行政院國家科學委員會專題研究計畫成果報告

利用口腔超音波研究舌頭慣性休息位置與齒顎形態之關係

Investigation of Tongue Habitual Rest Positions and the Corresponding Dentofacial Forms with the B+M -Mode Ultrasonography

計畫類別： ☑ 個別型計畫 □ 整合型計畫
計畫編號：**NSC89-2314-B-038-062**
執行時間：**89** 年 **7** 月 **1** 日~**90** 年 **7** 月 **31** 日

計畫主持人：彭建綸副教授
林哲堂教授

處理方式：□ 可立即對外提供參考
☑ 一年後可對外提供參考
□ 兩年後可對外提供參考

執行單位：台北醫學大學牙醫學系

中華民國九十一年十月二十八日

目錄

Abstract

To understand the role of tongue in the development of occlusion, the relationship between tongue movements during swallowing and dentofacial morphology was examined by ultrasonography, cephalometric radiography and dental casts. The computer-aided B+M-mode ultrasonography was used to assess their tongue movements. Duration, magnitude and speed of tongue movements in different swallowing phase were measured from 112 healthy adult volunteers and compared with their dentofacial morphology by means of a simple correlation analysis. The results showed that the movements of tongue during swallowing were related to the dentofacial morphology especially in the motion magnitude of the early final phase (phase IIIa), while only few correlations were found in the analysis of duration and speed of swallowing. The results also reported that the intermaxillary vertical relation had significantly positive relation with the motion magnitude of the tongue movements. Furthermore, arch length was found increased with prolonged duration of swallowing. This study elucidated that the computer-aided B+M-mode ultrasonography in combination with the cushion-scanning technique serves as a valuable tool for investigation of the relationship between tongue movements during swallowing and dentofacial morphology.

Introduction

Many researchers have studied the relationship between form and function of the stomatognathic system. It is widely accepted that an interaction exists between muscle function and dentofacial forms. However, it has long been debated that whether muscle function influenced bone morphology or merely adapted to local changes in the environment. For years orthodontists have theorized that the size, posture and function of the tongue must have some relationship to the surrounding oral cavity.[1-4] Several clinicians implicated the size of the tongue and its dysfunction were essential etiological factors in the development of malocclusion.[5-15] On the contrary, some reports had agreed that the tongue merely adapted to the environmental changes for swallowing and speech.[16-20] Because of this, it is important for the dental professional to identify abnormal tongue postures and movements that may have an adverse affect on the development of dentofacial morphology and may halt the orthodontic process or increase relapse in some cases.

Tongue movement could not be sufficiently examined due to the difficulty in access to the tongue in the oral cavity. In the past, examination of the tongue motor function was restricted to pure clinical observation. To date, various methods have been used to evaluate tongue movements such as electropalatography (EPG[21]), cineradiography[22], computerized tomography (CT[23]), magnetic resonance imaging (MRI[24]), electromagnetic articulography (EMA[25]) and ultrasonography.[26, 27] Because it was hard to swallow habitually in the cases of EPG and EMA, which receiver coils and wires attached to the palate or tongue, these two methods are not suitable for examination of normal tongue function. X-ray cinematography and CT have the disadvantage of radiation exposure. MRI is not suitable for examining swallowing movements because of its high cost and long acquisition time. Ultrasonography has the advantages of being noninvasive, rapid, easily repeatable and relatively inexpensive. Shawker and coworkers[28] first used B-mode sonography to investigate the tongue movement during swallowing. Peng and colleagues[29, 30] used M-mode ultrasonography for quantitative and qualitative evaluation of tongue functions. On the basis of M-mode images, the swallowing phase was reinterpreted and divided into five phases (Phase I, shovel phase; phase IIa, early transport phase; phase IIb, late transport phase; phase IIIa, early final phase; phase IIIb, late final phase) according to each turn point between two different directions of tongue movement. The cushion scanning technique (CST[31]) was used to overcome the problems including movements of the ultrasound transducer during swallowing and compression of the submental region that caused abnormal swallowing patterns. Therefore, using noninvasive real-time B+M-mode ultrasonography with CST has become the state-of-the-art tool to study tongue morphology as well as to observe tongue functions, such as swallowing or articulation.

The purposes of present study are to assess the relationship between movement of the tongue during swallowing and dentofacial forms, and to evaluate the applicability of real-time B+M-mode ultrasonography with CST for understanding the relationship between the duration and magnitude of tongue movements during swallowing and specific types of malocclusions.

Materials and Methods

Participants

One-hundred-and-twelve healthy volunteers (74 males, 38 females) ranging in age from 20 to 26 years (at the mean of 22 years) were chosen from students and members of the medical staff at Taipei Medical University and patients in the Department of Orthodontics of the University Hospital. They had no craniofacial deformity and sign of dysphagia or tongue functional disorders. Informed consent was obtained from all volunteers after a brief explanation of this study.

Measurement of tongue movement during swallowing

A noninvasive diagnostic technique, computer-aided B+M-mode ultrasonography was used in combination with the CST to assess the tongue movements (Peng et al.[31]). A 500ml polyvinyl chloride (PVC) bag for intravenous fluid injection (Y.F. chemical Corp, Taipei, Taiwan) filled with water as transmedium was used as a cushion. The PVC bag was connected to two drainage pipes, ensuring constant pressure in the cushion and an even distribution of the local pressure arising from movements of the submental area or the entire mandible (Fig. 1). The ultrasound transducer was fixed by a holder with adjustable hinges, which had scales to allow for reproducible registration of different scanning directions. The head supporter provided a firm and stable support for the forehead. This was supplemented with a head position-recording device, which consisted of frontal and lateral transparent acrylic plates. These plates allowed the head to be oriented repeatedly in relation to the

Frankford horizontal plane, extending from the upper rim of the tragus to the inferior border of the orbital rim (Fig. 2).

Swallowing was investigated with B+M-mode sonographic technique (Panasonic Panavista®-LSC I with 3.5 MHz, 13 mm in diameter, 100 degree mechanical sector transducer; Matsushita Corp, Tokyo, Japan). The ultrasound transducer was placed midway between the posterior border of the symphysis and the anterior margin of the hyoid bone in the midsagittal plane. At the same time, the transducer was oriented with its long axis perpendicular to the Frankfort horizontal plane. Ultrasound gel was applied to all coupling surfaces. The scan line (zero M-position) was placed through the middle of the B-mode sector image (Fig. 3). Imagine contrast was deliberately enhanced to emphasize the tongue surface. The sonographic signals were recorded on a digital video recorder (Sony DCR-TRV 110, Sony Corporation; Tokyo, Japan) and then transferred into an IBM-compatible personal computer via a frame grabber (Upmost DV FUN, Upmost Technology Corp.; Taipei, Taiwan) for digital assessment. The positions of each turn point along the tongue surface on the M-mode image were zoomed and digitized with the help of two graphic programs (Video studio 4.0 SE, Ulead Systems Inc; Taipei, Taiwan andPhotoshop 5.02, Adobe Systems Inc.; San Jose, CA, USA). This resulted in the successful separation and recording of the duration and magnitude of tongue movements in each swallowing phase.

In order to imitate a habitual swallowing or wet swallowing rather than a dry swallowing, all participants were asked to swallow 3 to 5 ml of water through a straw before the ultrasonographic registration started, waited 10 seconds, and then swallowed again. This swallowing was recorded as a standard and used for digital assessment. Each swallowing cycle was repeated three times with intervals of at least 20 seconds. Duration, magnitude and speed of motions during swallowing from 122 examined subjects were calculated in each phase of swallowing (Fig. 4). The mean of the three swallowing cycles was used as the representative value to proceed the statistic analysis.

Measurement of dentofacial dimensions

Dentofacial morphology was measured from lateral cephalometric radiographs (Orthophos CD; Siemens AG, Bensheim, Germany) and dental study models. From cephalometric radiographs, we obtained 16 angular, 22 linear and 1 ratio-related measurement items by 21 landmarks and 5 reference planes (Fig. 5), which were used in conventional cephalometric analysis. In order to simplify the redundant measurements, we grouped these variables into 3 categories and 14 principle components in clusters of related variables (Table I). Dental study models were obtained for each subject to measure the intercanine widths, the intermolar widths, and the arch length (Fig. 6) with a millimeter boley gauge.

Statistical Analysis

The measurements of the dentofacial forms and the movements of tongue from the 112 examined individuals were calculated and analyzed. To examine the relationship between the movements of tongue and dentofacial forms, a simple correlation analysis was performed. For all statistical analyses, the Statistica 4.0 for Windows (Statsoft, Inc. 1993) was used.

Measurement error

All measurements were performed by the same investigator to eliminate the inter-examiner variability. The intra-examiner errors for the ultrasound measurements, cephalometric, and study models were investigated on repeated measurements of a randomly selected participant 10 times by the same examiner with a 7-day interval. Coefficient of variation (Cv) was calculated for these measurements. The ultrasound measurement errors were 4.4% in duration and 1.08% in magnitude. The measurement errors of study model were 3.71%; the cephalometric ones were 2.29% in linear and 6.59% in angular. Furthermore, to evaluate the intra-individual reproducibility, one randomly selected participant was asked to swallow 10 times at the same visit. The results showed 5.65% in duration and 3.99% in magnitude measurement errors. In addition, we designed the standard reference material (SRM) to evaluate the validity of CST with a PVC cushion bag. The results indicated that the distortion was 0.93% using the B+M-mode ultrasonography.

Results

The means and standard deviations of the measurements of dentofacial morphology and the ultrasound measurements of tongue movements from 112 examined individuals were given in Table IIA and IIB. All linear and angular variables of dentofacial dimension appeared normally distributed. The total duration of tongue movement in a swallowing cycle ranged from 1.4 to 3.6 seconds; the mean was 2.5 seconds. The total magnitude of motion in a swallowing cycle ranged from 12.0 to 44.6 mm; the mean was 29.0 mm.

Results of simple correlations showed in Table III. The movements of tongue during swallowing were related to the dentofacial forms especially in the motion magnitude of the early final phase (phase IIIa). The significantly correlated cephalometric measurement items were AB, AFH, ALFH, UHF/LFH, L1-L1', L6-L6' value and OJ. Only few correlations were found in the duration and speed of the early and late transport phases (phase IIa and IIb). There was no correlation between the dentofacial morphology and swallowing in the duration of the shovel phase (Phase I) and the motion magnitude of late final phase (phase IIIb).

The intermaxillary vertical relation (the component 8) and the mandibular molar eruption (component 12) were found most significantly correlated with the tongue movements. In the component 14, we found that as the arch length increased, the duration of swallowing prolonged significantly in late final phase (phase IIIb). The cranial base (component 1) and the maxilla (component 2-4), except the palatal depth, showed no correlation to swallowing.

Discussion

Evaluation of interrelationship between swallowing and the dentofacial morphology

Results of the simple correlations showed the following trend. First of all, those who had greater motion magnitude of the early final phase (phase IIIa) during swallowing tended to have deeper palatal vault, more increased mandibular length, longer lower face, larger overjet, more overerupted molars and incisors, along with more labially inclined maxillary incisors, however, more decreased ANB angle and Wits appraisal as well as shallow overbite. Furthermore, those who had prolonged duration of swallowing had tendencies of increased gonial angle, steep mandibular plane, opened occlusal plane, as well as increased mandibular body and ramus length, raised anterior lower facial height, lingually inclined lower incisors and increased arch length.

Previous reports indicated that size, posture, and function of the tongue were significantly correlated with dentofacial morphology including jaw relation, abnormity of dental arch form and abnormal tooth position or malocclusion. With regard to jaw relation, Fuhrmann and Diedrich[32] showed that the majority of abnormal or inconsistent swallowing patterns were found in cases of mandibular prognathism. In our study, which agree with Fuhrmann's finding, also pointed out that as the mandibular length increased, the motion magnitude of the early final phase (phase IIIa) increased and duration of swallowing prolonged. Hopkins[19] studied the position of the mandible and concluded that the anteroposterior position of the mandible relative to the maxilla and the length of the mandible were key factors in determining the level of the tongue relative to the upper arch. Our findings deepened the Hopkins' study and elucidated that the intermaxillary antero-posterior relation (component 7), including ANB angle and Wits appraisal, had negative correlation with tongue movement in the motion magnitude of the early final phase (phase IIIa). In other words, those who had prognathous mandible showed to have a greater motion magnitude in the early final phase during swallowing. Ichida and coauthors[21] stated a prolonged lingual-palatal contact while swallowing had tendencies of opened mandibular and occlusal planes, as well as clockwisely rotated lower jaw. In our study, we found those who had prolonged duration of swallowing, especially in early final phase (phase IIIa), tend to show increased gonial angle, steep mandibular plane and opened occlusal plane. Our results corresponded with the Ichida's descriptions.

With reference to dental arch form and tongue, Lowe and Johnston[2] stated the frequency of low tongue postures and narrow maxillary arches appeared to increase with large lower facial heights. Mikell[33] reported that the flaccid, low-lying tongue allowed buccal pressure to constrict the upper arch and might cause the palate to develop a high, narrow, and arched construction. Compared to our results, the palatal depth had positive correlation with motion magnitude of tongue movement in early final phase (phase IIIa), however, showed no relation between arch width and tongue movement. In addition, as the arch length increased, the duration of swallowing prolonged significantly in late final phase (phase IIIb). In other words, there were correlations between tongue movement and palatal vault as well as arch length, rather than arch width. This result in combination with the Mikell's report might elucidate that tongue movement provide more effect on the vertical and sagital development of the dentoalveolar morphology; while buccal pressure might play more important role on a narrow arch form as tongue.

Relating to malocclusion and tongue, Fujiki and his colleagues[34] reported the tongue-tip position was more protrusive during deglutition in anterior open bite. Overstake[35] concluded that there was a functional relationship between deviant swallowing and open-bites as well as overjets. Therefore, swallowing therapy could be efficacious in the improvement of such dental malformation. Alexander[4] also pointed that a significant increase in the extent of anterior teeth proclination in the upper arch in the tongue thrust individuals was attributed to the effect of the increased frequency of electrical activity of the genioglossus muscle and prolonged duration of swallow. Hanson and coworkers[36] described the deleterious forces of the tongue resulted in the overeruption of the posterior teeth, and an open-bite or an overjet condition. In our study, we also found those who had a greater motion magnitude of the early final phase (phase IIIa) during swallowing tended to have more increased overjet, labially inclined maxillary incisors and overerupted molars, however, more decreased overbite. Our results agreed with the descriptions in these literatures.

Despite the significant correlations between tongue movements during swallowing and dentofacial morphology, we could not conclude that the abnormal swallowing would cause and maintain a malocclusion. Many factors must be considered: for example, the frequency of swallow or how often the tongue exerted a force on the teeth, the magnitude of the force itself when it was exerted on the teeth, the counteraction of these forces by other muscular structures such as lips, the resistance of dentoalveolar structures to displacement, and even the resting posture of the tongue when no swallowing activity occurs.

Evaluation of tongue movement during swallowing

Tongue movement during swallowing had been studied by having subjects to swallow a fixed amount of liquid such as water or natural swallowing saliva. Akiyoshi and coauthors[39] showed that swallowing of saliva, conscious or unconscious, was much more frequent than swallowing during drinking and eating. A normal adult person repeats this normal swallowing pattern between 1200 and 3000 times each day[40]. Therefore, habitual swallowing of saliva is considered to have more effect on dentofacial morphology than water swallowing, and was chosen to performed in the present study.

The duration of swallowing has been reported in many previous studies. In an electromyographic investigation by Findlay and Kilpatrick[37], the average swallowing time was found to be 2.02 seconds. The duration of lingual-palatal contact during saliva swallowing ranged from 1.1 to 2.9 seconds in Ichida's[21] study. Sonies and colleagues[38] reported that the time for swallowing was between 1.79 and 3.41 seconds for swallowing saliva. Peng and his coauthors[30] published the duration and magnitude of tongue movements in 165 examined swallows ranged from 0.95 to 4.69 seconds (with a 2.43 second mean) and from 5.01 to 71.67 mm (with a 24.06 mm mean). In the present study, the total duration and total magnitude of tongue movement in a swallowing cycle ranged from 1.4 to 3.6 seconds (at the mean of 2.5 seconds) and from 12.0 to 44.6 mm (at the mean of 29.0 mm) in 112 examined individuals. This result was quite similar to Peng's study, especially in the duration of swallowing.

The most common method used to determine the duration of swallowing sonographically was to analyze B-mode recordings of tongue movement frame by frame in the past. The definition of the start and the end of a tongue movement was somewhat arbitrary, especially if no superimpositions of consecutive frame were used. The exact timing of the tongue rest position could be identified as soon as the tongue surface and tongue muscles on the M-mode imagine came to a flat signal. Therefore, the determination of swallowing duration was more accurate and objective than other previous methods.

Validity and intra-individual reproducibility

The CST have been proven to create a buffer area between the transducer and the skin to avoid the problems including movements of the ultrasound transducer during swallowing and compression of the submental region that happened quite often in other ultrasound studies[31]. In order to evaluate the validity of CST, we designed a standard reference material (SRM) and found that the distortion was 0.93% when the SRM was measured with the technique used in this study. In order to evaluate the intra-individual reproducibility, one randomly selected participant was asked to swallow 10 times at the same visit. The results showed 5.65% in duration and 3.99% in magnitude measurement errors, which suggested a high intra-individual reproducibility. Further application of the CST supported real-time B+M-mode ultrasonography is highly recommended for understanding the relationship between the tongue function and dentofacial morphology.

Conclusion

The following conclusions can be drawn in this study --

(1) There were significant correlations between tongue movement during swallowing and dentofacial morphology.

(2) The movements of tongue during swallowing were related to the dentofacial forms especially in the motion magnitude of the early final phase.

(3) The significantly correlated cephalometric measurement items were AB, AFH, ALFH, UHF/LFH, L1-L1', L6-L6' value and OJ.

(4) The intermaxillary vertical relation and the mandibular molar eruption were found most significantly correlated with the tongue movements.

(5) As the arch length increased, the duration of swallowing prolonged significantly in late final phase.

(6) The computer-aided B+M-mode ultrasonography in combination with the cushion-scanning technique serves as a valuable tool for investigation of the relationship between tongue movements during swallowing and dentofacial morphology.

Acknowledgement

This study was supported by National Scientific Council of Taiwan (Grant: NSC89-2314-B-038-028). We are indebted to those students who spent numerous hours to make our research successful.

Reference:

1. Melson B, Attina L, Santuari M, and Attina A. Relationships between swallowing pattern, mode of respiration, and development of malocclusion. Angle Orthod 1987;April:113-119.
2. Lowe AA, Johnston WD. Tongue and jaw muscle activity in response to mandibular rotations in a sample of normal and anterior open-bite subjects. Am J Orthod 1979;76(5): 565-576.
3. Fuhrmann RAW, Dietrich PR. B-mode ultrasound scanning of the tongue during swallowing. Dentomaxillofac Radiol 1994;23:211-215.
4. Alexander S. Genioglosis muscle electrical activity and associated arch dimensional changes in simple tongue thrust swallow pattern. J Clin Pediatr Dent 1997;21:213-222.
5. Lauder R, Muhl Z. Estimation of tongue volume from magnetic resonance imaging. Angle Orthod 1991;61:175-183.
6. Andrews, R.G. Tongue thrusting. J South Calif Dent Assoc 1960;28:47-53.
7. Kortsch WE. The tongue, implicated in Class II malocclusion. J Wis Dent Soc 1965;41: 261-262.
8. Smirnoff GN. A preliminary study of mandibular morphology and the measurement of lingual thrusting pressures in subjects exhibiting tongue thrust swallowing and anterior open bites. Am J Orthod 1965;51:306-307.
9. Ricketts RM. Tonsils and dental abnormalities. JAMA 1965;192:1110-5.
10. Harvold EP. The role of function in the etiology and treatment of malocclusion. Am J

Orthod 1968;54:883-897.

11. McLaughlin PJ. Orofacial myology: current trends. Int J Orofacial Myol 1988;14:1-8.

12. Hanson ML. Orofacial myofunctional therapy: historical and philosophical considerations. Int J Orofacial Myol 1988;14:3-10.

13. Hale ST, Kellum GD, Bishop FW. Prevalence of oral muscle and speech differences in orthodontic patients. In J Orofacial Myol 1988;14:6-10.

14. Proffit WR. Equilibrium theory revisited: Factors influencing position of the teeth. Angle Orthod 1978;48:175-186.

15. Rainer Schwestka-Polly. Electromagnetic articulography as a method for detecting the influence of spikes on tongue movement. Eur J Orthod 1995;17:411-417.

16. Cleall, J.F. Deglutition: A study of form and function. Am J Orthod 1965;51:566-594.

17. Miline IM, Cleall JF. Cinefluorographic study of functional adaptation of the oropharyngeal structures. Angle Orthod 1970;40:267-283.

18. Subteley JD. Malocclusions, orthodontic corrections, and orofacial muscle adaptation. Angle Orthod 1970;40:170-201.

19. Hopkins, G.B. Neonatal and adult tongue dimensions. Angle Orthod 1967;37:132-133.

20. Lowe AA, Gurza S, Sessile BJ. Excitatory and inhibitory peripheral influences on tongue muscle activity in cat and monkey. Brain Res 1976;113:417-422.

21. 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.

22. Ekberg O, Hillarp B. Radiologic evaluation of the oral stage of swallowing. Acta Radiol Diag 1986;27:533-537.

23. Lowe AA, Gionhaku N, Takeuchi K, Fleetham JA. Three-dimensional CT reconstructions of the tongue and airway in adult subjects with obstructive sleep apnea. Am J Orthod Dentofac Orthop 1986;90:364-374.

24. Rainer Schwestka-Polly. Electromagnetic articulography as a method for detecting the influence of spikes on tongue movement. Eur J Orthod 1995;17:411-417.

25. Schwestka-polly R, Engelke W, Hoch G. Electromagnetic articulogrphy as a method for detecting the influence of spikes on tongue movement . Eur J Orthod 1995;17:411-417.

26. Peng C-L, Miethke R-R. A new cushion method, which makes possible a more accurate ultrasonic examination of tongue movements. Fortschr Kieferorthop 1994;55:209-218.

27. Fuhrmann R, Diedrich P. B-mode ultrasound scanning of the tongue during swallowing. Dentomaxillofac Radiol 1994;23:211-215.

28. Shawker T, Sonies B, Stone M, Baum B. Real time ultrasound visualization of tongue movement during swallowing. J Clin Ultrasound 1983;11:485-490.

29. Peng C-L, Jost-Brinkmann P-G, Lin C-T, et al: Classification and interpretation of the oral phase of swallowing with B+M-mode ultrasonography. Radiologe 1995;35:747-52.

30. Peng C-L, Jost-Brinkmann P-G, Miethke R-R, Lin C-T. Ultrasonographic measurement of tongue movement during swallowing. J Ultrasound Med 2000;19:15-20.

31. Peng C-L, Jost-Brinkmann P-G, Miethke R-R. 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;3:239-244.

32. Fuhrmann RAW and Diedrich PR. B-mode ultrasound scanning of the tongue during swallowing. Dentomaxillofac Radiol 1994;23:211-215.

33. Mikell B. Recognizing tongue related malocclusions. In J Orofac Myol 1982;10;12-16.

34. Fujiki T, Takano-Yamamoto T, Noguchi H, Tamashiro T, Guan G, Tanimoto K. A cineradiographic study of deglutitive tongue movement and nasopharyngeal closure in patients with anterior open bite. Angle Orthod 2000;70:284-289.

35. Overstake CP. Investigation of the efficiency of a treatment program for deviant swallowing and allied problems. Int J Orofacial Myol 1975;1:87-104.

36. Hanson ML, Barnard LW, Case JL. Tongue-thrust in preschool children. Part II: Dental

occlusal patterns. Am J Orthod 1970;57:15-22.

37. Findly IA, Kilpatrick SJ. An analysis of myographic records of swallowing in normal and abnormal subjects. J Dent Res 1960;39:629-35.

38. Sonies BC, Parent LJ, Morrisch K, et al. Durational aspects of the oropharyngeal phase of swallowing in normal adults. Dysphagia 1988;3:1-10.

39. Akiyoshi M, Suzuki S, Kawamura M, Terashima T, Noguchi K, Kuroda T. Study on the tongue movement and the tongue-palatal relation in deglutition. J Jpn Orthod Soc 1995;54:102-111.

40. Kydd WL and Neff CW. Frequency of deglutition of tongue thrusters compared to a sample population of normal swallowers. J Dent Res 1964;43:363-9.

Fig. 1.

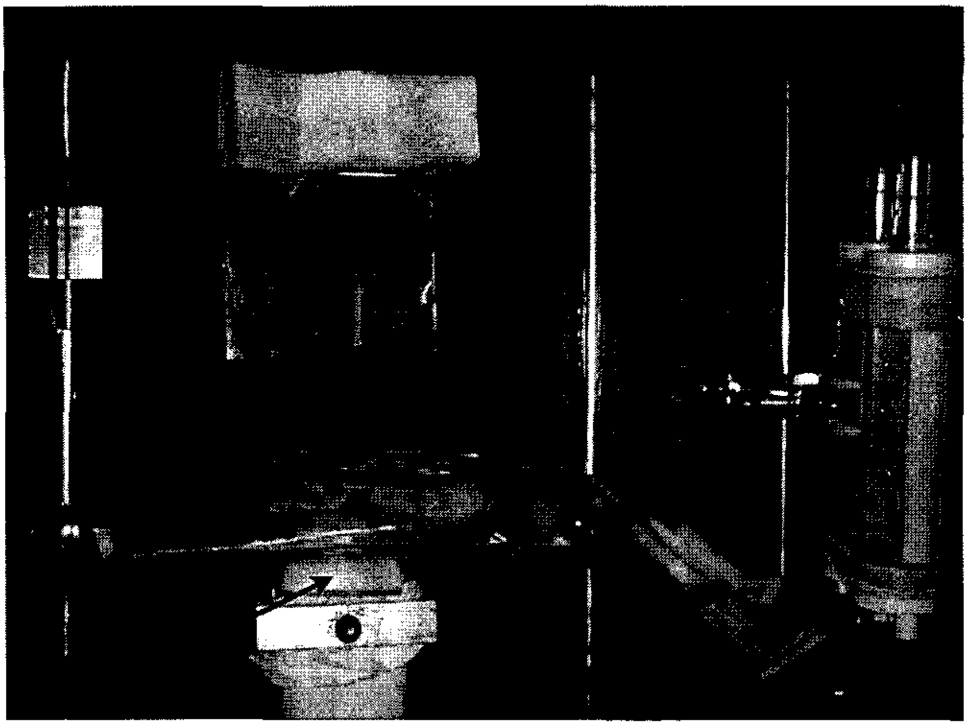


Fig. 2.

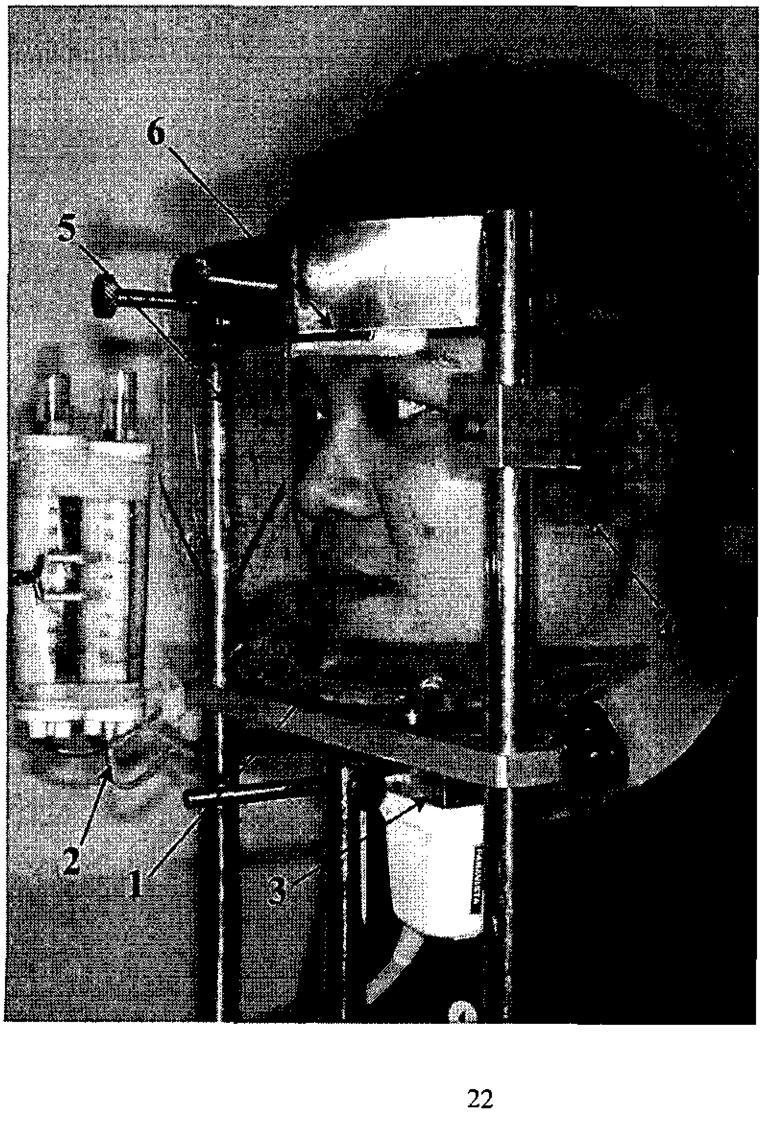


Fig. 3.

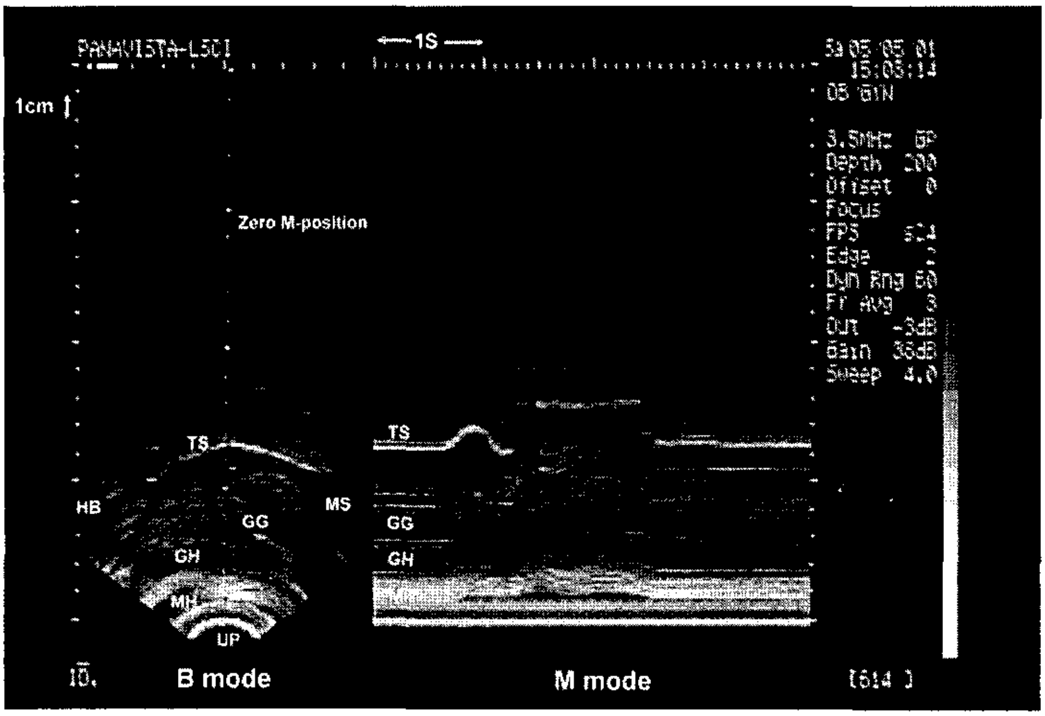
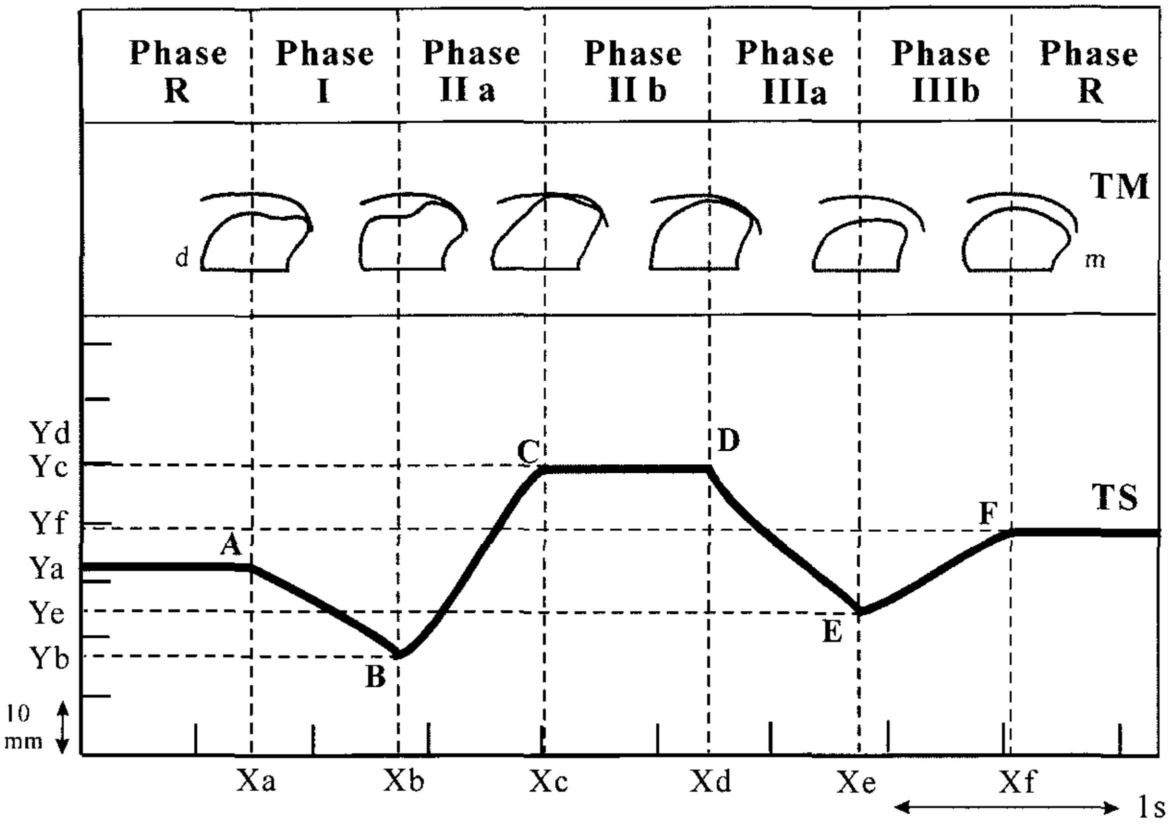

PANAVISTA-L5CI
1S
1cm
Zero M-position
TS
HB
GG
MS
GH
MH
UP
TS
GG
GH
B mode
M mode
3.5MHz
Depth 200
Offset 0
Focus
FPS
Edge
Dyn Rng 60
Fr Avg 3
Out -3dB
Gain 36dB
Sweep 4.0

Fig.4.



	Phase I	Phase II a	Phase II b	Phase III a	Phase III b
D(s)	Xb-Xa	Xc-Xb	Xd-Xc	Xe-Xd	Xf-Xe
M(mm)	/Yb-Ya/	/Yc-Yb/	/Yd-Yc/	/Ye-Yd/	/Yf-Ye/

Fig. 5.

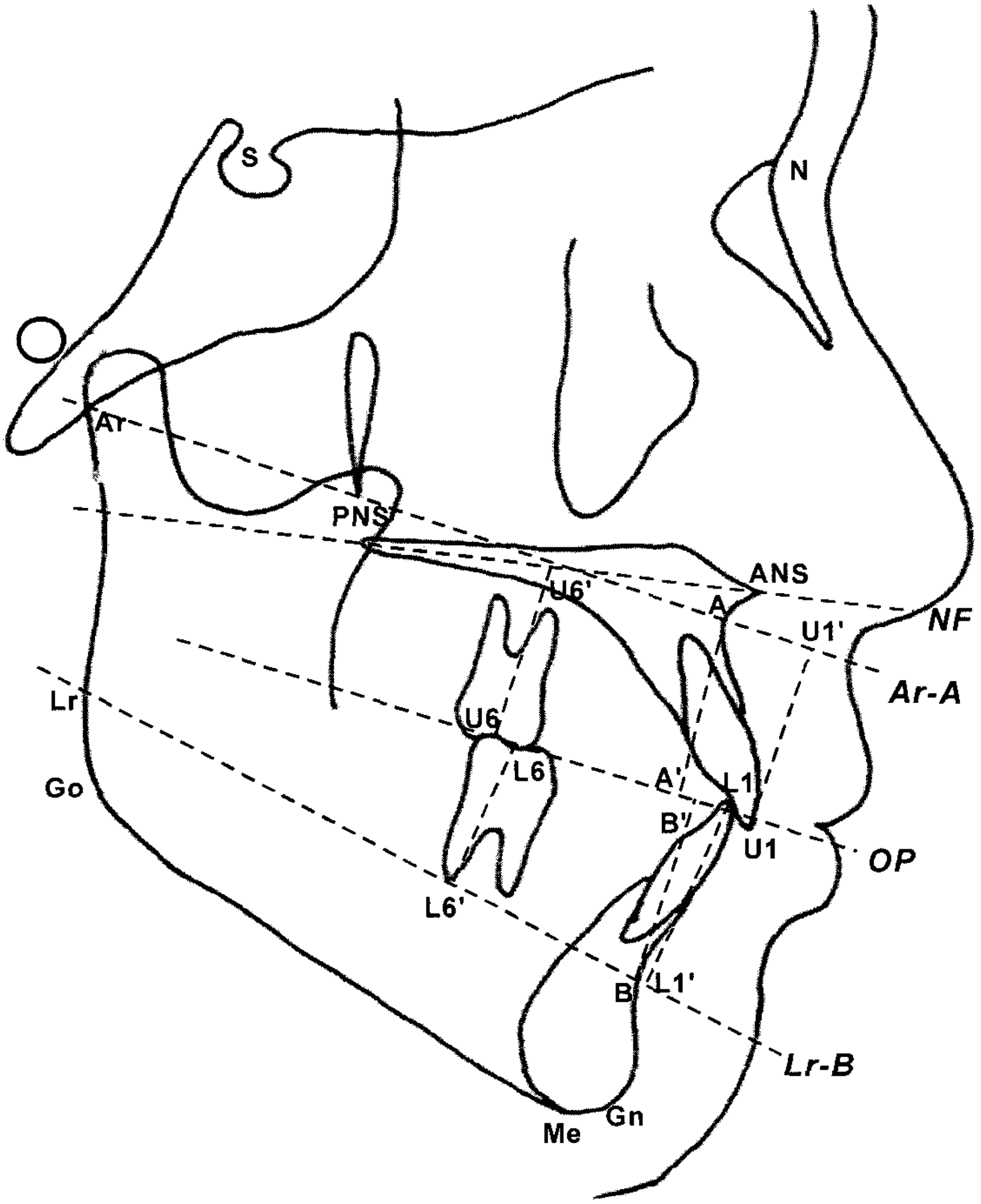


Fig. 6.

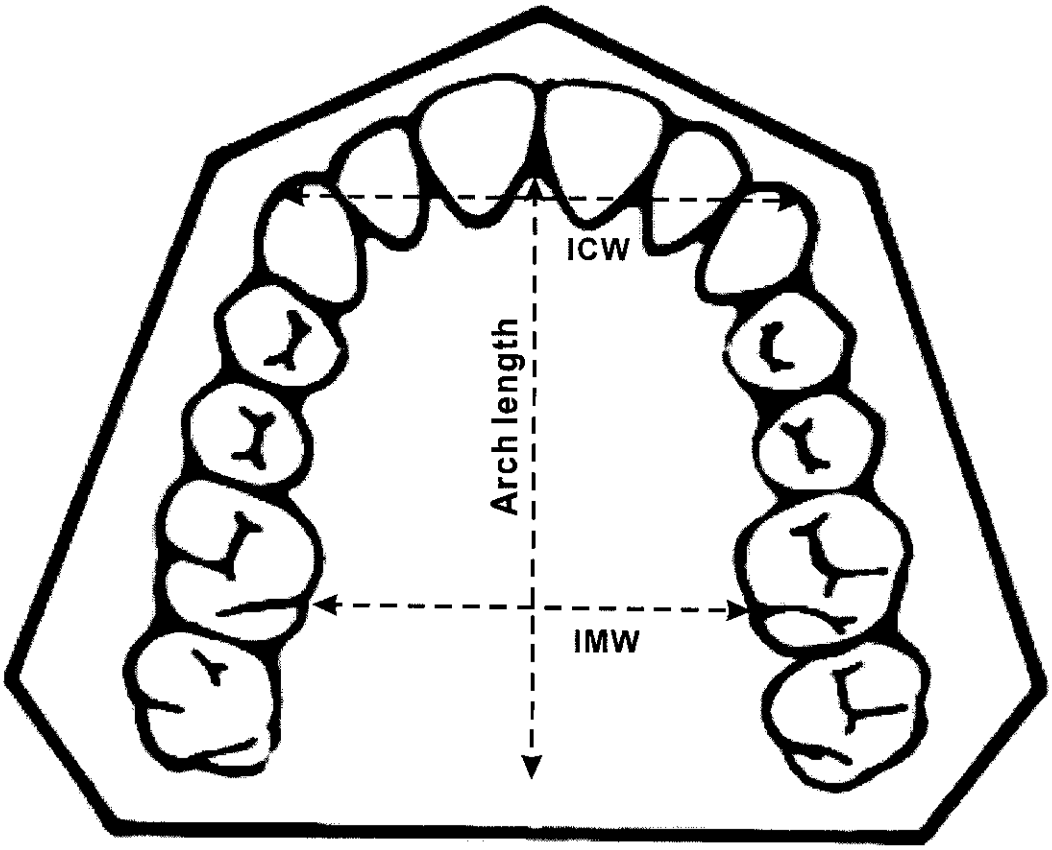


Fig. 1. Illustration of the relationship between the cushion device and the ultrasound transducer (1. Cushion; 2. Drainage pipe; 3. Cushion device supporter; 4. Ultrasound transducer)

Fig. 2. Illustration of the components of the CST (1. Cushion; 2. Drainage pipe; 3. Ultrasound transducer holder; 4. Lateral head position recording device; 5. Frontal head position recording device; 6. Head support)

Fig. 3. B+M mode ultrasonogram (TS: tongue surface; HB: hyoid bone; MS: mandibular symphysis; UP: ultrasound probe; GG: genioglossus muscle; GH: geniohyoid muscle; MH: mylohyoid muscle)

Fig. 4. Duration and magnitude of tongue movement in each phase was determined graphically (R: rest phase; TS: tongue surface; TM: tongue movement; d: distal; m: mesial; D: duration; M: magnitude)

Fig. 5. Landmarks of cephalometric analysis

Fig. 6. Measurements on maxillary dental casts
(ICW: intercanine width; IMW: intermolar width)

Table I Measurement items of the dentofacial dimension

A. Skeletal pattern

- (1) Cranial base ---
  - ***Component 1***：SN，SAr，NSAr
- (2) Maxilla ---
  - ***Component 2***：(*Antero-posterior*) ArA，SNA
  - ***Component 3***：(*Vertical*) NA，palatal depth，AUFH
  - ***Component 4***：(*Rotation*) SN/NF，SN/OP
- (3) Mandible ---
  - ***Component 5***：(*Antero-posterior*) Ar-Gn，Ar-Go，Go-Me，SNB
  - ***Component 6***：(*Rotation*) ∠Go，FMA，SN/MP，OP/MP，SGn/SN
- (4) Intermaxillary ---
  - ***Component 7***：(*Antero-posterior*) ANB，Wits
  - ***Component 8***：(*Vertical*) AB，AFH，ALFH，PFH，UFH/LFH

B. Dental pattern

- ***Component 9***：(*U1*) U1-U1'，U1axis/NF，U1-NA，U1axis/NA
- ***Component 10***：(*L1*) L1-L1'，L1axis/MP，L1-NB，L1axis/NB
- ***Component 11***：(*U6*) U6-U6'
- ***Component 12***：(*L6*) L6-L6'
- ***Component 13***：(*Interincisal*) OJ，OB，U1/L1

C. Dental arch form

- ***Component 14***：ICW，IMW，arch length

Palatal depth: the distance between mesio-buccal cusp of maxillary first molar with nasal floor (NF)
NF: nasal floor (PNS-ANS); OP: occlusal plane
AUFH: anterior upper facial height (N-ANS); AFH: anterior facial height (N-Me)
ALFH: anterior lower facial height (ANS-Me); PFH: posterior facial height (S-Go)
U1/L1: interincisal angle

Table IIA Descriptive statistics of the dentofacial dimension

Variable	Mean	SD	Min	Max	Variable	Mean	SD	Min	Max
Component 1					***Component 8***				
SN	70.7mm	3.4mm	62.0mm	79.7mm	AB	45.1mm	3.8mm	36.7mm	55.2mm
SAr	41.4mm	4.1mm	31.3mm	51.6mm	AFH	132.9mm	7.4mm	116.0mm	148.8mm
NSAr	122.7°	4.8°	112.4°	132.7°	ALFH	74.0mm	5.7mm	62.1mm	89.7mm
Component 2					PFH	91.4mm	7.9mm	73.0mm	110.6mm
ArA	90.6mm	5.3mm	79.0mm	105.2mm	UFH/LFH	79.9%	6.4%	58.1%	92.4%
SNA	83.5°	3.5°	75.2°	91.4°	***Component 9***				
Component 3					U1-U1’	23.4mm	2.6mm	18.1mm	30.1mm
NA	65.1mm	3.6mm	56.5mm	73.0mm	U1axis/NF	118.0°	7.2°	93.5°	131.4°
Palatal depth	27.1mm	2.7mm	21.0mm	35.0mm	U1-NA	8.1mm	2.8mm	-3.4mm	14.5mm
AUFH	58.9mm	3.4mm	49.6mm	66.7mm	U1axis/NA	26.3°	7.1°	1.5°	40.1°
Component 4					***Component 10***				
SN/NF	8.1°	3.5°	0.1°	16.8°	L1-L1’	22.8mm	2.2mm	17.1mm	29.6mm
SN/OP	14.0°	5.0°	2.1°	31.0°	L1axis/MP	97.4°	6.9°	79.0°	114.7°
Component 5					L1-NB	7.5mm	2.6mm	1.0mm	13.3mm
Ar-Gn	118.9mm	7.8mm	99.0mm	135.9mm	L1axis/NB	28.1°	6.3°	4.5°	43.6°
Ar-Go	54.3mm	6.3mm	41.0mm	74.8mm	***Component 11***				
Go-Me	79.4mm	6.2mm	68.7mm	109.7mm	U6-U6’	25.4mm	2.5mm	20.3mm	32.7mm
SNB	81.5°	4.0°	70.6°	90.8°	***Component 12***				
Component 6					L6-L6’	17.6mm	2.7mm	11.5mm	31.8mm
∠Go	116.5°	6.6°	100.3°	133.6°	***Component 13***				
FMA	23.9°	5.3°	13.4°	41.4°	OJ	3.3mm	1.8mm	-2.5mm	8.5mm
SN/MP	29.5°	6.2°	15.4°	45.9°	OB	2.0mm	1.8mm	-4.5mm	6.5mm
OP/MP	15.5°	4.5°	4.0°	29.2°	U1/L1	123.4°	9.2°	102.8°	160.1°
SGn/SN	68.9°	3.7°	60.8°	78.3°	***Component 14***				
Component 7					ICW	35.4mm	2.2mm	29.4mm	41.6mm
ANB	2.0°	2.5°	-6.9°	7.8°	IMW	42.7mm	3.6mm	34.7mm	55.0mm
Wits	-2.4mm	3.4mm	-10.2mm	6.8mm	Arch length	49.1mm	4.4mm	40.1mm	61.0mm

Table IIB Descriptive statistics of the tongue movement

Variable	Mean	SD	Min	Max
I (d)	0.54	0.26	0.05	1.52
I (m)	4.25	3.27	0.00	11.79
IIa (d)	0.20	0.07	0.07	0.41
IIa (m)	16.20	4.41	4.18	28.01
IIa (s)	96.34	46.67	18.63	246.10
IIb (d)	0.94	0.38	0.34	1.95
IIIa (d)	0.29	0.11	0.11	0.62
IIIa (m)	12.70	3.53	5.67	22.19
IIIa (s)	50.50	21.63	12.28	144.21
IIIb (d)	0.56	0.21	0.11	1.19
IIIb (m)	1.13	0.99	0.00	4.88
Total (d)	2.53	0.47	1.37	3.56
Total (m)	29.02	6.84	12.01	44.63

d= duration (sec), m= magnitude (mm), s= speed of tongue movement (mm/sec)

Table III Results of simple correlation analysis

	I(d)	I(m)	IIa(d)	IIa(m)	IIa(s)	IIb(d)	IIIa(d)	IIIa(m)	IIIa(s)	IIIb(d)	IIIb(m)	Total(d)	Total(m)
Component 1													
SN													
SAr													
NSAr													
Component 2													
ArA													
SNA													
Component 3													
NA													
Palatal D								+0.29**					+0.25**
AUFH													
Component 4													
SN/NF													
SN/OP													
Component 5													
Ar-Gn								+0.23*					
Ar-Go										+0.25*			
Go-Me						+0.22*		+0.20*				+0.19*	
SNB													
Component 6													
∠Go							+0.20*						
FMA													
SN/MP				+0.19*									
OP/MP							+0.19*						
SGn/SN				+0.24*									
Component 7													
ANB								-0.28**					
Wits								-0.22*					

	I(d)	I(m)	IIa(d)	IIa(m)	IIa(s)	IIb(d)	IIIa(d)	IIIa(m)	IIIa(s)	IIIb(d)	IIIb(m)	Total(d)	Total(m)
Component 8													
AB		-0.20*		+0.24*			+0.21*	+0.36***					+0.33***
AFH		-0.23*					+0.20*	+0.31***					+0.25*
ALFH		-0.24*		+0.19*			+0.20*	+0.37***					+0.31***
PFH								+0.25*					
UFH/LFH								-0.31***					-0.27**
Component 9													
U1-U1'													
U1axis/NF													
U1-NA								+0.27**					
U1axis/NA								+0.21*					
Component 10													
L1-L1'		-0.29**					+0.20*	+0.32***					+0.26*
L1axis/MP													
L1-NB										-0.22*			
L1axis/NB										-0.20*			
Component 11													
U6-U6'							+0.21*	+0.26*					
Component 12													
L6-L6'				+0.23*				+0.38***	+0.21*	-0.22*			+0.33***
Component 13													
OJ								+0.32***					+0.24*
OB								-0.21*					-0.22*
U1/L1													
Component 14													
ICW													
IMW													
Arch L			+0.21*		-0.24*		+0.19*		-0.23*	+0.41***		+0.22*	

(*$P < .05$; **$P < .005$; ***$P < .001$)