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Dr. Harvold

Primate experiments on oral respiration

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Oral respiration associated with obstruction of the nasal airway is a common finding among patients seeking orthodontic treatment. The primate experiments reported here are part of a series designed to test some of the current hypotheses regarding the relationship between mouth breathing and dental malocclusions, that is, between deviations in orofacial muscle recruitment and jaw morphogenesis. Mouth-breathing was developed in the animals of this experiment by obstruction of the nasal passages with silicon nose plugs. The experiments showed that the monkeys adapted to nasal obstruction in different ways. In general, the experimental animals maintained an open mouth. Some increased the oral airway rhythmically, while others maintained the mandible in a lower position with or without protruding the tongue. All experimental animals gradually acquired a facial appearance and dental occlusion different from those of the control animals. From these and the previously reported primate experiments in this laboratory, it can be deduced that orthodontic appliances in general affect the morphology of the orofacial structure in two ways: by direct force and by sensory stimulation. (1) The appliance exerts a direct physical force which alters the strain distribution in the bone and elicits bone remodeling and tooth movement. (2) The presence of the appliance initiates sensory input which triggers a neuromuscular response. This change in neuromuscular activity, in turn, affects both muscle development and bone remodeling. The fixed orthodontic appliance may work mainly on the first principle. Certain removable appliances may have a significant effect based on the second principle.

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The frequently observed association between oral respiration and dental malocclusion has been reported by many investigators. In 1956, for example, Brash[1] reveiwed earlier experimental and clinical studies. Linder-Aronson,[2] in 1979, discussed the subject and presented his own extensive studies on nasal obstruction and its influences on human cranial growth. The clinical observations suggest that a rather close association exists between nasal obstruction, oral respiration, and dental malocclusion, but a direct cause-and-effect relationship in the human being has not been established.

Animal experiments in this laboratory[3-5] have shown that induced nasal obstruction in healthy rhesus monkeys leads to oral respiration and subsequently to changes in both the facial skeleton and the dentition. However, even though their noses were blocked by the same method and at the same age, the animals did *not* develop the same type of dental malocclusions. It was evident that the response to nasal obstruction differed considerably among the animals. It appeared that, under the pressure of the respiratory drive, each animal would find its own most convenient way to secure the oral airflow and then develop a dental malocclusion in accordance with this new function.

This assumption can be expressed as follows: The changes in the facial skeleton and the developing dental malocclusion which is caused by oral respiration depend on which muscles are recruited and how they are used in the deviant respiratory pattern. It is recognized that the craniofacial muscles are involved in a series of functions, of which the more important may be head movements, posture, mastication, deglutition, speech, facial expressions, and grimaces. The question is posed: Under which circumstances will the additional activity of respiration change the muscles sufficiently to produce an abnormal jaw morphology and tooth position? Presumably, an increase in craniofacial muscle activity will not, in itself, necessarily cause a deviant development of the jaws and facial skeleton. Now that a series of experiments has been completed, the latest observations can be reported and the over-all findings discussed.

Material

The rhesus monkey, *Macaca mulatta,* was used as a model in all experiments. Forty-two animals, of which four were females, ranged in age from 2 to 6 years. Age and sex distributions are shown in Table I. All animals were born at the Center for Primate Biology, University of California, Davis.

Design

The animals were arranged in pairs on the basis of sex and maximum similarity in facial morphology, age, and size. One of each pair was designated the experimental animal, and the other served as the control. Before and after the experiment, the recorded data were analyzed by standard statistical methods for intrapair and group differences.

Method

Each animal was given 15 mg./kg. Ketalar intramuscularly in the cage and 1 c.c./kg. 50 percent Nembutal intravenously in the operating room when subjected to any procedure

Table I. Age and sex of animals at onset of experiments

	*Age (yr.)**				
	2	*3*	*4*	*5*	*6*
Males	18	10	2	6	2
Females		2	2		

*Ages 2 to 4 years correspond to the late deciduous and mixed-dentition stages.

except electromyographic recordings. At the onset, metal bone markers were placed in the jaws and skull as previously described.[5] The nasal airway was blocked in the experimental animals. The control animals were not subjected to any special procedures except record taking.

Records were taken at 3-month intervals during the experiment and every 6 months after the nose was reopened. The records included cephalometric roentgenograms in five projections, photographs of the face and dentition, casts of the dentition, and body weight. Electromyographic recordings were made at separate times as described by Miller and Vargervik.[6] The fabrication and secure placement of the nose plugs represent a critical part of the method. Soft, hollow, cone-shaped silicon plugs, approximately 1 cm. long and cast to fit the individual nares, were used. The plugs were held in position by a silk ligature through the septum. The plugs obstructed inspiration but allowed some air to escape during expiration.

Findings

The soft-tissue changes recorded on the photographs were not measured, but the following morphologic changes were noted:

Lips. The animals in the control group kept their lips together most of the time, and the closed mouth presented the postural position shown in Fig. 1. The experimental animals kept their mouths open after the nasal airway was blocked. During the first month of oral respiration, lip and jaw movements varied considerably. Later, oral respiration occurred in a relaxed fashion, and all animals in the experimental group kept their lips apart. The lips made occasional contact or separated more with respiratory movements.

All mouth breathers showed a tendency to develop a notch in the upper lip. The notch corresponded to the special muscle activity in the lip elevators described by Miller and Vargervik.[6] The notch was marked in some animals, particularly Animal 6992 (Fig. 2), which frequently kept the mandible in a steady, low forward position. Animal 7042 consistently kept the tongue protruding between the separated lips so that the lip-tongue combination formed an oral opening (Fig. 3). Animal 8108 (Fig. 4) also developed a marked notch in the lip. In this case, however, the protruding tongue occupied the notch most of the time.

Usually the notch in the upper lip gradually disappeared when the animal resumed nasal respiration (Fig. 2). Animal 8108 still had a notch in the lip, occupied by the protruding tongue, 1 year after nasal respiration had been restored, and Animal 16496 continued mouth breathing after the plugs were removed; however, these were exceptions (Figs. 4 and 5).

Tongue. Only the expected growth changes in the tongue were observed in the control

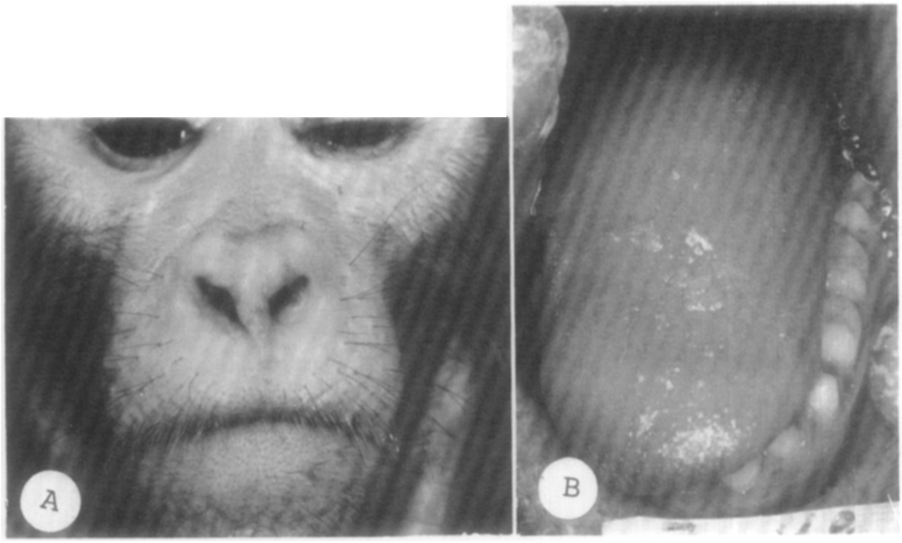

Fig. 1. Normal postural positions of lips **(A)** and tongue **(B)**. The photographs are not of the same animal. The lips pictured are those of a former mouth-breathing animal which now has resumed nasal respiration.

group. The normal contact between the dorsum of the tongue and the soft palate was maintained, obstructing the view of the uvula and the oropharyngeal isthmus (Fig. 1). In all animals in the experimental group, the dorsal section of the tongue became thinner, usually creating an open passage to the pharynx (Fig. 2). It appeared that the morphology and elevation of the soft palate and uvula were also changed in the experimental group. This feature is being studied in a new experiment.

The changes observed in the middle and front of the tongue showed considerable variability. In Animals 6992 and 16440, the tongue became long and narrow (Figs. 2 and 6). Animal 7042 developed one groove down the midline of the protruding tongue (Fig. 3). In Animal 6848 one groove developed on each side of the tongue, extending from the tip to the pharyngeal section and establishing two tubes of airflow (Fig. 7, *C*). Animal 6830 developed three longitudinal grooves (Fig. 7, *B*).

A tendency to develop a median groove in the tongue was found in several experimental animals. Another typical feature seen in several animals was enlargement of the midsection of the tongue, combined with a pointed tip. In a few animals a flattening of the upper surface and the edges of the tongue occurred (Figs. 6, *A* and 7, *B*).

In all instances the changes in the shape of the tongue served to secure an oral airway. The changes in tongue morphology were evident when the animals were anesthetized and respiration was unobstructed. The shapes were not influenced by muscle activity in the tongue when the photographs were taken and the notations were made. The shapes of the tongues returned to normal within a few months after nasal respiration had been restored at the end of the experiment (Fig. 3).

Dentition. The dentition developed normally in the control animals. Maximum occlusal contact was established when the mandible was near the most retruded position, that is, centric relation. The changes in the dentition of the experimental animals were

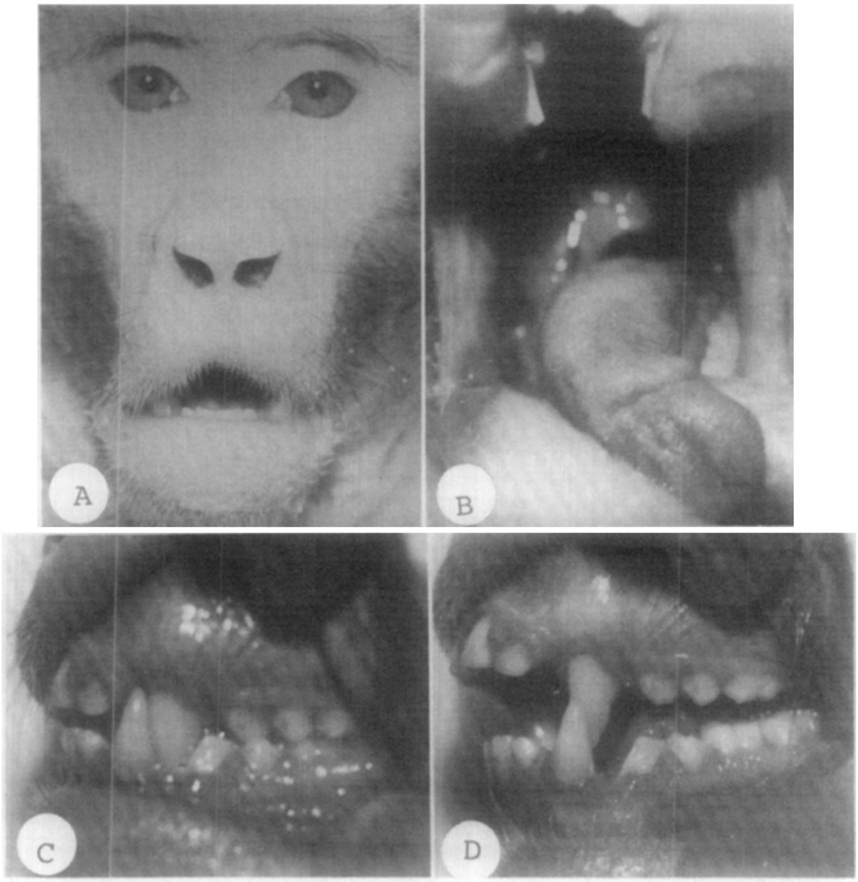

Fig. 2. Three years of oral respiration caused a notch in the upper lip and an open mouth posture (**A**), as well as a long and slender tongue with midline groove, an open pharyngeal port, and a dental malocclusion (**B**). The forward positioning and the rhythmic movements of the mandible produced a dual bite (**C** and **D**).

similar to those described in the previous experiment on oral respiration.[5, 9] The common finding was a *narrowing* of the *mandibular* dental arch and a decrease in maxillary arch length, causing an *incisor cross-bite*. Animal 7042 developed the most severe dental malocclusion of this type, a full Class III according to Angle's classification (Fig. 3).

Some animals developed other types of malocclusion. The permanent maxillary canines erupted into cross-bite in Animal 6992 but showed a strong tendency to upright themselves after the nasal respiration had been restored and the animal could again keep its mouth closed (Fig. 2). Animal 8108 developed a severe open-bite, but a neutral molar relationship was maintained (Fig. 4), while animal 16440 developed a maxillary overjet and overbite with a tendency toward a Class II molar relationship (Fig. 6).

Mandibular movements. In all control animals optimal dental occlusion was obtained with the mandible near its most retruded position. In the experimental animals with a Class II tendency there was a dual bite. The most severe was in Animal 6992 (Fig. 2),

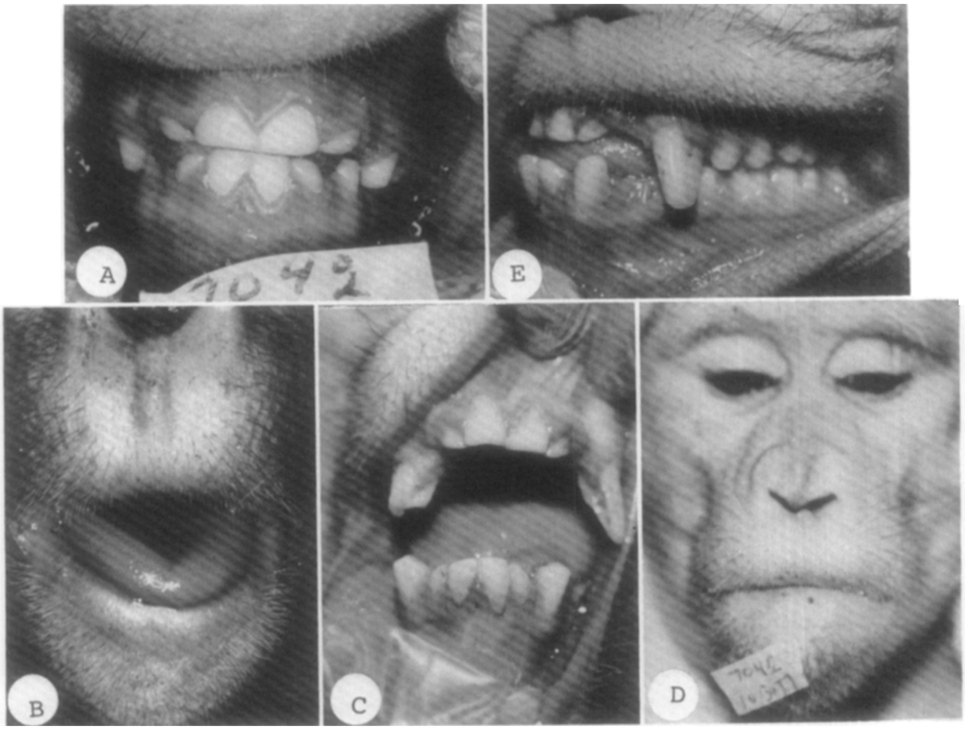

Fig. 3. Young adult animal **(A)** responded to nasal obstruction by placing the mandible downward and forward with the tongue below the maxillary teeth. A notch in the upper lip and a midline groove in the tongue developed and provided the oral airway **(B)**. Lip and tongue returned to normal when nasal respiration was resumed (**C** and **D**), but the dental malocclusion was retained **(E)**.

where the teeth could not make occlusal contact with the mandible in the retruded position because of canine interferences. Thus, oral respiration can *induce* mesioclusion, maxillary protrusion with distoclusion, open-bite, and dual bite.

Cephalometric measurements. The control and experimental data obtained at the onset of the experiment, which lasted 3 years, were compared for base line assessment. The experimental group had slightly larger jaws than the control group, as indicated by measurements 2, 3, and 5 (Table II). Otherwise, there was no significant difference. During the experiment, the increments were significantly larger in the experimental group for linear measurements 5 and 7 and for angular measurements 8, 10, and 12. A significant difference in one of these measurements could have been expected to be due to chance alone.

The two independent sample t tests performed on rates of change of dimension values to a measure of size (dimension 4, TM-symphysis = mandibular length) showed that the ratio of TM-prosthion to TM-symphysis was significantly different in the two groups. The ratio of face height to TM-symphysis was not significantly different.

Electromyographic and behavioral findings. At the time the installation of the electromyographic instruments in the laboratory was completed, the animals in one group of eight pairs had been mouth breathers for 3 years. Another group of sixteen pairs was

Fig. 4. The animal lowered the mandible and protruded the tongue. Eighteen months of mouth breathing produced a notch in the upper lip **(A)** and a severe open-bite **(B)**.

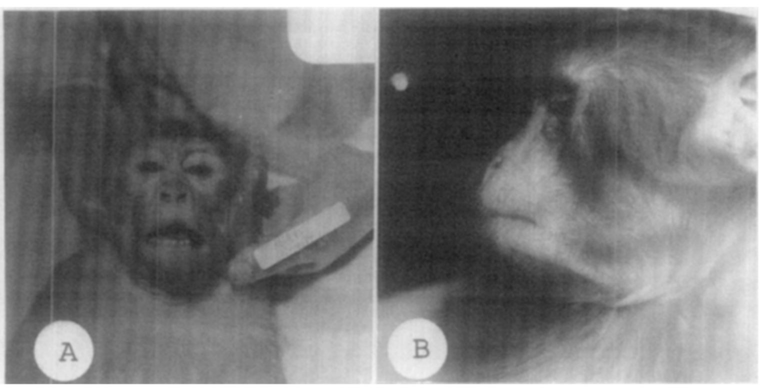

Fig. 5. This animal developed a notch in the lip and an open-mouth posture **(A)**. Mouth breathing continued 1 year after the nose was reopened, and the facial features were retained **(B)**.

started. The experiment lasted for 18 months with oral respiration, followed by 1 year of restored nasal respiration. In the first group the animals with a well-developed oral airway showed less active movement than animals with more normal features. The movements served to increase the established oral airway by lowering the jaw, protruding the tongue, and elevating the upper lip in various combinations (Table III).

The other group of experimental animals, which were studied electromyographically from the onset of the experiment, also demonstrated a variety of breathing patterns. For the group, however, it could be established that the genioglossus and intrinsic tongue muscles were rhythmically recruited for tongue protrusion and the lip elevator increased the mouth opening. The geniohyoid and diagastric muscles were recruited for lowering the mandible. The anterior part of the temporal muscles and the lateral pterygoid muscles were used for advancing the mandible.

The mouth breathers demonstrated increased tonic activity in the tongue and in the upper and lower lips, as well as in the medial and lateral pterygoid muscles (Table IV).

Further details on muscle recruitment have been described by Miller and Vargervik.[6]

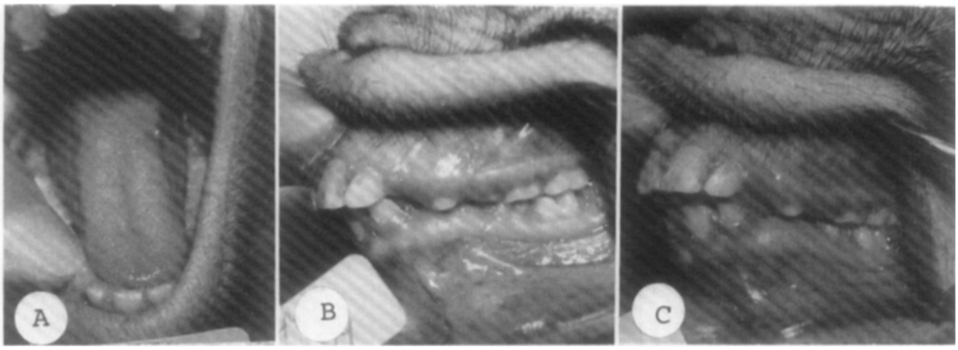

Fig. 6. This animal developed a flattening of the upper surface and at the edges of the tongue, providing three channels for airflow **(A)**. An incisor overjet, a dual bite, and a mild Class II malocclusion characterized the dentition (**B** and **C**).

Table II. Comparison of cephalometric measurement from the control and experimental groups after 3 years of oral respiration with seven pairs of animals (Wilcoxon signed rank test)

	Before experiment		*During experiment*	
Dimension	*Group in which dimension was larger*	*Two-tailed P*	*Group in which increments were larger*	*Two-tailed P*
1. Sella-nasion	E	0.25	C	0.094
2. Sella-prosthion	E	0.047	C	0.218
3. T.M.—prosthion	E	0.016*	C	0.078
4. T.M.—mandibular symphysis	E	0.031*	C	1.000
5. Nasion—palatal plane	E	0.44	E	0.016*
6. M. symphysis—palatal plane	E	0.094	E	0.44
7. Nasion—M. symphysis	E	0.063	E	0.031*
8. Angle S-N, palatal plane	E	0.69	E	0.031*
9. Angle S-N, occlusal plane	E	0.43	E	0.30
10. Angle S-N, lower mandibular border	C	0.94	E	0.016*
11. Angle posterior ramus border, S-N	E	0.84	E	0.38
12. Gonial angle	C	0.47	E	0.031*

E = Experimental.
C = Control.
*Statistically significant.

Discussion

The objectives of these experiments were twofold: (1) To test the effect of recruitment of orofacial muscles for respiration on the shape of the jaws and the relation between them and the position of the teeth and (2) to relate respiratory movement patterns and changes in posture to changes in skeletal morphology and tooth position. Could a distinction in morphogenic impact be made between induced rhythmic movements at the usual respiration rate and induced change in postural position? This was a central question.

During the first month of oral respiration the animals consistently kept their mouths

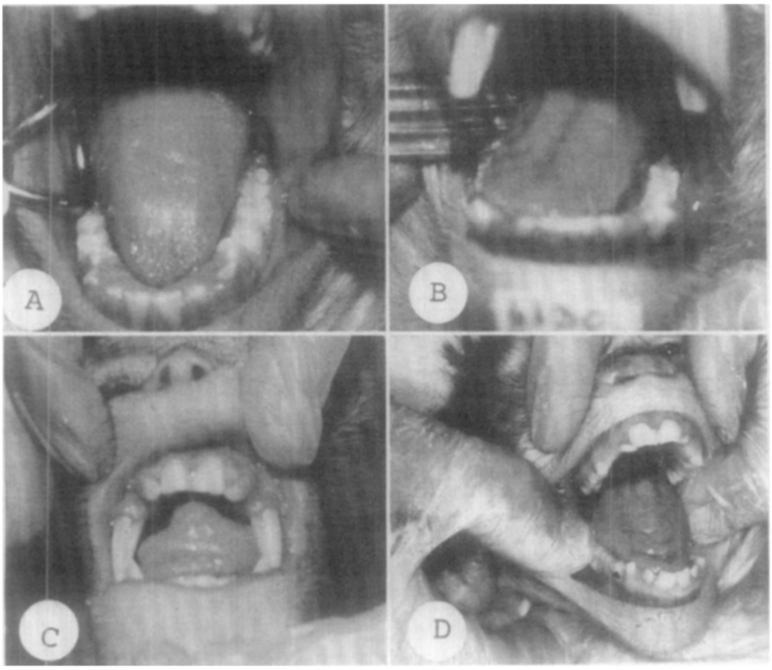

Fig. 7. Some samples of tongue changes associated with oral respiration.

open and protruded their tongues. The attempt to maintain an open oral airway was associated with increased activity in the muscles of the face and tongue and those controlling the position of the mandible. These continuously changing movements of the lip, tongue, and mandible occurred simutaneously with the rhythmic movements connected with each breath. The usual voluntary and involuntary movements of mouth opening and closing also took place. The sudden changes in lip, tongue, and jaw position and the rhythmic movements distinguished the experimental animals from the controls. The activity of the experimental animals was so erratic that no meaningful data could be recorded during this initial period.

After a few weeks the lips remained separated in the experimental animals, and the upper lip showed rhythmic movements as well as increased tonic activity. Similar lip activity occasionally occurred in the control animals, but with no morphologic consequences. All experimental animals tended to develop a midline notch in the upper lip. The most striking manifestations of this tendency were observed in Animal 8108 of the younger group (Fig. 4) and in Animal 6992 of the older group (Fig. 2). These animals also showed both rhythmic and increased tonic activity in the lip's elevator muscles. Therefore, the notching could not be linked to any particular type of activity. Only the cause-and-effect relationship between altered muscle activity and notching was established. The notch disappeared when nasal respiration was restored and the deviant rhythmic and tonic activities were discontinued. Only one, Animal 16495, continued with oral respiration one year after the nose plugs were removed, and the notch became marked (Fig. 5).

The tongue changes in the experimental animals were more complex, although a distinction may be made between the formation of a long and slender tongue (Fig. 2) and

Table III. Muscles showing rhythmic movements and the associated behavioral characteristics after 3 years of mouth breathing in eight animals

Animal	*Suprahyoid muscle group*	*Lip elevators*	*Genioglossus muscle*	*Anterior temporalis muscle*
1	Y	X	O	O
2	Y	O	O	O
3	O	X	X	O
4	O	O	O	O
5	O	X	X	X
6	O	X	X	X
7	X	O	X	X
8	Y	O	X	O
Animal	*Rhythmic movements of jaws*	*Raising of upper lip*	*Protrusion of tongue*	*Notching of upper lip*
1	O	X	O	O
2	Y	O	O	X
3	O	X	O	X
4	Y	O	O	O
5	X	X	X	O
6	X	Y	Y	X
7	X	O	X	O
8	O	O	Y	O

No rhythmic muscle recruitment or movements were observed in the seven control animals. One control animal was lost before the final recordings.
Key to symbols:
X = Rhythmic.
Y = Rhythmic occasionally.
O =Normal behavior.

the formation of longitudinal grooves in the tongue (Fig. 7). The continuous forward positioning of the tongue, as well as the rhythmic protrusion, could serve to produce a tongue that was longer and more slender.

The longitudinal grooves, on the other hand, were probably not a result of gross rhythmic respiratory movements. It appeared more likely that the select muscle activity in the tongue, which resulted in groove formations, was under the influence of another centrally controlled sensory feedback system linked to respiration. For example, the animals may have attempted to find the most convenient tongue position that would allow respiration with minimal tongue and jaw movements. This possibility would be consistent with the observations in previous experiments. In the latter, tactile sensation of a plastic insert in the palatal vault caused grooves across the tongue and it is unlikely that the animals could have produced these grooves on a voluntary basis.[3]

It would appear that continuous sensory stimulation, either tactile or through central pathways, occurring when the animal tried consciously, and probably unconsciously as well, to accommodate oral respiration without rhythmic movements had a significant effect on muscle development. This may apply to both the upper lip and the tongue. Strands of fibers within the tongue muscles might be selectively activated and cause changes in the morphology, as illustrated in Fig. 7. The most severe changes in skeletal

Table IV. Muscles showing increased rhythmic and tonic activity in the experimental animals in response to 18 months of nasal obstruction*

Muscles	Rhythmic	Tonic
Face		
Lip elevator	X	
Superior orbicularis oris		X
Inferior orbicularis oris		X
Tongue		
Genioglossus	X	
Dorsal fibers	X	X
Suprahyoid		
Geniohyoid	X	
Digastric	X	
Masticatory muscles		
Anterior temporalis	X	
Medial pterygoid		X
Lateral pterygoid	X	X

For details, see Miller and Vargervik.[6]

morphology and tooth position were associated with the grooving and forward positioning of the tongue. Further study of the recruitment of tongue muscles and the sequence of changes in muscle activity associated with grooving are in progress.

The changes in face height (nasion–palatal plane, symphysis–palatal plane) and the alterations in mandibular morphology were most extreme in those animals that acquired a low postural position of the mandible. The lowering of the mandible for oral respiration was followed by a downward displacement of the maxilla and also by an increased extrusion of the teeth. The respiratory drive may initially cause the mandible to assume a lower position. The subsequent downward maxillary displacement and tooth extrusion would limit mandibular movements in an upward direction, both physically and by proprioceptive sensory input, particularly in the periodontal system.

The relative significance of the various sources of sensory input to the motoneuron pool for mandibular positioning could not be determined by these experiments. It was established, however, that the remodeling of the bones was most pronounced in the animals with a more consistently low postural position. When an animal was sitting in the recording chair, the low chin position could be established without increased activity in any particular muscle. The animals which relied mainly on *rhythmic* changes in jaw position showed the *least* changes in jaw morphology and dental occlusion.

The lowering of the chin for oral respiration gradually resulted in a steeper mandibular plane and a more open gonial angle. The posterior border of the mandibular ramus did not change inclination, demonstrating that this part of the bone would undergo remodeling as the chin assumed a lower position (Table II, dimension 10). The changes at the lower border of the mandible also were slightly different in the experimental animals. When the bony contour was related to the metal markers, there was more bone resorption at the gonion and antegonial notch in the experimental animals than in the control group.

It was apparent that the changes in mandibular shape and the direction of mandibular growth (the forward or backward rotation) were dependent on the altered activity in the *facial* and *neck* muscles suspending the anterior part of the mandible and the chin. The powerful muscles of mastication, on the other hand, were relatively unaffected by the additional task of respiratory activity. They maintained the original shape and position of the ramus and gonial region through gradual remodeling.

There was no indication in these experiments that the direction of bone apposition on the condyles was a primary factor in shaping the mandible. The apposition on the condyles continued toward the joints *independent* of chin position. A detailed discussion of the observed changes in mandibular growth will be presented in a separate publication.

The developing dual bite in the experimental animals merits special interest since the cause of dual bite in human beings is obscure. The electromyographic recordings revealed that the mouth breathers frequently had increased tonic activity in both the medial and the lateral pterygoid muscles. These muscles, as well as the anterior temporalis muscles, also demonstrated rhythmic respiratory activity. The tonic activity would place the mandible in a forward position. In order to cause a dual bite, however, the maxillary dentition also must come *forward.* This can be accomplished by occlusal forces as well as by the advanced tongue position associated with protrusion of the mandible.

Since all experimental animals demonstrated an open-mouth posture and gradually developed some type of malocclusion, it appears that the initial ideal *occlusion* could *not* be secured by occlusal interdigitation. The *tongue,* on the other hand, *could* maintain sufficient contact with the maxillary teeth and alveolar process to effect a forward positioning. Concurrently, respiration was secured by rhythmic lowering of the mandible or through longitudinal grooves in the tongue. Supporting this assumption is the observation that the other animals which positioned the mandible downward and forward, with the tongue below the maxillary incisors developed a Class III malocclusion. In these animals forward growth of the maxilla was markedly reduced (Fig. 3).

No significant change in growth in mandibular length was found in those experimental animals whose jaws were in a protruding position. Reporting on a few experimental primates, Ramfjord and Enlow[7] observed that prolonged forced *protrusion* of the mandible had *little* effect on mandibular growth. McNamara and Carlson,[8] using the same method as Ramfjord and Enlow, found a *temporary* increase in condylar cartilage proliferation with a microscopic increase in thickness. These findings demonstrate that the condylar cartilage and its underlying bone have the *potential* to respond to a prolonged protrusion of the mandible by increased proliferation. However, both the experiments of Ramfjord and Enlow and those reported here indicate that over several months *adaptive* changes in the *maxilla* and probably at the *base* of the skull *release* the tension on the joints. *No* lasting alteration has been traced to the length of the mandible.

A distinction must be made between experiments that induce a forced protrusion of the mandible by covering the teeth with casts, which alters the proprioceptive input through the periodontal system,[7, 8] and experiments on oral respiration. Most important, the animals may cope with nasal obstruction in different ways and, consequently, the distortions are not uniform. The resulting malocclusions, for example, include open-bites, Class II as well as Class III. A few traits—increased face height, steeper mandibular inclination, larger gonial angle, and an oral airway—are common to all. These characteristics can be identified statistically.

The relation between respiratory movement patterns, posture, and morphologic changes can be expressed as follows: Changes in mandibular form will occur when the lowering of the mandible is sufficiently consistent. Downward displacement of the maxilla and excessive extrusion of teeth may or may not be associated with the change in mandibular posture. The maxillary response is mainly determined by tongue posture and movements. Lower face height will *increase* significantly only when there is a downward displacement of the maxilla and/or excessive molar extrusion.

The significance of tooth extrusion suggests that the animals would be most susceptible to changes in jaw morphology during certain stages of dental development, particularly during eruption of the maxillary first, second, and third molars.

The relative influence of consistent rhythmic movements versus postural positioning on jaw morphology could not be determined by these experiments, for several reasons. The muscles that exhibited changes in tonic activity also showed rhythmic activity. The postural positions registered in the recording chair did not necessarily correspond to the preferred natural positions. Furthermore, any significant change in rhythmic as well as tonic activity may affect muscle hypertrophy and subsequent postural positioning. The relation between muscle activity and bone remodeling, therefore, is being studied in a different experimental model.[9]

Clinical findings by several investigators reveal that human beings with nasal obstructions develop certain traits similar to those found in the experimental animals. For example, Linder-Aronson,[2] Woodside and Linder-Aronson,[10] and Bushey[11] have established that nasal obstruction and mouth breathing are associated with increased face height and a steeper mandibular plane. The upper face height, determined by the distance from nasion to the anterior nasal spine, is *not* increased in the human face, but the hard palate *may* change form and inclination. Since the monkeys do *not* have an anterior nasal spine, upper face height is determined between nasion and the hard palate. The nasal cartilage between the anterior nasal spine and the ethmoid bone in the human face may hinder a downward displacement of the anterior part of the maxilla.

Human beings with a severely restricted airway, such as that seen in Crouzon's syndrome, usually develop longitudinal grooves in the tongue and an open pharyngeal port. Protrusion of the tongue and forward positioning of the mandible are also frequent findings in children who depend on oral respiration, particularly children who have small mandibles or neurologic deficits in the pharyngeal region. This active support of the respiratory function may decrease at night and cause sleep apnea. In the monkeys the rhythmic protrusion of tongue and mandible continued under light anesthesia but disappeared when anesthesia became deeper.

Like the monkeys, human beings may develop different ways to cope with nasal obstructions, and the morphologic deviations may *vary* accordingly.

Summary and conclusions

The primates in these experiments developed an oral airway in response to nasal obstruction. The response was not uniform among the animals. However, some traits were common: increased face height, steeper mandibular plane, and larger gonial angle. Various animals recruit different muscle combinations for rhythmic movements or for changing position of the lips, tongue, and mandible. The morphologic changes in the orofacial region, facial skeleton, and dental occlusion did vary accordingly.

It is *unlikely* that a correlation can be established between oral respiration and a particular type of dental malocclusion. On the other hand, it can be postulated that increased tonic activity in certain muscles and a specific change in jaw positioning may cause corresponding bone remodeling, which should be predictable. This hypothesis is presently subjected to testing in the laboratory.

We may assume that the human being is as resourceful as the monkey when forced to establish an oral airway. The human mouth breather may also present a variety of symptoms, ranging from normal appearance to severe skeletal and dental irregularities. Nasal obstruction presents the trigger factor, but it is the deviant muscle recruitment which causes maldevelopment. Therefore, the diagnosis and treatment of such conditions require, first of all, a clinical method for identification and assessment of orofacial muscle recruitment similar to the method described by Miller and Vargervik.[6]

REFERENCES

1. Brash, J. C.: The etiology of irregularity and malocclusion of teeth, London, 1956, Dental Board of the United Kingdom.
2. Linder-Aronson S.: Naso-respiratory function and craniofacial growth. *In* McNamara, James A., Jr. (editor): Naso-respiratory function and craniofacial growth, Monograph No. 9, Craniofacial Growth Series, Center for Human Growth and Development, Ann Arbor, 1979, The University of Michigan, pp. 121-147.
3. Harvold, E. P.: The role of function in the etiology and treatment of malocclusion, AM. J. ORTHOD. **54:** 883-898, 1968.
4. Harvold, E. P., Chierici, G., and Vargervik, K.: Experiments on the development of dental malocclusions, AM. J. ORTHOD. **61:** 38-44, 1972.
5. Harvold, E. P., Vargervik, K., and Chierici, G.: Primate experiments on oral sensation and dental malocclusion, AM. J. ORTHOD. **63:** 494-508, 1973.
6. Miller, A. J., and Vargervik, K.: Neuromuscular changes during long-term adaptation of the rhesus monkey to oral respiration. *In* McNamara, James A., Jr. (editor): Naso-respiratory function and craniofacial growth, Monograph No. 9, Craniofacial Growth Series, Center for Human Growth and Development, Ann Arbor, 1979, The University of Michigan, pp. 1-26.
7. Ramfjord, S. P., and Enlow, R. D.: Anterior displacement of the mandible in adult rhesus monkeys: Long-term observations, J. Prosthet. Dent. **26:** 517-531, 1971.
8. McNamara, J. A., Jr., and Carlson, D. S.: Quantitative analysis of temporomandibular joint adaptations to protrusive function, AM. J. ORTHOD. **76:** 593-611, 1979.
9. Harvold, E. P.: Neuromuscular and morphological adaptations in experimentally induced oral respiration, *In* McNamara, James A., Jr. (editor): Naso-respiratory function and craniofacial growth, Monograph No. 9, Craniofacial Growth Series, Center for Human Growth and Development, Ann Arbor, 1979, The University of Michigan, pp. 149-164.
10. Woodside, D. G., and Linder-Aronson, S.: The channeling of upper and lower anterior face heights compared to population standard in males between ages 6 to 20 years, Eur. J. Orthod. **1:** 25-40, 1979.
11. Bushey, R. S.: Adenoid obstruction of the nasopharynx. *In* McNamara, James A., Jr. (editor): Naso-respiratory function and craniofacial growth, Monograph No. 9, Craniofacial Growth Series, Center for Human Growth and Development, Ann Arbor, 1979, The University of Michigan, pp. 199-232.