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Tongue movements in patients with skeletal Class III malocclusions evaluated with real-time balanced turbo field echo cine magnetic resonance imaging

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Introduction: The aim of this study was to evaluate the position and movements of the tongue in patients with skeletal Class III malocclusion. **Methods:** Sixty-six patients (31 male, 35 female) with Class III malocclusion were divided into 3 groups according to cephalometric analysis. The first group comprised 23 patients (13 male, 10 female) with mandibular prognathism, the second group comprised 21 patients (9 male, 12 female) with maxillary retrognathism, and the third group comprised 22 patients (9 male, 13 female) with both maxillary retrognathism and mandibular prognathism. Twenty-two skeletal Class I patients (10 male, 12 female) were also included as the control group. **Results:** Dentofacial morphology affects the position and the movements of the tongue during deglutition. Contact of the anterior portion of the tongue with the rugae area of the hard palate decreased in the Class III malocclusion groups. The posterior portion of the dorsal tongue was positioned more inferiorly, and the root of the tongue was positioned more inferiorly and anteriorly in patients with Class III malocclusion than in the control group. The tip of the tongue was also in a more anterior position in the Class III groups. When the deglutition stages were evaluated, we observed that the manner of bolus transfer was different in patients with skeletal Class III malocclusion than in those with skeletal Class I malocclusion. **Conclusions:** Tongue posture is affected by dentofacial structures, and adaptive changes occur in the tip, dorsum, and root of the tongue. Deglutitive tongue movements in patients with skeletal Class III malocclusion are also different from those with skeletal Class I malocclusion. (Am J Orthod Dentofacial Orthop 2011;139:e405-e414)

Evaluation of swallowing is an important part of oral diagnosis. Several techniques have been applied to observe tongue movements during deglutition. Cineradiography and video-fluoroscopy have been reported as acceptable methods in assessing deglutition, but radiation exposure makes their use questionable.[1] Deglutition has also been investigated by ultrasound scanning.[2,3] In ultrasonography, direct transducer skin coupling scanning caused various artifacts, resulting in inaccurate measurements of tongue movements.[3,4] The cushion-scanning technique was developed to overcome this problem.[3,5] However, this technique restricts the physiologic movements of the head. Cleall[1] reported that anything that restricts the movement of the head and its structures is unphysiologic in the study of movement. In addition, the observation of the oral stage of deglutition was difficult in this technique. Electropalatography is another method to measure dynamic tongue function. In this technique, the patient wears an acrylic plate base with electrodes that record the location and the timing of tongue contacts.[6,7] However, this plate might affect the position and movement of the tongue during deglutition.

Recently, dynamic magnetic resonance imaging (MRI), another noninvasive method to evaluate swallowing function, has become available. Foucart et al[8] reported that kinetic MRI could be used to investigate the oropharyngeal apparatus. Anagnostara et al[9]

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Table I. Mean ages and cephalometric values of the groups

	Age (y)		SNA (°)		SNB (°)		ANB (°)		N vertical-A (mm)		N vertical-Pg (mm)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group 1	17.09	5.77	80.14	4.05	84.21	3.95	−4.07	2.43	−0.43	3.03	6.21	6.85
Group 2	15.58	3.45	75.80	3.28	79.13	2.92	−3.20	2.14	−5.73	3.73	−4.33	5.96
Group 3	19.21	3.87	76.13	2.31	82.31	2.98	−6.19	3.45	−7.19	4.69	2.75	5.32
All Class III groups	17.41	4.55	77.27	3.96	82.03	4.09	−4.70	3.21	−4.43	4.82	1.43	7.70
Group 4	18.26	5.22	81.27	1.01	79.36	1.12	1.91	0.83	0.10	1.30	−6.73	2.05
Overall	17.54	4.66										

reported that high-speed kinetic MRI provided direct soft-tissue imaging without radiation exposure with comparable near real-time resolution, compared with video-fluorography. Hartl et al[10] demonstrated that dynamic MRI with single-shot fast spin echo provided clear images of the oral and pharyngeal surfaces as well as of the deep tissue structures. Real-time balanced turbo field echo has been used in subjects with anterior open bite for the evaluation of deglutition events, transit times, and tongue movements.[11-14]

Proffit[15] reported that tongue posture and swallowing pattern were affected by the dentofacial structures. Akin et al[11] showed that, in patients with open bite, the tongue tip was positioned more anteriorly than in patients with a normal overbite. Karacay et al[14] evaluated alterations of tongue movements after correction of Class II malocclusion and open bite by advancement of the mandible in a forward and upward direction with a sagittal split osteotomy. Dynamic MRI showed that the tongue tip was retruded behind the incisors, and contact of the tongue with the palate increased after treatment. It was also determined that the anterior and middle portions descended, whereas the posterior portion was elevated at all stages. Sayın et al[13] reported that tongue movements in deglutition immediately adapted to changes in the local environment that were created by the tongue crib. Fuhrmann and Diedrich[16] evaluated the swallowing pattern by using video-based dynamic B-mode ultrasound and reported that patients with an Angle Class III malocclusion had the highest rate of abnormal swallowing.

In skeletal Class III malocclusions, generally patients have a greater mandibular bone size and a smaller maxillary bone size.[17,18] In this study, we intended to evaluate the deglutition pattern in Class III malocclusion, since the size and position of the jaws and the maxillomandibular relationship can change tongue posture and movements during deglutition. Cine images of the tongue were obtained by using real-time balanced turbo field echo. To our knowledge, this technique has not been used before in the evaluation of the swallowing patterns of patients with Class III malocclusion.

Fig 1. Stage 1: loss of contact between the tongue's dorsum and the soft palate.

MATERIAL AND METHODS

This prospective study was carried out after institutional approval from the Ethics Committee of Gulhane Military Medical Academy in Ankara, Turkey.

Eighty-eight patients (45 male, 43 female; mean age, 17.54 ± 4.66 years) participated in this study, and all signed informed consent forms. The participants were divided into 4 groups according to their skeletal structures (Table I). The skeletal classifications were made by the evaluation of the sagittal components of the jaws, based on the SNA, SNB, and ANB angles, and

Fig 2. Stage 2: passage of the bolus head across the posterior or inferior margin of the ramus of the mandible.

Fig 3. Stage 3: passage of the bolus head through the opening of the esophagus.

N vertical-A and N vertical-Pg linear measurements (distance between A point and nasion perpendicular [the line beginning from nasion point and perpendicular to Frankfurt horizontal line [the line between porion and orbita points]] and distance between pogonion point and nasion perpendicular) of the lateral cephalograms. Twenty-three Class III patients (13 male, 10 female; mean age, 17.09 ± 5.77 years) with mandibular prognathism were included in the first group. In the second group, there were 21 Class III patients (9 male, 12 female; mean age, 15.58 ± 3.45 years) with maxillary retrognathism. The third group comprised 22 Class III patients (9 male, 12 female; mean age, 19.21 ± 3.87 years) with both maxillary retrognathism and mandibular prognathism. Finally, 22 subjects (10 male, 12 female; mean age, 18.26 ± 5.22 years) with skeletal Class I malocclusion composed the control group.

All patients were examined with a 1.5-T super conducting magnetic resonance scanner with a quad H coil and version 9 software (New Intera Nova, Philips Medical Systems, Best, The Netherlands). Real-time balanced turbo field echo images (shortest TR/TE:2.1/1.09 ms) were taken with a 50° flip angle in the midsagittal plane, 10 mm thickness, 350 × 350 mm field of view dimensions, and 96 × 96 matrix width during the patient's water swallowing. A hundred dynamic scans were captured in 11 seconds.

The images were obtained while the subjects were swallowing 10 mL of water that was taken with a syringe just before imaging. For each patient, images matching the following 3 stages were determined by 3 specialists and printed out on a radiograph: stage 1: loss of contact of the dorsal tongue with the soft palate (Fig 1); stage 2: passage of the bolus head across the posterior or inferior margin of the ramus of the mandible (Fig 2); and stage 3: passage of the bolus head through the opening of the esophagus (Fig 3).

Linear measurements defined by Fujiki et al[19-21] were made on these radiographs for each stage by 1 author (E.A.) to prevent interobserver variability. The reference points and planes are shown in Table II. Since AM-E and AM-PM are distances on tje palatal mucosa, they were curved lines. A ligature wire was used for the measurement of these parameters. MM-MT, MM-MS, PM-PT, PM-PS, C1-D, C1-Me, and PS-I are straight distances. P'-Ti is the shortest distance from a line crossing at a right angle to the NF plane through PNS to Ti (Fig 4).

The points and measurements of 24 patients were reevaluated 1 month later, and the method error was

Table II. Reference points and planes used in the study

Landmark	*Definition*
ANS	Most anterior point of the maxilla at the level of the palate
PNS	Most posterior point on the bony hard palate
Me	Lowest point on the symphyseal outline of the chin
I	Edge point of the maxillary incisor
C1	Front-most point of the atlas
NF	Plane through both ANS and PNS
SP	Plane passing the edge of the maxillary incisor and parallel to the palatal plane
AM	Boundary point between the maxillary central incisor and the palatal mucosa
E	Point nearest to the tongue base in the contact region between the tongue and the palatal mucosa
MM	Point at which the line crossing at a right angle to NF through the middle point between ANS and PNS intersects the palatal mucosa
MT	Point at which the line crossing at a right angle to NF through the middle point between ANS and PNS intersects the dorsum of the tongue
MS	Point at which the line crossing at a right angle to NF through the middle point between ANS and PNS intersects SP
PM	Point at which the line crossing at a right angle to NF through PNS intersects the palatal mucosa
PT	Point at which the line crossing at a right angle to NF through PNS intersects the dorsum of the tongue
PS	Point at which the line crossing at a right angle to NF through PNS intersects SP
D	Point at which the line through Me and C1 intersects the dorsum of the tongue
Ti	Tongue tip

determined by Dahlberg's formula, $ME = \sqrt{\sum d^2/2n}$, where n is the number of subjects and d is the difference between the 2 measurements of a pair.[22] The method error did not exceed 0.153 mm. All statistical analyses of the groups were performed with the Statistical Package for Social Sciences for Windows software (version 13, SPSS, Chicago, Ill). The variables were examined visually and with the Shapiro-Wilks analysis for normal distribution. Table I shows the mean ages and various cephalometric values used to define the groups.

All descriptive statistics are given as means and standard deviations (Table III). Analysis of variance (ANOVA) for repeated measurements was used to evaluate the measurements obtained from the 3 stages, the 4 groups, and interactions of the 3 stages with the 4 groups. In case of differences, the Bonferroni post-hoc test was used to determine the causes of the differences between the stages or the groups. $P \leq 0.05$ was accepted as the level of significant difference.

RESULTS

In the within-group comparison of the stages (Table IV), the degree of contact between the anterior portion of the tongue and palate (AM-E/AM-PM) (Fig 5) was significantly greater at stage 2 than at stage 1 ($P < 0.05$) in the mandibular protrusion group (group 1). The increase between stages 2 and 3 or 1 and 3 was not statistically significant ($P > 0.05$). This parameter also increased in the other groups, but it was not significant.

In patients with mandibular prognathism (group 1) and maxillary retrognathism (group 2), the distances between the middle portion of the dorsal tongue and the palatal mucosa (MM-MT/MM-MS) (Fig 6) were significantly smaller at stage 3 than at stage 1 ($P < 0.01$). In the mandibular prognathism and maxillary retrognathism group (group 3), this decrease was significant between stages 1 and 2 ($P < 0.01$) and stages 1 and 3 ($P < 0.05$), and it was significant between stages 1 and 3 ($P < 0.001$) and 2 and 3 ($P < 0.001$) in the control group.

When the posterior portion of the dorsal tongue (PM-PT/PM-PS) (Fig 7) was evaluated statistically, significant alterations were determined only in the control group (group 4). The distance between the posterior portion of the dorsal tongue and the palatal mucosa was smaller at stage 2 than at stage 1 ($P < 0.05$) and larger at stage 3 than at stage 2 ($P < 0.001$).

Evaluation of the root of the dorsal tongue (C1-D/C1-Me) (Fig 8) showed that the distance between the root of the tongue and the front point of the atlas increased significantly at stage 3 compared with stage 1 ($P < 0.01$) in the maxillary retrognathism group (group 2).

In the evaluation of the tongue tip (P'-Ti/P'-I) (Fig 9), it was determined that, in the mandibular prognathism group (group 1) and the control group, the tongue tip was retruded more in stage 2 than in stage 1 ($P < 0.01$ and $P < 0.05$, respectively).

In the between-groups comparisons of tongue positions (Table V), when the degree of contact between the anterior portion of the tongue and the palate (AM-E/AM-PM) (Fig 5) was compared between the

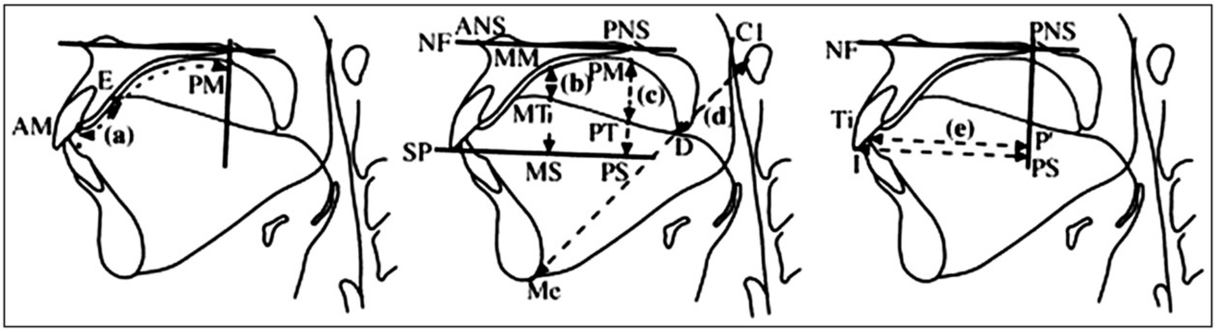

Fig 4. Linear measurements by MRI: (*a*), AM-E/AM-PM, the anterior portion of the tongue's dorsum, contact of tongue and palate; (*b*), MM-MT/MM-MS, the midportion of the tongue's dorsum; (*c*), PM-PT/PM-PS, the posterior portion of the tongue's dorsum; (*d*), C1-D/C1-Me, root of the tongue; (*e*), P'-Ti/PS-I, the tongue's tip, and AM-E AM-PM are distances on the palatal mucosa. MM-MT, MM-MS, PM-PT, PM-PS, C1-D, C1-Me, and PS-I are straight distances. P'-Ti is shortest distance from a line crossing at a right angle to the NF plane through PNS to Ti (from Fujiki et al[19]).

Table III. Descriptive statistics of all measurements for all groups and all stages

	Group 1		*Group 2*		*Group 3*		*Group 4*	
	Mean (mm/mm)	*SD*	*Mean (mm/mm)*	*SD*	*Mean (mm/mm)*	*SD*	*Mean (mm/mm)*	*SD*
Stage 1								
AM-E/AM-PM	0.175	0.095	0.175	0.090	0.185	0.090	0.266	0.057
MM-MT/MM-MS	0.575	0.170	0.586	0.229	0.568	0.209	0.607	0.157
PM-PT/PM-PS	0.554	0.228	0.545	0.211	0.565	0.208	0.308	0.080
C1-D/C1-Me	0.243	0.058	0.245	0.053	0.247	0.045	0.215	0.060
P'-Ti/PS-I	0.992	0.064	0.988	0.063	1.008	0.098	0.945	0.120
Stage 2								
AM-E/AM-PM	0.233	0.090	0.227	0.097	0.225	0.101	0.297	0.070
MM-MT/MM-MS	0.469	0.285	0.445	0.273	0.416	0.132	0.663	0.153
PM-PT/PM-PS	0.538	0.220	0.511	0.203	0.522	0.154	0.239	0.100
C1-D/C1-Me	0.271	0.063	0.273	0.041	0.272	0.048	0.186	0.053
P'-Ti/PS-I	0.930	0.058	0.910	0.143	0.926	0.126	0.850	0.125
Stage 3								
AM-E/AM-PM	0.238	0.091	0.225	0.083	0.232	0.089	0.271	0.051
MM-MT/MM-MS	0.391	0.162	0.401	0.175	0.383	0.155	0.403	0.219
PM-PT/PM-PS	0.449	0.187	0.478	0.199	0.441	0.147	0.382	0.153
C1-D/C1-Me	0.274	0.055	0.290	0.055	0.277	0.067	0.223	0.073
P'-Ti/PS-I	0.977	0.051	0.983	0.062	0.982	0.098	0.904	0.147

groups, there was a statistically significant decrease in all Class III groups compared with the control group ($P < 0.001$).

There was no significant difference in the distance between the middle portion of the dorsal tongue and the palatal mucosa (MM-MT/MM-MS) (Fig 6) ($P > 0.05$).

When the posterior portion of the dorsal tongue (PM-PT/PM-PS) (Fig 7) was evaluated, statistically significant increases were found in all Class III groups compared with the control group ($P < 0.001$). These increases showed the inferior position of the posterior portion of the dorsal tongue in patients with Class III malocclusion.

Evaluation of the root of the dorsal tongue (C1-D/C1-Me) (Fig 8) showed that the distance between the root of the tongue and the front point of the atlas increased significantly in all Class III groups compared with the control group ($P < 0.001$). This increase was due to the inferior position of the root of the tongue in patients with Class III malocclusion.

The tongue-tip (P'-Ti/P'-I) (Fig 9) evaluation also showed statistically significant alterations in the Class III groups. In patients with mandibular prognathism, maxillary retrognathism, and both mandibular prognathism and maxillary retrognathism, the tongue tip was

Table IV. Comparison of intragroup differences between stages

	Group	Stages		Mean difference	SE	P	Significance
Anterior portion of tongue	Mandibular prognathism	1	2	−0.058	0.020	0.026	*
			3	−0.063	0.026	0.063	NS
		2	3	−0.006	0.029	1.000	NS
	Maxillary retrognathism	1	2	−0.051	0.023	0.109	NS
			3	−0.049	0.026	0.224	NS
		2	3	0.002	0.029	1.000	NS
	Bimaxillary	1	2	−0.039	0.033	0.731	NS
			3	−0.046	0.026	0.253	NS
		2	3	−0.007	0.028	1.000	NS
	Control	1	2	−0.031	0.019	0.359	NS
			3	−0.005	0.018	1.000	NS
		2	3	0.026	0.018	0.532	NS
Middle portion of tongue	Mandibular prognathism	1	2	0.106	0.071	0.439	NS
			3	0.184	0.050	0.004	†
		2	3	0.078	0.060	0.615	NS
	Maxillary retrognathism	1	2	0.140	0.061	0.095	NS
			3	0.184	0.047	0.003	†
		2	3	0.044	0.052	1.000	NS
	Bimaxillary	1	2	0.151	0.040	0.003	†
			3	0.184	0.057	0.012	*
		2	3	0.033	0.040	1.000	NS
	Control	1	2	−0.056	0.052	0.882	NS
			3	0.204	0.046	0.001	‡
		2	3	0.260	0.058	0.001	‡
Posterior portion of tongue	Mandibular prognathism	1	2	0.017	0.055	1.000	NS
			3	0.106	0.053	0.183	NS
		2	3	0.089	0.049	0.255	NS
	Maxillary retrognathism	1	2	0.034	0.056	1.000	NS
			3	0.067	0.069	1.000	NS
		2	3	0.033	0.047	1.000	NS
	Bimaxillary	1	2	0.043	0.058	1.000	NS
			3	0.125	0.057	0.124	NS
		2	3	0.081	0.047	0.295	NS
	Control	1	2	0.069	0.024	0.031	*
			3	−0.074	0.037	0.170	NS
		2	3	−0.142	0.034	0.001	‡
Root of tongue	Mandibular prognathism	1	2	−0.028	0.015	0.230	NS
			3	−0.032	0.017	0.233	NS
		2	3	−0.003	0.017	1.000	NS
	Maxillary retrognathism	1	2	−0.028	0.014	0.212	NS
			3	−0.045	0.013	0.007	†
		2	3	−0.017	0.014	0.641	NS
	Bimaxillary	1	2	−0.025	0.013	0.217	NS
			3	−0.030	0.016	0.210	NS
		2	3	−0.005	0.019	1.000	NS
	Control	1	2	0.029	0.018	0.348	NS
			3	−0.008	0.020	1.000	NS
		2	3	−0.037	0.018	0.153	NS
Tip of tongue	Mandibular prognathism	1	2	0.062	0.016	0.002	†
			3	0.015	0.014	0.843	NS
		2	3	−0.047	0.016	0.023	*
	Maxillary retrognathism	1	2	0.078	0.035	0.108	NS
			3	0.004	0.013	1.000	NS
		2	3	−0.074	0.036	0.165	NS
	Bimaxillary	1	2	0.082	0.036	0.096	NS
			3	0.026	0.033	1.000	NS
		2	3	−0.056	0.037	0.429	NS
	Control	1	2	0.095	0.035	0.038	*
			3	0.041	0.045	1.000	NS
		2	3	−0.054	0.045	0.728	NS

*$P < 0.05$; †$P < 0.01$; ‡$P < 0.001$; *NS*, Not significant.

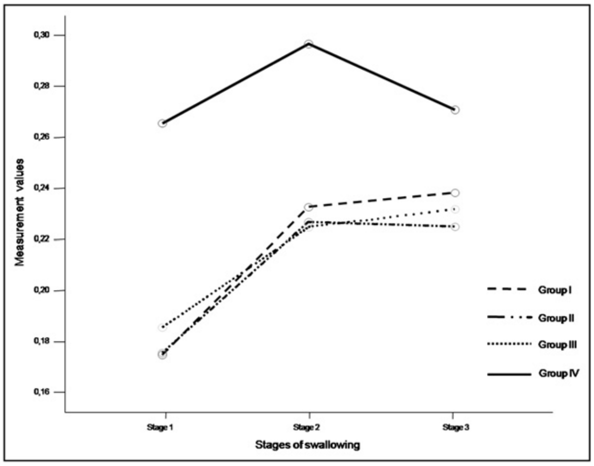

Fig 5. Changes of AM-E/AM-PM proportions of all groups in all stages.

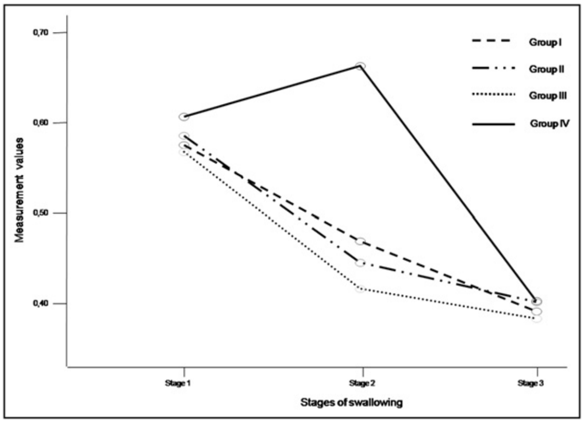

Fig 6. Changes of MM-MT/MM-MS proportions of all groups in all stages.

positioned more anteriorly than in the control group (P <0.001, P <0.01, and P <0.001, respectively).

DISCUSSION

In this study, dynamic MRI was preferred for the evaluation of tongue movements because it is a noninvasive and reliable technique that has been used successfully to obtain cine images of deglutition in previous studies.[11-14] Researchers observed that the accuracy of kinetic MRI was greater than with all previous techniques because of its capacity to image soft-tissue anatomy.[11-13] Various high-speed MRI sequences have also been compared (EPI, FLASH, and turbo-FLASH), and the turbo-FLASH sequence was reported to provide the best temporal resolution and sufficient spatial resolution during motion.[9] In the light of these reports, the turbo-FLASH sequence was preferred in this study.

Hartl et al[10] reported that water had an intense signal and proved to be a high-contrast liquid bolus material in dynamic MRI. Ali et al[23] compared 2 and 10 mL of barium solutions as the bolus in their study with video radiography and reported that the amount of bolus did not affect deglutition. In our study, 10 mL of water was used as a bolus because of its capacity to show the soft-tissue anatomy with cine MRI. Water swallowing sets were more reliable than were dry swallowing sets, since the stages of deglutition and the borders of the soft tissues, especially the tongue, were easily and correctly determined with water.[12]

Deglutition is a complex action involving multiple anatomic structures and deglutitive tongue movements that are also important in swallowing. During normal swallowing, the tongue tip rests on the lingual part of the dentoalveolar area, and the middle portion of the tongue elevates from front to back. In recent years, some investigators have suggested that there are correlations between deglutitive tongue movements and maxillofacial morphology.[4,7,17] The posture and function of the tongue have been found to be significantly correlated with jaw relationship, abnormality of dental arch form, and abnormal tooth position. Therefore, in our study, the position of the jaws and the interrelationship between the maxilla and the mandible were considered while creating the study groups, and the patients with Class III malocclusion were divided into 3 groups according to the source of the skeletal malocclusion. If only the ANB angle was taken into account, the results would not have been reliable.

Evaluation of the contact between the anterior portion of tongue and the rugae area of the hard palate showed decreases in all Class III malocclusion groups compared with the patients with skeletal Class I malocclusion (control group) (Table V). In our opinion, this contact was affected by the negative overjet. With a negative overjet, it was difficult to seal the front of the mouth during swallowing, and the contact between the anterior portion of the tongue and the rugae area of the hard palate decreased. In the patients with mandibular protrusion, the degree of contact was greater when the head of the bolus passed across the posterior or inferior margin of the ramus of the mandible (stage 2) than when the dorsal tongue lost contact with the soft palate (stage 1) (Table IV). This portion of the tongue showed mild alterations in the degree of contact with the rugae area during the deglutition stages of the other groups, but they were not statistically significant. Hopkins[24] studied the position of the mandible and

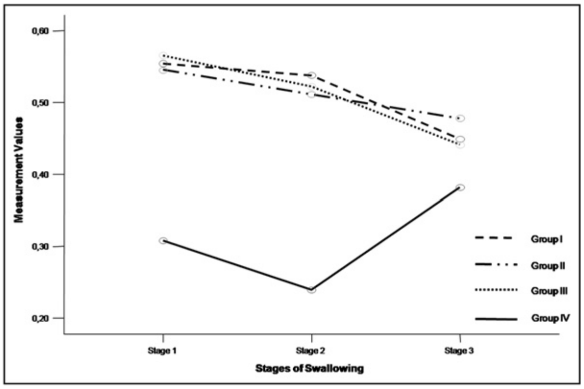

Fig 7. Changes of PM-PT/PM-PS proportions of all groups in all stages.

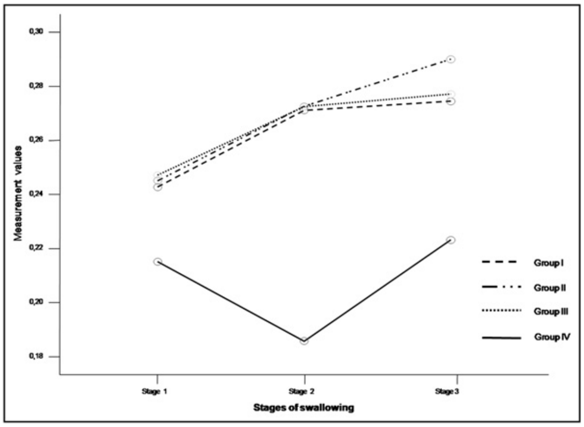

Fig 8. Changes of C1-D/C1-Me proportions of all groups in all stages.

reported that its anteroposterior positions relative to the maxilla and length are the key factors in determining the level of the tongue. Hopkins and Cheng et al[4] reported that, in patients with prognathic mandibles, the motionof the tongue increased during swallowing. Similar to these results, an increased contact with the rugae area was observed in the second stage of deglutition only in the mandibular protrusion group.

The results of our study showed no difference at the middle portion of the dorsal tongue between the groups (Table V). Nevertheless, movements of this portion were different during the deglutition stages. In the mandibular protrusion group and the maxillary retrusion group, the middle portion of the tongue was positioned more superiorly in stage 3 compared with stage 1. However, in the patients with bimaxillary Class III malocclusion, this portion of the tongue was positioned more superiorly in stages 2 and 3 compared with stage 1 (Table IV). When the skeletal malocclusion originated from both jaws, the middle portion of the tongue was positioned superiorly not only in stage 3 but also in stage 2. When 1 jaw was the source of the Class III malocclusion, superior positioning of the middle portion was significant in stage 3, but, when both jaws were malpositioned, it was also significant in stage 2. In the control group, the middle portion of the tongue was in a more superior position in stage 3 than in stages 1 and 2 (Table IV). Our results showed that dentofacial morphology affects the movements of the middle portion of the tongue during deglutition; this result agrees with that of Cheng et al,[4] who reported significant correlations between tongue movement during swallowing and dentofacial morphology.

Comparison of the study groups with the control group showed that the posterior portion of the tongue

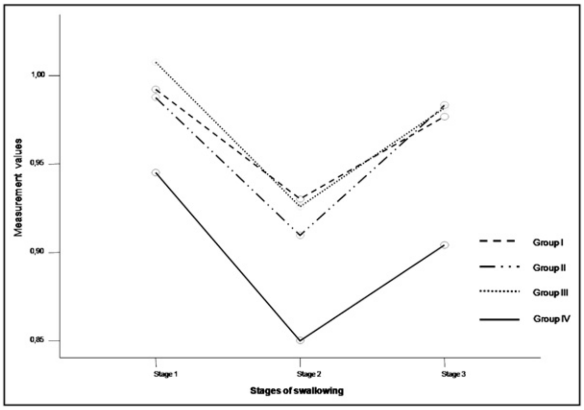

Fig 9. Changes of P'-Ti/PS-I proportions of all groups in all stages.

was positioned more inferiorly in all Class III groups. This result was consistent with the study of Ichida et al,[7] who reported that, when the corpus length increases, the tongue is positioned more inferiorly. In the evaluation of the tongue movements according to the deglutition stages, it was determined that the posterior portion of the dorsal tongue moved superiorly in the second stage and inferiorly in the third stage in the control group. Fujiki et al[20] also reported similar movements in patients with open bite and normal overbite. This is a physiologic function of the tongue for transportation of the bolus. However, in patients with Class III malocclusion, the posterior portion of the dorsal tongue had a different movement series compared with the control group. Since this portion was inferiorly positioned in the Class III groups, it moved superiorly at both stages 2 and 3. However, the amount of this movement was not sufficient to create statistically significant differences.

Table V. Multiple comparisons of groups in all stages

	Groups		Mean difference	SE	P	Significance
Anterior portion of tongue	Mandibular prognathism	Maxillary retrognathism	0.006	0.016	1.000	NS
		Bimaxillary	0.001	0.015	1.000	NS
		Control	−0.063	0.015	0.001	‡
	Maxillary retrognathism	Bimaxillary	−0.005	0.016	1.000	NS
		Control	−0.069	0.016	0.001	‡
	Bimaxillary	Control	−0.064	0.016	0.001	‡
Middle portion of tongue	Mandibular prognathism	Maxillary retrognathism	0.001	0.041	1.000	NS
		Bimaxillary	0.023	0.040	1.000	NS
		Control	−0.079	0.040	0.319	NS
	Maxillary retrognathism	Bimaxillary	0.022	0.041	1.000	NS
		Control	−0.080	0.041	0.332	NS
	Bimaxillary	Control	−0.102	0.041	0.086	NS
Posterior portion of tongue	Mandibular prognathism	Maxillary retrognathism	0.002	0.036	1.000	NS
		Bimaxillary	0.004	0.035	1.000	NS
		Control	0.204	0.035	0.001	‡
	Maxillary retrognathism	Bimaxillary	0.002	0.036	1.000	NS
		Control	0.202	0.036	0.001	‡
	Bimaxillary	Control	0.200	0.036	0.001	‡
Root of tongue	Mandibular prognathism	Maxillary retrognathism	−0.006	0.011	1.000	NS
		Bimaxillary	−0.003	0.011	1.000	NS
		Control	0.055	0.011	0.001	‡
	Maxillary retrognathism	Bimaxillary	0.004	0.011	1.000	NS
		Control	0.061	0.011	0.001	‡
	Bimaxillary	Control	0.058	0.011	0.001	‡
Tip of tongue	Mandibular prognathism	Maxillary retrognathism	0.006	0.016	1.000	NS
		Bimaxillary	−0.005	0.016	1.000	NS
		Control	0.067	0.016	0.001	‡
	Maxillary retrognathism	Bimaxillary	−0.012	0.017	1.000	NS
		Control	0.060	0.017	0.003	†
	Bimaxillary	Control	0.720	0.163	0.001	‡

†*P* <0.01; ‡*P* <0.001; *NS*, Not significant.

Evaluation of the root of the tongue showed that it was positioned more inferiorly and anteriorly in all Class III groups compared with the control group. In the evaluation of the deglutition stages, it was observed that, in the control group, the root of the tongue moved in a superior and posterior direction at stage 2 and in an inferior and anterior direction at stage 3. These movements were similar to the movement of the posterior portion of the dorsal tongue in the control group. However, the alterations in the root of the tongue were not statistically significant. In the Class III groups, the root of the tongue moved inferiorly and anteriorly at stages 2 and 3, but it was statistically significant only at stage 3 in the maxillary retrusion group. Probably, the movement of the root of the tongue is affected by the movement of the posterior portion of the dorsal tongue. In the Class III malocclusion groups, the posterior portion of the dorsal tongue moved superiorly and the root of the tongue moved inferiorly and anteriorly at both stages 2 and 3.

The results of our study showed that the tongue tip was positioned more anteriorly in the Class III groups than in the Class I control group. This result agrees with the study of Ichida et al,[7] who reported that, when corpus length and posterior rotation of the mandible increase, the tongue is positioned more inferiorly and anteriorly. Fuhrmann and Diedrich[16] also determined that, in patients with Class III malocclusion, the tongue is positioned more anteriorly. When the movement of the tongue tip was evaluated according to the stages, it was observed that it moved in the posterior direction at stage 2 and in the anterior direction at stage 3. The tongue tip had the same motion in both the Class III and Class I groups, but the posterior movement of the tongue tip was significant only at the second stages of the mandibular protrusion group (group 1) and the control group (group 4). Anterior movement of the tongue tip at stage 3 was significant only in patients with mandibular protrusion. According to Subtelny and Subtelny,[25] the tongue was positioned anteriorly for obstruction only at stage 3 in patients with Class III malocclusion. Our study showed that the source of the skeletal Class III malocclusion affects the movement of the tongue tip because anterior positioning of the tongue tip at stage 3 was not statistically significant in patients with maxillary retrusion or bimaxillary malocclusion. It was affected only by the anterior positioning of the mandible.

Evaluations of the movements of the middle portion, the posterior portion, and the root of the tongue (Table III) showed the manner of bolus transfer in patients with Class III and Class I malocclusion. In all Class III groups, the middle and posterior portions of the dorsal tongue moved superiorly in stages 2 and 3, whereas the root of the tongue moved inferiorly and anteriorly in these stages. On the other hand, evaluation of the tongue movements in the Class I occlusion group showed that bolus transfer was obtained by a fluctuation motion of the tongue. In this group, the middle portion of the dorsal tongue moved inferiorly in stage 2 and superiorly in stage 3, and the posterior portion and root of the tongue moved superiorly in stage 2 and inferiorly in stage 3. However, some of these alterations were not statistically significant, since their magnitudes were not sufficient to create statistically significant differences.

CONCLUSIONS

1. Dentofacial morphology affects the position of the dorsal tongue and movements during deglutition.
2. In patients with Class III malocclusion, the tongue is positioned more inferiorly and anteriorly than in those with skeletal Class I malocclusion.
3. The manner of bolus transfer is different in patients with skeletal Class III and Class I malocclusions. Linear motion of the tongue was observed in patients with Class III malocclusion, and a fluctuation motion of the tongue occurs in patients with Class I malocclusion.
4. Further studies are needed to determine the adaptive changes after the correction of Class III malocclusion, and this is the issue of another investigation planned at our department.

REFERENCES

1. Cleall JF. Deglutition: a study of form and function. Am J Orthod Dentofacial Orthop 1965;51:566-94.
2. Peng CL, Brinkmann PGJ, Yoshida N, Miethke RR, Lin CT. Differential diagnosis between infantile and mature swallowing with ultrasonography. Eur J Orthod 2003;25:451-6.
3. Peng CL, Miethke RR. A damping method makes possible a more exact sonographic study of tongue movements. Fortschr Kieferothop 1994;55:209-18.
4. Cheng CF, Peng CL, Chiou HY, Tsai CY. Dentofacial morphology and tongue function during swallowing. Am J Orthod Dentofacial Orthop 2002;122:491-9.
5. Peng CL, Jost-Brinkmann PG, Miethke RR. The cushion scanning technique—a method of dynamic tongue sonography and its comparison with the transducer-skin coupling scanning technique during swallowing. Acad Radiol 1996;3:239-44.
6. Cayley AS, Tindall AP, Sampson WJ, Butcher AR. Electropalatographic and cephalometric assessment of tongue function in open bite and non-open bite subjects. Eur J Orthod 2000;22:463-74.
7. Ichida T, Takiguchi R, Yamada K. Relationship between the lingual-palatal contact duration associated with swallowing and maxillofacial morphology with the use of electropalatography. Am J Orthod Dentofacial Orthop 1999;116:146-51.
8. Foucart JM, Carpentier P, Pajoni D, Rabischong P, Pharaboz C. Kinetic magnetic resonance imaging analysis of swallowing: a new approach to pharyngeal function. Surg Radiol Anat 1998;20:53-5.
9. Anagnostara A, Stoeckli S, Weber OM, Kollias SS. Evaluation of the anatomical and functional properties of deglutition with various kinetic high-speed MRI sequences. J Magn Reson Imaging 2001;14:194-9.
10. Hartl DM, Albiter M, Kolb F, Luboinski B, Sigal R. Morphologic parameters of normal swallowing events using single-shot fast spin echo dynamic MRI. Dysphagia 2003;18:255-62.
11. Akın E, Sayın MÖ, Karaçay Ş, Bulakbaşı N. Real-time balanced turbo field echo cine-magnetic resonance imaging evaluation of tongue movements during deglutition in subjects with anterior open bite. Am J Orthod Dentofacial Orthop 2006;129:24-8.
12. Karaçay Ş, Akın E, Sayın Ö, Bulakbaşı N. Real time balanced turbo field echo cine-MRI in the analysis of deglutition events and transit times. J Oral Rehabil 2006;33:646-53.
13. Sayın MÖ, Akin E, Karaçay Ş, Bulakbaşı N. İnitial effects of the tongue crib on tongue movements during deglutition. Angle Orthod 2006;76:400-5.
14. Karacay S, Akin E, Ortakoğlu K, Bengi AO. Dynamic MRI evaluation of tongue posture and deglutitive movements in a surgically corrected open bite. Angle Orthod 2006;76:1057-65.
15. Proffit WR. Equilibrium theory revisited: factors influencing position of the teeth. Angle Orthod 1978;48:175-86.
16. Fuhrmann R, Diedrich P. B-mode ultrasound scanning of the tongue during swallowing. Dentomaxillofac Radiol 1994;23:211-5.
17. Sato S. Case report: developmental characterization of skeletal Class III malocclusions. Angle Orthod 1994;64:105-11.
18. Miyajima K, McNamara JA Jr, Sana M, Murata S. An estimation of craniofacial growth in the untreated Class III female with anterior crossbite. Am J Orthod Dentofacial Orthop 1997;112:425-34.
19. Fujiki T, Inoue M, Miyawaki S, Nagasaki T, Tanimoto K, Takano-Yamamoto T. Relationship between maxillofacial morphology and deglutitive tongue movement in patients with anterior open bite. Am J Orthod Dentofacial Orthop 2004;125:160-7.
20. Fujiki T, Takano-Yamamoto T, Noguchi H, Yamashiro T, Guan G, Tanimoto K. A cineradiographic study of deglutitive tongue movement and nasopharyngeal closure in patients with anterior open bite. Angle Orthod 2000;70:284-9.
21. Fujiki T, Takano-Yamamoto T, Tanimoto K, Sinovcic JNP, Miyawaki S, Yamashiro T. Deglutitive movement of the tongue under local anesthesia. Am J Physiol Gastrointestinal Liver Physiol 2001;280:1070-5.
22. Dahlberg G. Statistical methods for medical and biological students. New York: Interscience Publications; 1940.
23. Ali GN, Cook IJ, Laundl TM, Wallace KL, de Carle DJ. Influence of altered tongue contour and position on deglutitive pharyngeal and UES function. Am J Physiol 1997;273(5 Pt 1):G1071-6.
24. Hopkins GB. Neonatal and adult tongue dimensions. Angle Orthod 1967;37:132-3.
25. Subtelny JD, Subtelny JD. Oral habits—studies in form, function, and threapy. Angle Orthod 1973;43:349-83.