Original Article

A Cineradiographic Study of Deglutitive Tongue Movement and Nasopharyngeal Closure in Patients with Anterior Open Bite

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Abstract: The purpose of this study was to investigate the movement of the tip and the dorsal surface of the tongue during deglutition in patients with anterior open bite using cineradiography. The subjects were 10 female patients with anterior open bites and 10 female controls with normal overbites. By cineradiography we established 7 stages of tongue movement and bolus position during deglutition and analyzed the tongue position, tongue movement and the time. The tongue-tip position was more protrusive during deglutition in anterior open bite than in the controls. After the head of the bolus arrived at the opening of the esophagus, the rear part of the dorsal surface of the tongue demonstrated slower movement in patients with anterior open bite than in controls. The nasopharynx closed earlier in patients with anterior open bite than in controls. It is suggested that anterior open bite patients had compensatory coordination of tongue movement, soft palate movement and pharyngeal constrictor muscle activity during deglutition. (*Angle Orthod* 2000;70:284–289.)

Key Words: Deglutition; Tongue; Open bite; Cineradiography

INTRODUCTION

Most patients with anterior open bite have tongue-tip protrusion during deglutition.[1–4] Some investigators have suggested that such protrusion is a cause of the anterior open bite.[4–6] Others, however, have suggested that tongue-tip protrusion during deglutition is a result of functional adaptation to an anterior open bite.[1–3] Thus, there has been long-standing controversy about the relationship between anterior open bite and deglutition.[1–6]

Deglutition is a very basic and important function and is a complex action involving multiple anatomical structures.[7,8] Tongue movement is particularly important in deglutition. However, in orthodontic practice, appliances such as the tongue crib[9,10] and myofunctional therapy[11,12] have often been applied with consideration of the tongue-tip position only, without considering the movement of the dorsal surface of the tongue and the tongue's deglutition function.[9–12]

The purpose of the present study was to investigate the movements of the tongue tip and dorsal surface of the tongue during deglutition in patients with anterior open bite by use of cineradiography. Furthermore, during the swallowing action in anterior open bite patients bolus movement and nasopharyngeal closure were evaluated by time measurement.

MATERIALS AND METHODS

Subjects

The subjects were 10 female patients (ages 15 to 24) with anterior open bites and 10 female controls (ages 23 to 24) with normal overbites. The patients with anterior open bite had a definite separation between the upper and lower incisal edges when measurements were made relative to the occlusal plane.[13] Cephalometric measurements of the anterior open bite subjects showed an overbite ranging from −0.5 to −8.1 mm (mean −2.9 mm) and an overjet ranging

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from 0.2 to 7.0 mm (mean 3.0 mm). The controls had an overbite ranging from 0.8 to 5.2 mm (mean 2.8 mm) and an overjet ranging from 1.6 to 5.0 mm (mean 3.2 mm).

Cineradiography

A lead marker was fixed at the tongue tip, and barium paste (Fushimi Pharmaceutical Co Ltd, 100 wt/vol, Barytgensol, Kagawa, Japan) was applied to the nasal pharynx of each subject. Each subject was seated on a chair turned parallel to the face of the image intensifier and her head was stabilized in a cephalostat attached to the chair. Each subject was asked to swallow 10 mL of liquid barium diluted 10% (wt/vol) with water, while looking at her eyes in a mirror in front of her. Cineradiographic recordings were obtained at 68-85 keV with a 9-inch intensifier (Shimadzu Corporation, DIGITEX2400UX, Kyoto, Japan) and appropriate collimation so that a lateral image of the entire mouth and pharynx could be obtained. The cineradiographic image was recorded on 35 mm imaging film (Fuji Film, MI-CF, Tokyo, Japan) at 30 or 60 frames per second. These swallowing events were recorded 3 times.

The cineradiographic image was analyzed in slow motion and by single-frame analysis using the playback capability of a Cineangio-projecter (ELK, CAP35B, Aichi, Japan). We established the following 7 stages of deglutition: stage 1, contact of the tongue tip with the maxillary incisors and/or the palatal mucosa; stage 2, loss of contact of the dorsal tongue with the soft palate; stage 3, passage of the bolus head across the posterior/inferior margin of the ramus of the mandible; stage 4, passage of the bolus head through the opening of the esophagus; stage 5, passage of the bolus tail through the point below the posterior nasal spine (PNS); stage 6, passage of the bolus tail across the posterior/inferior margin of the ramus of the mandible; and stage 7, passage of the bolus tail through the opening of the esophagus. By modification of oral and pharyngeal transit times,[14] we measured the times between each stage and the times from each stage to closure of the nasopharynx. Furthermore, cineradiographic images were traced, and the linear measurements were analyzed at several stages (Figure 1). As deglutitive tongue movements were highly variable among different individuals,[8] the data was recorded 3 times in each subject and averaged.

One investigator performed all of the tracings and measurements. To evaluate intra-examiner error in tracing and measurements, 1 frame of cineradiography was traced and measured twice during deglutition in each subject on 2 separate occasions at least 1 month apart. The method error was determined by Dahlberg's formula, $ME = \sqrt{\Sigma d^2/2n}$ where n is the number of subjects and d is the difference between 2 measurements of a pair. The method error did not exceed 0.012.

The data of linear and time measurements were compared between the patients with anterior open bite and the controls by the Mann-Whitney U-test. The changes in values of linear measurements were compared between several stages in each subject by the Wilcoxon signed rank test.

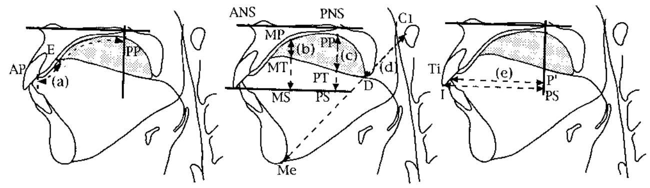

FIGURE 1. Standard points and linear measurements. Standard points were AP, the boundary point between the upper central incisor and palatal mucosa; E, the point nearest to tongue base in the contact region between tongue and palatal mucosa; ANS, the most anterior point of the maxilla at the level of the palate; PNS, the most posterior point on the bony hard palate; MP, the point at which the line crossing at a right angle to the palatal plane (through ANS and PNS) through the middle point between ANS and PNS intersects the palatal mucosa; MT, the point at which the line crossing at a right angle to the palatal plane through the middle point between ANS and PNS intersects the dorsal tongue; MS, the point at which the line crossing at a right angle to the palatal plane through the middle point between ANS and PNS intersects the standard plane (passing the edge of the maxillary incisor and parallel to the palatal plane); PP, the point at which the line crossing at a right angle to the palatal plane through PNS intersects the palatal mucosa; PT, the point at which the line crossing at a right angle to the palatal plane through PNS intersects the dorsal tongue; PS, the point at which the line crossing at a right angle to the palatal plane through PNS intersects the standard plane; Me, the lowest point on the symphyseal outline of the chin; C1, the front most point of the atlas; D, the point at which the line through Me and C1 intersects the dorsal tongue; I, the edge point of the maxillary incisor; and Ti, the tongue-tip point. Linear measurements were the following: (a) Contact of tongue and palate, AP~E/AP~PP; (b) Front part of dorsal tongue, MP-MT/MP-MS; (c) Middle part of dorsal tongue, PP-PT/PP-PS; (d) Rear part of dorsal tongue, C1-D/C1-Me; and (e) Tongue tip, P'-Ti/PS-I. AP~E and AP~PP are distances on the palatal mucosa. MP-MT, MP-MS, PP-PT, PP-PS, C1-D, C1-Me, and PS-I are straight distances. P'-Ti is the shortest distance from the line crossing at a right angle to the palatal plane through PNS to Ti.

RESULTS

The values of linear measurements

The linear measurement of tongue tip in patients with anterior open bite was 0.98 ± 0.04 mm/mm at the stage at which the dorsal surface of the tongue lost contact with the soft palate (stage 2), 0.99 ± 0.05 mm/mm at the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3) and 0.98 ± 0.05 mm/mm at the stage of the head of the bolus passing through the opening of the esophagus (stage 4) (Tables 1 through 3). These data were significantly greater for the patients with anterior open bite than for the controls. Thus, the tongue-tip position in the patients with anterior open bite was more protrusive than that of the controls. The other values of linear measurements were not significantly different between patients with anterior open bite and controls (Tables 1 through 3).

TABLE 1. Linear Measurements at Stage 2[a]

Stage 2	Control	Anterior Open Bite
Contact of tongue and palate	0.21 ± 0.09	0.16 ± 0.10
Front part of dorsal tongue	0.50 ± 0.17	0.66 ± 0.17
Middle part of dorsal tongue	0.63 ± 0.16	0.69 ± 0.10
Rear part of dorsal tongue	0.31 ± 0.05	0.30 ± 0.07
Tongue tip	0.92 ± 0.04	0.98 ± 0.04**

[a] Values are means ± SD (mm/mm).
** $P < .01$; anterior open bite patients vs controls.

TABLE 2. Linear Measurements at Stage 3[a]

Stage 3	Control	Anterior Open Bite
Contact of tongue and palate	0.35 ± 0.12	0.29 ± 0.17
Front part of dorsal tongue	0.25 ± 0.13	0.32 ± 0.19
Middle part of dorsal tongue	0.57 ± 0.19	0.70 ± 0.10
Rear part of dorsal tongue	0.34 ± 0.03	0.36 ± 0.06
Tongue tip	0.93 ± 0.04	0.99 ± 0.05*

[a] Values are means ± SD (mm/mm).
* $P < .05$; anterior open bite patients vs controls.

TABLE 3. Linear Measurements at Stage 4[a]

Stage 4	Control	Anterior Open Bite
Contact of tongue and palate	0.71 ± 0.12	0.59 ± 0.23
Front part of dorsal tongue	0.04 ± 0.06	0.06 ± 0.09
Middle part of dorsal tongue	0.37 ± 0.23	0.42 ± 0.20
Rear part of dorsal tongue	0.35 ± 0.03	0.37 ± 0.07
Tongue tip	0.94 ± 0.03	0.98 ± 0.05*

[a] Values are means ± SD (mm/mm).
* $P < .05$; anterior open bite patients vs controls.

Changes in values of linear measurements

In both anterior open bite patients and controls, the degree of contact between tongue and palate was significantly larger at: (A) the stage of the head of the bolus passing across the posterior/inferior margin of the ramus of the mandible (stage 3) than at the stage of the dorsal tongue losing contact with the soft palate (stage 2) and, (B) the stage of the bolus head going through the opening of esophagus (stage 4) than at the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3) (Figure 2a).

In patients with anterior open bite and in controls, the front part of the dorsal surface of the tongue was significantly smaller: (A) at the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3) than at the stage of the dorsal tongue losing contact with the soft palate (stage 2), and (B) at the stage of the bolus head going through the opening of the esophagus (stage 4) than at the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3) (Figure 2b).

In patients with anterior open bite and in controls, the middle part of the dorsal tongue was significantly smaller at the stage of the bolus head going through the opening of the esophagus (stage 4) than at the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3) (Figure 2c).

In patients with anterior open bite and in controls, the rear part of the dorsal tongue was significantly larger at the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3) than at the stage of the dorsal tongue losing contact with the soft palate (stage 2), and significantly smaller at the stage of the bolus tail passing across the posterior/inferior margin of the ramus of the mandible (stage 6) than at the stage of the bolus tail going through the point below the PNS (stage 5).

Furthermore, the rear part of the dorsal tongue in controls was significantly smaller at the stage of the bolus tail going through the point below the PNS (stage 5) than at the stage of the bolus head going through the opening of the esophagus (stage 4), although patients with anterior open bite showed no change for this period (Figure 2d). In other words, in the patients with anterior open bite the value of the rear part of the dorsal surface of the tongue began to decrease in size after the stage of the bolus tail going through the point below the PNS (stage 5), but in the controls the value of the rear part of the tongue began to decrease after the stage of the bolus head going through the opening of esophagus (stage 4). These findings indicate that the rear part of the dorsal tongue in the anterior open bite patients had slower movement than in controls after the stage of the bolus head going through the opening of the esophagus (stage 4).

Values of time measurements

There was no significant difference between patients with anterior open bite and controls for the time between each stage (Table 4). The times of nasopharyngeal closure in the patients with anterior open bite were 33.2 ± 25.0 months from the stage of the dorsal tongue losing contact with the soft palate (stage 2), −62.6 ± 45.9 months from the stage of the bolus head passing across the posterior/inferior margin of the ramus of the mandible (stage 3), −138.4 ± 53.7 months from the stage of the bolus head going through the opening of the esophagus (stage 4), and −211.0 ± 60.8 months from the stage of the bolus tail passing through the point below PNS (stage 5) (Table 5). These times were significantly smaller for the patients with anterior open bite than for the controls. Thus, nasopharyngeal closure was earlier in patients with anterior open bite than in controls.

DISCUSSION

Recently, Schwestka-Polly et al[15] showed that an orthodontic appliance with spikes influenced tongue movement during swallowing in a patient with anterior open bite. Furthermore, Yashiro and Takada[16] indicated that the electromyographic pattern of genioglossus muscle ac-

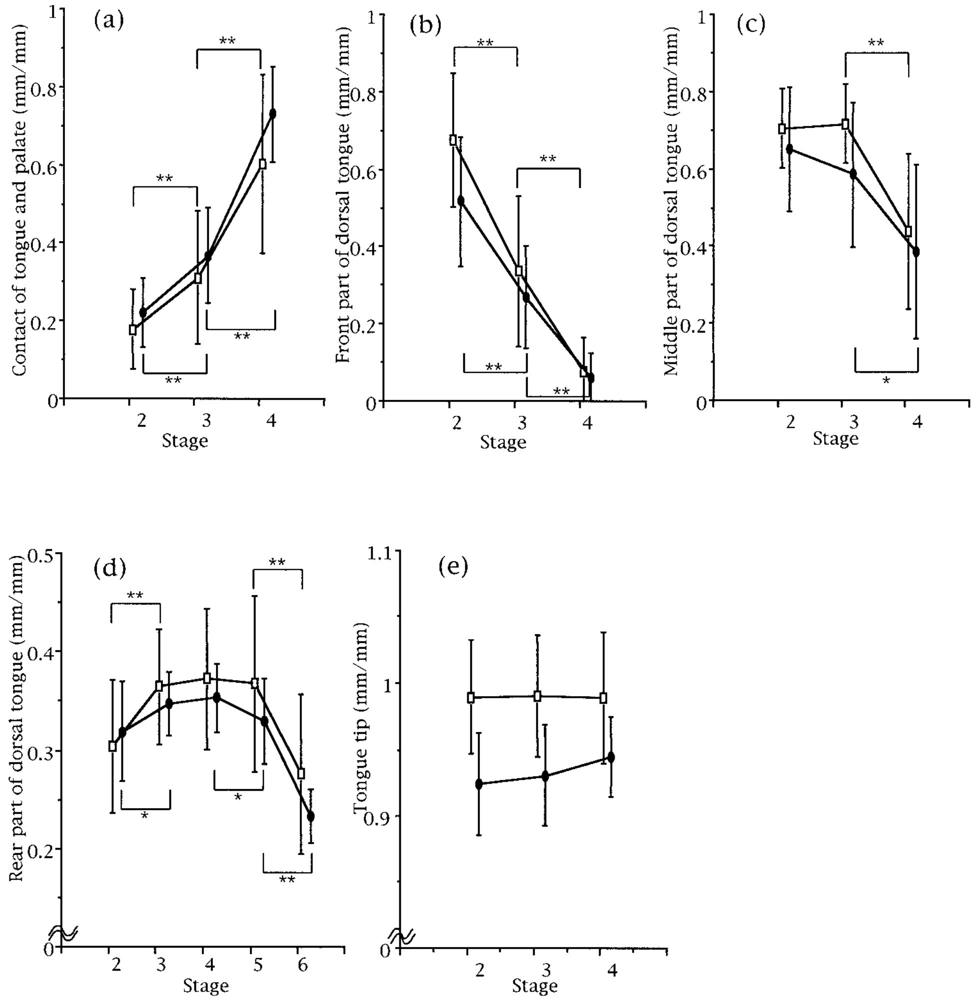

FIGURE 2. Changes in values of linear measurements at stages 2, 3, 4, 5, and 6. (a) contact of tongue and palate; (b) front part of dorsal tongue; (c) middle part of dorsal tongue; (d) rear part of dorsal tongue; and (e) tongue tip. Values are mean ± SD (mm/mm) in anterior open bite patients, □, and controls ●. *$P < .05$, **$P < .01$ Stage 2 vs stage 3, stage 3 vs stage 4, stage 4 vs stage 5, and stage 5 vs stage 6.

TABLE 4. The Time between 7 Stages[a]

Stage	Control	Anterior Open Bite
1		
2	143.0 ± 105.6	180.9 ± 104.5
3	80.2 ± 30.8	95.8 ± 34.3
4	109.9 ± 68.9	75.9 ± 19.2
5	65.7 ± 29.7	72.6 ± 34.7
6	176.7 ± 47.0	158.5 ± 38.6
7	286.3 ± 67.9	275.8 ± 67.2

[a] Values are means ± SD (ms).

TABLE 5. The Time from Each Stage to Nasopharyngeal Closure[a]

Stage	Control	Anterior Open Bite
1	246.0 ± 51.6	214.2 ± 98.9
2	103.0 ± 89.9	33.2 ± 25.0*
3	22.9 ± 89.6	−62.6 ± 45.9*
4	−87.0 ± 35.7	−138.4 ± 53.7*
5	−152.6 ± 40.7	−211.0 ± 60.8*
6	−329.4 ± 65.2	−369.5 ± 55.2
7	−615.7 ± 71.7	−645.4 ± 73.5

[a] Values are means ± SD (ms).
* $P < .05$; anterior open bite patients vs controls.

tivity during deglutition adapted for orthodontic change of occlusal form for the anterior open bite. Although these reports[15,16] showed only 1 case, it was obvious that occlusal form and deglutitive tongue movement were related to each other.

Deglutitive tongue movements are important in swallowing events.[7,17,18] In normal swallowing, the tongue tip and sides are in contact with the alveolar ridge, and the center portion of the tongue sequentially elevates from front to back.[14] However, in most anterior open bite patients, the tongue tip protrudes without contact with the alveolar ridge during deglutition.[1–4] Kahrilas et al[17] suggested that it was important for tongue tip and sides to seal against the alveolar ridge during deglutition and that the seal was related to the motions of the center portion of the tongue during deglutition. In the present study, the anterior open bite patients not only had tongue-tip protrusion, but also slower movement in the rear part of the dorsal tongue after the stage of the bolus head going through the opening of the esophagus. The movements of the rear part of the dorsal surface of the tongue may have changed with tongue-tip protrusion during deglutition.

Tongue movements during deglutition are actually only up and down movements of each region on the tongue.[17] These tongue movements cause bolus propulsion.[7,17,18] In this study, the rear part of dorsal tongue in patients with anterior open bite showed slower movement than the controls after the stage of the bolus head going through the opening of the esophagus. Therefore, we speculate that bolus movement in patients with anterior open bite becomes slower than normal after the stage of the bolus head going through the opening of the esophagus. However, the time of bolus movement between stages was not significantly different between the controls and anterior open bite patients. Bolus propulsion is also aided by pharyngeal constrictors,[7,17,18] hypopharyngeal suction,[18] and upper esophageal sphincter opening[19]; although the tongue movement is the main propulsion for bolus transport.[7,18] Taken together, the present findings suggest that bolus propulsion in patients with anterior open bite is made mainly by pharyngeal constrictors, hypopharyngeal suction, and upper esophageal sphincter opening.

Nasopharyngeal closure during deglutition consists of both elevation of the soft palate and adduction of the superior pharyngeal constrictor muscle.[20] The pattern of nasopharyngeal closure during deglutition is different from that in speech[21] and belching.[20] In our study, the nasopharynx closed significantly earlier in the patients with anterior open bite than in the controls. Therefore, the pattern of nasopharyngeal closure during deglutition in anterior open bite patients may be different from that in controls in terms of coordination of the soft palate and the superior pharyngeal constrictor muscle. The pharyngeal constrictor muscle is involved not only in nasopharyngeal closure,[20] but also in bolus propulsion during deglutition.[7,17,18] In our study, bolus propulsion in the anterior open bite patients might have occurred mainly by the action of the pharyngeal constrictor muscle, hypopharyngeal suction, and upper esophageal sphincter opening; however, the main bolus propulsion in the controls was tongue movement. Therefore, earlier closure of nasopharynx during deglutition may indicate compensatory function by the pharyngeal constrictor muscle for bolus propulsion in patients with anterior open bite.

During deglutition, patients with anterior open bite showed tongue-tip protrusion, slower movement of rear part of dorsal tongue, and earlier closure of nasopharynx. These coordinated motions of tongue, soft palate, and pharyngeal constrictor muscle may be compensatory or adaptive functions in the case of anterior open bite. Further investigation is necessary to determine whether the compensatory or adaptive functions shown during deglutition in our study change with the improvement of the anterior open bite by orthodontic treatment.

CONCLUSIONS

Anterior open bite patients showed tongue-tip protrusion, slower movement of rear part of dorsal tongue, and earlier closure of nasopharynx compared with controls during deglutition. These results suggest that patients with anterior open bite had compensatory coordination of tongue and soft palate movements during deglutition.

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