more increase in the experimental group; − = significantly less.

mented changes were presumably caused by the chain of events resulting from the need for an oral airway and from the return to nasal breathing.

In order to establish an oral airway, the animals had to separate the lips, lower the jaw, and get the tongue away from the palate by a lowered position and/or protrusion. These required positional changes could presumably be maintained consistently or rhythmically in synchrony with respiration. It could also be assumed that the required changes in the positions of the lower jaw and tongue would be achieved by increased and/or decreased contractions of the muscles that control the position of these structures. The mandibular and tongue muscles that are accessible for electromyography were therefore tested by periodic EMG recordings, along with certain facial muscles.

The question to be answered was: Can certain neuromuscular recruitment patterns as recorded by EMG be related to (1) specific changes in soft-tissue morphology, (2) movements and positional characteristics of the upper lip, tongue, and mandible, and (3) the documented skeletal and dental changes?

EMG data and changes in shape of tongue and upper lip

Rhythmicity was recorded in the lip-elevator region of six animals while the nasal airway was blocked. Tonic discharge was recorded in two of them (Table I). Two of the animals developed a notch in the upper lip; in one of these the lip-elevator muscle demonstrated rhythmic discharge, and in the other both rhythmic and tonic discharge was demonstrated. Rhythmicity in the dorsal fibers of the tongue was recorded in four animals, and tonicity in only one, which was also rhythmic. Only one of the animals with recorded

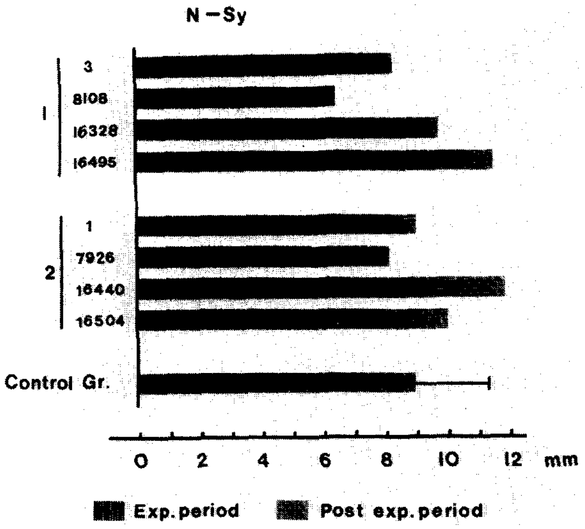

Fig. 3. Adjusted rate of increase in total anterior face height (nasion to symphysis) for each of the experimental animals and for the control group.

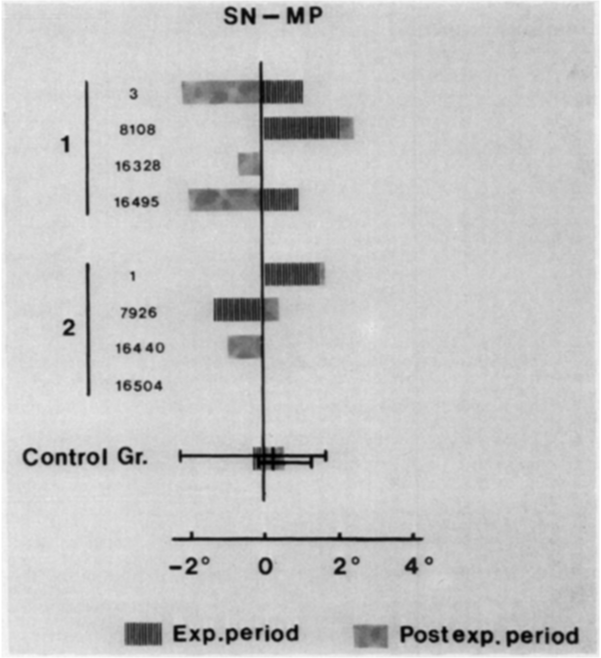

Fig. 4. Adjusted rate of change in the mandibular plane angle (SN-MP) for each of the experimental animals and for the control group. Decreases in the angle are shown to the left and increases to the right of the vertical zero line.

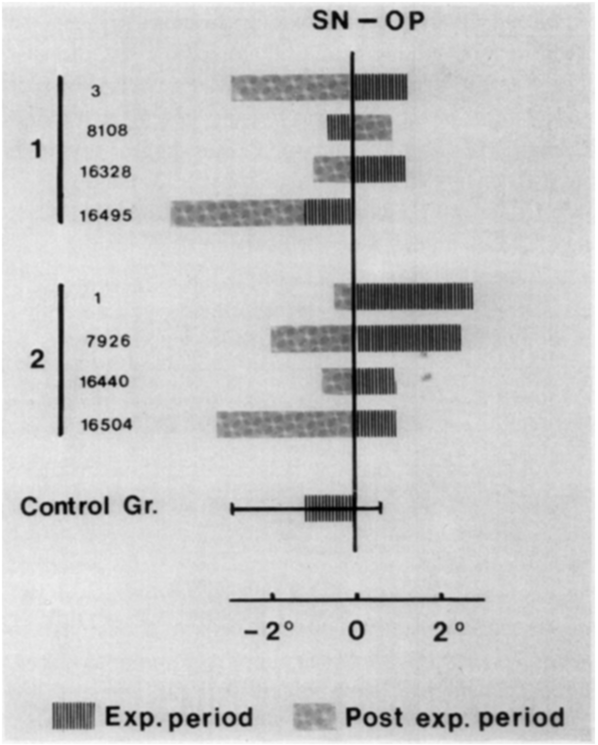

Fig. 5. Adjusted rate of change in the occlusal plane angle (SN-OP) during the experimental and postexperimental periods.

rhythmicity in dorsal tongue fibers developed a midline groove in the tongue, while all four without rhythmicity developed longitudinal tongue grooves. It was concluded that there was no direct relationship between the EMG recorded at the end of the experimental period and the morphologic soft-tissue changes that had taken place. Data obtained earlier in the experimental period and previously reported[27] indicated, however, that localized consistent tonic discharges occurred with the morphologic changes in the tongue and the lip and that when the soft tissue responded with form changes (that is, shortening of muscle fibers in certain areas), the EMG discharge was diminished. A certain stimulus must be necessary to maintain the soft-tissue morphologies, however, for they gradually disappeared when the mouth breathing ceased.

EMG data and the movement and postural changes of the upper lip, tongue, and mandible

Upper lip. Four of the six animals with persistent EMG rhythmicity in the lip-elevator region also demonstrated rhythmic raising of the upper lip. This shows a direct relationship between the recorded rhythmicity and the observed movement, but it also shows that rhythmic discharge can be recorded without an observable movement of the lip.

Tongue. The genioglossus and dorsal tongue fibers showed rhythmic discharge in four animals at the end of the experimental period, but none of the animals protruded their tongues rhythmically at that time. It was concluded that there was no direct relationship between the recorded rhythmicity in the tongue muscles and the

Table VI. Description of the dental occlusion before (1), at the end of (2), and 2 years following the experimental period (3)

	1	*2*	*3*
3	Normal occlusion	Anterior crossbite	Reduction to partial crossbite
8,108	Anterior open bite	Open bite extending to the last molar	No change
16,328	Slight overjet	End-to-end incisor relationship	Slight overjet and overbite
16,495	Slight overjet	Anterior crossbite	No change
1	Normal occlusion	End-to-end incisor relationship, midline shift	Normal overjet, persistence of midline shift
7,926	Normal occlusion	Buccal crossbite, midline shift	Correction of crossbite, persistence of midline shift
16,440	Normal occlusion	Anterior open bite, left side	Overjet, anterior open bite, right side, upper arch asymmetry
16,504	Normal occlusion	Slight reduction of overjet	Slight increase of overjet

observed movements of the tongue. A longitudinal midline groove developed in the four animals without rhythmic discharge. This may indicate that the soft-tissue changes in these animals were adequate for oral respiration and that the deviant morphology was maintained by low levels of tonic activity in certain fibers of the tongue not distinguished by our technique. A tonic discharge of the genioglossus was recorded in six of the animals. This discharge was consistent with the observed lowered position of the mandible and tongue.

Mandible. All animals were observed to keep the mouth open and the mandible lowered. A tonic discharge in the geniohyoid muscle was recorded in four animals and in the digastric muscle in one of the animals. Three of the animals demonstrated rhythmic EMG discharge in either the geniohyoid or the digastric muscles, or both, but without observed rhythmic lowering of the mandible. The EMG rhythmicity disappeared when nose breathing was restored. These findings indicated that the respiratory requirements still recruited these muscles, but without involving enough fibers to cause a visible change in tongue or jaw position.

EMG data and skeletal and dental responses

No significant change was recorded electromyographically in any of the jaw-closing muscles or in the lateral pterygoid muscle. The lowered posture of the mandible would therefore appear to be the result of the recorded increased activity in the suprahyoid and tongue muscles and/or an unmeasurable decrease in postural tonic activity of the supramandibular muscles. Induced change in head posture was not assessed but cannot be excluded as a contributing factor.[33] The experimentally induced increases in upper and total face height and the tipping of the palatal, occlusal, and mandibular planes would appear to be the result of the constant lowered mandibular posture, which would change the force systems and strain distribution in the maxilla. The increase in face height was fairly uniform among the animals (Figs. 2 and 3), but the angular changes demonstrated a wide range in response to induced oral respiration (Figs. 4, 5, and 6). The individual differences in shape, posture, and movement patterns of the tongue may be the most important factors causing the variations in skeletal response. The dental changes in the four animals with EMG rhythmicity in the suprahyoid and tongue muscles were more marked than in the other animals, which had more adjustments in the shape of the tongue (Fig. 7, Table VI).

Changes occurring after return to nasal breathing

Following removal of the nasal airway obstruction, the rhythmic discharges in the suprahyoid and tongue muscles disappeared. In most of the animals, tonic discharges did not disappear and were recorded in the geniohyoid, genioglossus, and lip-elevator muscles as long as 1 year after restoration of nasal breathing (Table I).

The experimentally induced increases in the palatal, occlusal, and mandibular plane angles measured to SN were reversed during the postexperimental period. The anterior face height continued to increase, but in this period the rate of increase was not significantly different from that of the control group.

During the postexperimental period the anterior crossbites that had developed during the experimental period were reduced but not fully corrected. The anterior open bite that developed in two of the animals persisted throughout the postexperimental period. The

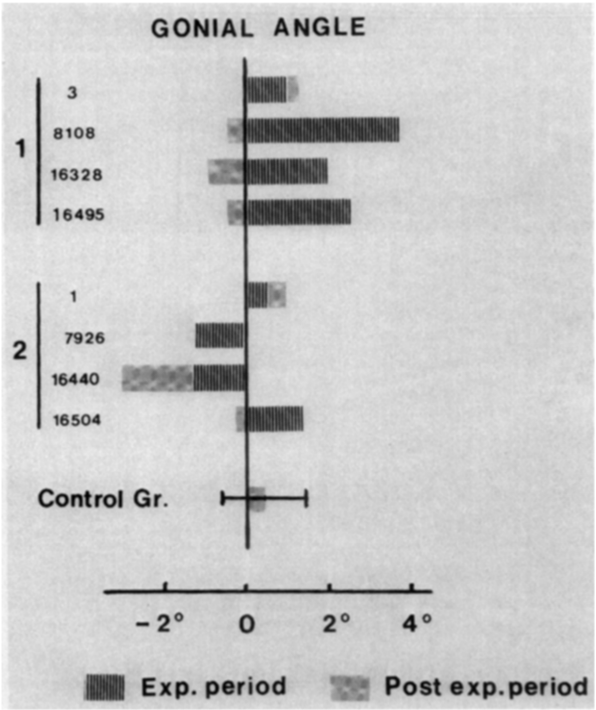

Fig. 6. Adjusted rate of change in the gonial angle during the experimental and postexperimental periods.

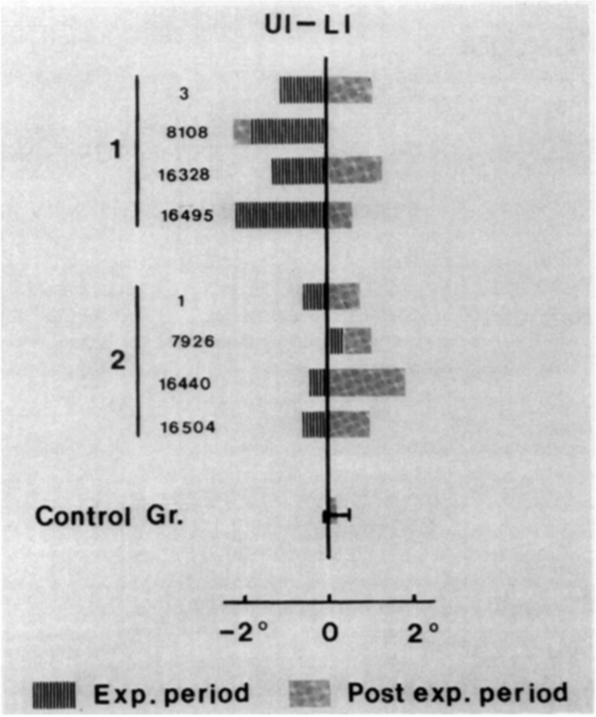

Fig. 7. Adjusted rate of change in the distance between the incisal edges of the maxillary and mandibular incisors measured along the occlusal plane.

midline shifts and malpositions of individual teeth were not self-corrected.

CONCLUSION

The changes in neuromuscular recruitment patterns, which were necessary to establish and maintain an oral airway, resulted in altered soft-tissue and skeletal morphology. The extent of the skeletal changes appeared to depend on the degree of soft-tissue alterations. In the animals with the most marked morphologic tongue changes, the skeletal and dental changes tended to be less than in the other animals. Specific neuromuscular changes as recorded by our EMG technique could not be directly related to specific changes in morphology.

All of the animals had similar degrees of nasal obstruction, but they demonstrated a wide range in morphologic adaptation. The degree of morphologic change, therefore, does not depend on the amount of air that flows through the mouth or nose, as has been suggested by some authors.[34, 35] Rather, it depends on the nature of the neuromuscular and soft-tissue adaptations.[20, 23, 26, 36] The same is true in human beings, where a great variation in soft-tissue and skeletal morphology can be observed in response to complete nasal airway obstruction (Crouzon's syndrome, Apert's syndrome, choanal atresia) as well as in response to partial nasal airway obstruction.

The data demonstrate a wide individual variation in response to an identical stimulus. In assessing the contribution of oral respiration to the development of certain dental malocclusions and facial morphologies, the clinician should be aware of the great variation in individual response to similar stimuli.

REFERENCES

1. Avis V: The significance of the angle of the mandible: an experimental and comparative study. Am J Phys Anthropol **19:** 55-61, 1961.
2. Boyd TG, Castelli WA, Huelke D: Removal of the temporalis muscle from its origin: effects on the size and shape of the coronoid process. J Dent Res **46:** 997-1001, 1967.
3. Charlier JP, Petrovic A, Herrman-Stutzman J: Effects of mandibular hyperpropulsion on the prechondroblastic zone of young rat condyle. AM J ORTHOD **55:** 71, 1969.
4. Gardner DE, Luschei ES, Joondeph DR: Alterations in the facial skeleton of the guinea pig following a lesion of the trigeminal motor nucleus. AM J ORTHODONT **78:** 66-80, 1980.
5. Horowitz SL, Shapiro HH: Modification of mandibular architecture following removal of the temporalis muscle in the rat. J Dent Res **30:** 276-280, 1951.
6. Horowitz SL, Shapiro HH: Modification of skull and jaw architecture following removal of the masseter muscle in the rat. Am J Phys Anthropol **13:** 301-308, 1955.

7. McNamara JA Jr: Neuromuscular and skeletal adaptation to altered function in the orofacial region. AM J ORTHOD **64:** 578-606, 1973.
8. Moss ML: Extrinsic determination of sutural area morphology. Acta Anat **44:** 263-272, 1961.
9. Moss ML, Simon M: Growth of the human mandibular angular process: a functional cranial analysis. Am J Phys Antropol **28:** 127-138, 1968.
10. Moss ML: The regulation of skeletal growth. *In* Regulation of organ and tissue growth, New York, 1972, Academic Press, Inc., pp. 127-142.
11. Moss ML, Moss-Salentijn L: The muscle-bone interface: an analysis of morphological boundary. *In* Carlson, DS, McNamara JA Jr (editors): Muscle Adaptation in the Craniofacial Region, Monograph 8, Craniofacial Growth Series, Ann Arbor, 1978, Center for Human Growth and Development, University of Michigan.
12. Nanda KS, Merow WW, Sassouni V: Repositioning of the masseter muscle and its effect on skeletal form and structure. Angle Orthod **37:** 304-308, 1967.
13. Petrovic AG, Strutzmann JJ, Oudet CL: Control processes in the postnatal growth of the condylar cartilage of the mandible. *In* McNamara JA Jr (editor): Determinants of Mandibular Form and Growth, Ann Arbor, 1975, University of Michigan, pp. 101-153.
14. Sarnat BG, Feigenbaum JA, Krogman WM: Adult monkey coronoid process after resection of trigeminal nerve motor root. Am J Anat **150:** 129-137, 1977.
15. Soni NN, Malloy RB: Effect of removal of the temporalis muscle on the coronoid process in guinea pigs: quantitive triple flourochrome study. J Dent Res **53:** 474, 1974.
16. Washburn SL: The effect of removal of the zygomatic arch in the rat. J Mammal **27:** 169, 1946.
17. Washburn SL: The relation of the temporal muscle to the form of the skull. Anat Rec **99:** 239-248, 1947.
18. Harvold EP: The role of function in the etiology and treatment of malocclusion. AM J ORTHOD **54:** 883-898, 1968.
19. Harvold EP, Chierici G, Vargervik K: Experiments on the development of dental malocclusions. AM J ORTHOD **61:** 38-44, 1972.
20. Harvold EP, Vargervik K, Chierici G: Primate experiments on oral sensation and dental malocclusion. AM J ORTHOD **63:** 494-508, 1973.
21. Chierici G, Harvold EP, Vargervik K: Morphogenetic experiments in cleft palate: mandibular response. Cleft Palate J **10:** 51-61, 1973.
22. Chierici G, Harvold EP, Vargervik K: Morphogenetic experiments in facial asymmetry: the nasal cavity. Am J Phys Anthropol **38:** 291-299, 1973.
23. Harvold EP: Neuromuscular and morphological adaptations in experimentally induced oral respiration. *In* McNamara JA Jr (editor): Nasorespiratory function and craniofacial growth, Craniofacial Growth Series, Monograph 9, Ann Arbor, 1979, Center for Human Growth and Development, University of Michigan, pp. 149-164.
24. Miller AJ, Vargervik K: Neuromuscular changes during long-term adaptation of the rhesus monkey to oral respiration. *In* McNamara JA Jr (editor): Nasorespiratory function and craniofacial growth, Craniofacial Growth Series, Monograph 9, Ann Arbor, 1979, Center for Human Growth and Development, University of Michigan, pp. 1-26.
25. Miller AJ, Vargervik K: Neuromuscular adaptations in experimentally induced oral respiration in the rhesus monkey *(Macaca mulatta)*, Arch Oral Biol **25:** 579-589, 1980.
26. Harvold EP, Tomer B, Vargervik K, Chierici G: Primate experiments on oral respiration. AM J ORTHOD **79:** 359-372, 1981.
27. Miller AJ, Vargervik K, Chierici G: Sequential neuromuscular changes on rhesus monkeys during the initial adaptation to oral respiration. AM J ORTHOD **81:** 99-107, 1982.
28. Tomer BS, Harvold EP: Primate experiments on mandibular growth direction. AM J ORTHOD **82:** 114-119, 1982.
29. Harvold EP, Vargervik K: Morphogenetic response to activator treatment. AM J ORTHOD **60:** 478-490, 1971.
30. Harvold EP: The activator in interceptive orthodontics, St. Louis, 1974, The C.V. Mosby Company.
31. Harvold EP: Altering craniofacial growth: force application and neuromuscular-bone interaction. *In* McNamara JA Jr (editor): Altering craniofacial growth, Monograph 13, Craniofacial Growth Series, Ann Arbor, 1983, Center for Human Growth and Development, University of Michigan.
32. Miller AJ, Chierici G: The bilateral response of the temporal muscle in the rhesus monkey *(Macaca mulatta)* to short term detachment of the muscle and increased loading of the mandible. J Dent Res **56:** 1620-1628, 1977.
33. Solow B, Greve E: Craniocervical angulation and nasal respiratory resistance. *In* McNamara JA Jr (editor): Naso-respiratory function and craniofacial growth, Monograph 9, Craniofacial Growth Series, Ann Arbor, 1979, Center for Human Growth and Development, University of Michigan, pp. 87-119.
34. O'Ryan FS, Gallagher DM, La Blanc JP, Epker BN: The relation between nasorespiratory function and dentofacial morphology; a review. AM J ORTHOD **82:** 403-410, 1982.
35. Vig PS, Sarver DM, Hall DJ, Warren DW: Quantitative evaluation of nasal airflow in relation to facial morphology. AM J ORTHOD **79:** 263-272, 1981.
36. Vig PS: Respiratory mode and morphological types: some thoughts and preliminary conclusions. *In* McNamara JA Jr (editor): Naso-respiratory function and craniofacial growth, Monograph 9, Craniofacial Growth Series, Ann Arbor, 1979, Center for Human Growth and Development, University of Michigan, pp. 233-250.

Reprint requests to:
Dr. Karin Vargervik
Craniofacial Center S-747
University of California
San Francisco, CA 94143