J Exp Clin Med 2011;3(2):93–98

Contents lists available at ScienceDirect

Journal of Experimental and Clinical Medicine

journal homepage: http://www.jecm-online.com

ORIGINAL ARTICLE

Changes in the Pharyngeal Airway and Position of the Hyoid Bone After Treatment With a Modified Bionator in Growing Patients With Retrognathia

Yen-Chun Lin [1], Hsiang-Chien Lin [2], Hung-Huey Tsai [3,4]*

[1] Division of Orthodontics, Department of Dentistry, Taipei Medical University Hospital, Taipei, Taiwan
[2] School of Dentistry, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan
[3] School of Oral Hygiene, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan
[4] Division of Pediatric Dentistry, Department of Dentistry, Taipei Medical University Hospital, Taipei, Taiwan

ARTICLE INFO

Article history:
Received: Dec 3, 2010
Revised: Jan 21, 2011
Accepted: Jan 24, 2011

KEY WORDS:
cephalometric radiograph;
hyoid bone;
modified bionator;
pharyngeal airway;
retrognathia

Background: To understand changes in (1) the anteroposterior dimensions of the pharyngeal airway and (2) the position of the hyoid bone after newly modified bionator treatment in growing patients with retrognathia.
Methods: Data of 86 patients (51 males aged 10.83 ± 1.40 years and 35 females aged 10.25 ± 1.47 years) with an Angle class II, Division I malocclusion, and a retruded mandible in mixed dentition were analyzed. All patients were treated using a modified bionator. The average treatment time was 1.86 years. After treatment, 56 patients were followed-up for approximately 2 years, and 22 patients were followed-up for 4 years. Lateral cephalometric radiographs were taken in four stages: before treatment (T0), at the time bionator treatment was stopped (T1), at 2 years of follow-up (T2), and at 4 years of follow-up (T3). Nine linear and 17 angular items of the craniofacial morphology, five linear items of the pharyngeal airway dimensions, and six linear items of the hyoid bone position were measured. Analysis of variance was used to compare measurements in the four stages.
Results: The anteroposterior dimensions of the pharyngeal airway did not change after the modified bionator treatment, except for the nasopharynx area in both genders and the hypopharynx area in males. Vertically, the hyoid bone remained in a constant position relative to the mandible and third cervical vertebra through the four stages in both genders. Horizontally, the hyoid bone moved forward during treatment but returned to a posterior position after use of the modified bionator was stopped.
Conclusions: Even with mandible advancement by the modified bionator in growing patients with retrognathia, there were no significant changes in the anteroposterior dimensions of the pharyngeal airway, and the hyoid bone remained in a vertical position relative to the mandible during the pubertal growth phase.

1. Introduction

The bionator, a functional appliance considered to stimulate mandibular growth in growing patients with retrognathia, is widely used in daily orthodontic practice. The development of the bionator is credited to Wilhelm Balters, who emphasized that equilibrium between the tongue and circumoral buccinator mechanism was responsible for the shape of the dental arches and intercuspation.[1] His main object of Angle class II malocclusion treatment was to bring the tongue forward by stimulating the distal part of the dorsum of the tongue and developing the mandible in an anterior position to achieve an Angle class I relationship.[2] There are many published studies on the skeletal and dentoalveolar effects of bionator treatment. However, the effects of bionator therapy on changes in the anteroposterior dimensions of the pharyngeal airway and position of the hyoid bone have not been explored.

The pharynx lies posterior to the nasal cavity, mouth cavity, and larynx. It is further divided into three parts: the nasopharynx, oropharynx, and hypopharynx. Kirjavainen and Kirjavainen[3] found that the oro- and hypopharynxes were narrowed in Angle class II, Division 1 patients. Narrowing of the pharyngeal airway is also a commonly described characteristic in patients with obstructive sleep apnea/hypopnea syndrome (OSAHS).[4] In some OSAHS patients, such as Angle class II malocclusion patients, the mandible is relatively short and/or posteriorly placed.[5]

The hyoid bone is connected to the pharynx, mandible, and cranium through muscles and ligaments.[6] It is an anchoring structure for the tongue. With the attached muscles on it, the hyoid bone plays an important role in maintaining a patent airway and regulating deglutition and mandibular movement. In normal

* Corresponding author. School of Oral Hygiene, College of Oral Medicine, Taipei Medical University, 250 Wu-Hsing St, Taipei 110-31, Taiwan.
E-mail: hunghuey@tmu.edu.tw (H.-H. Tsai).

1878-3317/$ – see front matter
doi:10.1016/j.jecm.2011.02.005

untreated patients from childhood to adulthood, the hyoid bone becomes more inferiorly positioned and the anteroposterior dimensions of the pharyngeal airway increase, which is especially obvious in puberty.[7–9] It was pointed out that most adult OSAHS patients have a lower-positioned hyoid bone than the normal population.[10] The musculature of the tongue relaxes during sleep, which with an anatomical predisposition, can lead to obstruction of the airway during sleep. Oral appliances that produce mandibular advancement were established as a treatment modality for primary snoring and/or mild OSAHS.[11] These move the mandible forward and open the bite, thus widening the pharyngeal airway.

The conventional type of bionator used for correcting Angle class II malocclusions has long been popular; however, it still has some limitations. A modified bionator[12] was designed by our group to overcome the shortcomings of the conventional bionator. In addition to encouraging tongue elevation, just like mandibular-advancement oral appliances used in adult OSAHS patients, the modified bionator produces a forward and downward positioning of the lower jaw, promoting a new postural position of the jaw to correct a retrognathic mandible, and causing mesial migration of the lower dentition. The aim of this longitudinal study was to evaluate the treatment effects of this modified bionator appliance on the anteroposterior dimensions of the pharyngeal airway and position of the hyoid bone in patients during puberty. Morphological changes were evaluated using lateral cephalometric radiographs.

2. Materials and Methods

2.1. Patients

In this retrospective study, we selected the records of 86 (51 males aged 10.83 ± 1.40 years and 35 females aged 10.25 ± 1.47 years) Taiwanese growing patients with an Angle class II, Division 1 malocclusion. Oral informed consent was obtained from the parents of all patients before orthodontic treatment. The patients had been treated with the modified bionator by the same orthodontist between 1988 and 2004. The following selection criteria were used.

1. ANB angle (angle between reference points A, N, and B; A cephalometric measurement of the anterior-posterior relationship of the maxilla with the mandible) was greater than 4° with a clinically retrognathic mandible (determined by the soft tissue of the chin being posterior to Bass' analysis vertical reference line[13]).
2. There was an Angle class II molar relationship with a clinically retrognathic mandible.
3. There were no congenital missing teeth except for the third molar.
4. Quality cephalograms were available from the beginning and end of the bionator treatment or follow-up periods. Standard lateral cephalometric radiographs were taken with the teeth in centric occlusion and with the head oriented horizontally with the Frankfort plane.

Table 1 Mean age and number of patients at each stage

Stage	Male		Female	
	n	Age	*n*	Age
T0	51	10.83 ± 1.40	35	10.25 ± 1.47
T1	51	12.51 ± 1.28	35	12.30 ± 1.58
T2	32	14.19 ± 1.39	24	14.56 ± 2.53
T3	13	16.49 ± 1.54	9	16.91 ± 2.97

T0 = before the bionator treatment; T1 = after the bionator treatment; T2 = about 2 years after retention; T3 = 4-year follow-up after the bionator treatment.

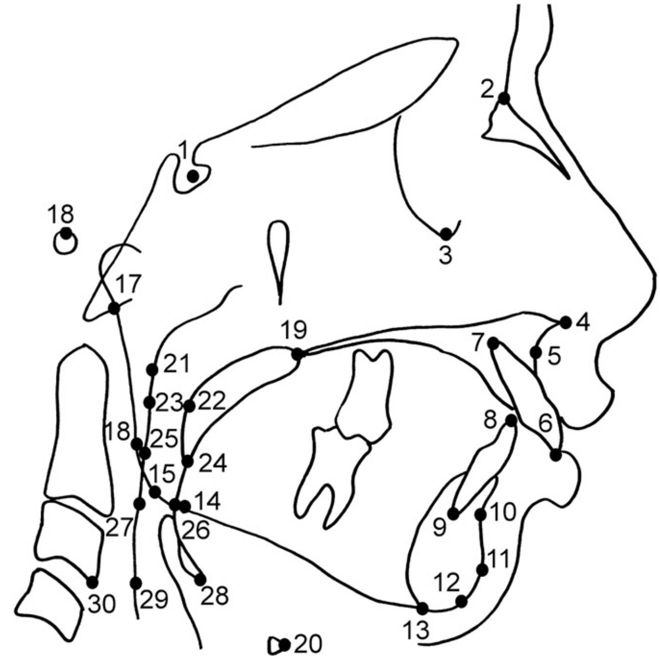

Figure 1 Landmarks. 1: S; 2: N; 3: Or; 4: ANS; 5: A; 6: U1; 7: U1 apex; 8: L1; 9: L1 apex; 10: B; 11: Pog; 12: Gn; 13: Me; 14: GoL; 15: Go; 16: GoP; 17: Ar; 18: Po; 19: PNS; 20: H (the anterior-most point of the hyoid bone); 21: SPU (the point on the posterior pharyngeal wall along the palatal plane); 22: SAM (the point on the soft palate where the distance to the posterior pharyngeal wall is narrowest); 23: SPM (the point on the posterior pharyngeal wall where the distance to SAM is the shortest); 24: P (the tip of the soft palate); 25: SPML (the point on the posterior pharyngeal wall where the distance to P is the shortest); 26: SAL (the point on the tongue along the mandibular lower border); 27: SPL (the point on the pharyngeal wall where the distance to SAL is the shortest); 28: E (epiglottis); 29: SPLL (the point on the pharyngeal wall where the distance to E is the shortest); 30: C3 (the anteroinferior-most point of the third vertebra).

2.2. Treatments

A modified bionator, with lower incisor resin caps and an expansion screw, was used in all patients. Resin caps were used to prevent lower-incisor flaring.[14] The expansion screw was used to relieve mild dental crowding. Construction bites were taken 2–3 mm vertically between the upper and lower incisor edge. Either single- or two-step anterior activation was performed depending on the

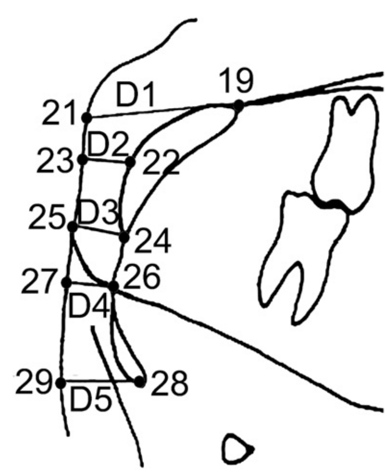

Figure 2 Linear measurements of the pharyngeal airway dimension. D1: the distance between landmarks 19 and 21; D2: the distance between landmarks 22 and 23; D3: the distance between landmarks 24 and 25; D4: the distance between landmarks 26 and 27; and D5: the distance between landmarks 28 and 29.

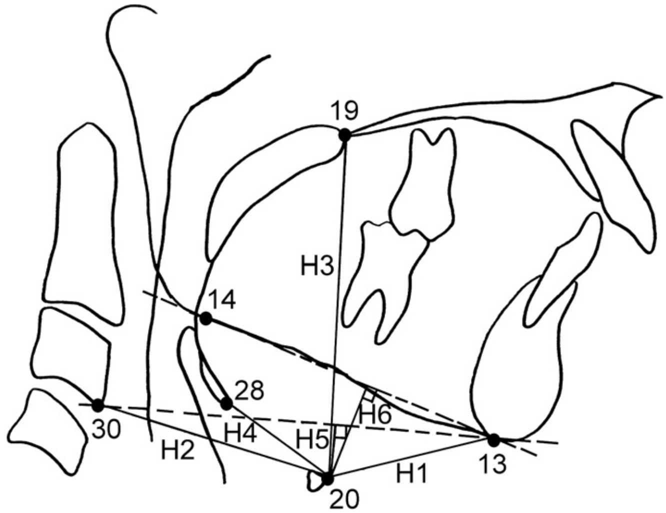

Figure 3 Linear measurements of the hyoid bone position. H1: H—Me; H2: H—C3; H3: H—PNS; H4: H—E; H5: the perpendicular distance from the hyoid bone to the plane formed by C3 and Me; H6: the perpendicular distance from the hyoid bone to the mandibular plane. H = hyoid bone; Me = menton.

severity of the anteroposterior discrepancy. During the active phase of treatment, the patient was instructed to wear the appliance 24 hours a day, except during meals, tooth brushing, language lessons, and playing contact sports. Patients were advised to keep their lips together to form a seal when the appliance was being worn. After the modified bionator treatment (achievement of an Angle class I molar relationship), a tooth positioner was used as a retainer for minor adjustments of the teeth. Cephalometric radiographic records were taken at four stages: T0, before bionator treatment; T1, immediately after bionator treatment has stopped; T2, after about 2 years of the retention phase; and T3, after about 4 years of treatment. The details of the mean age and number of patients in each stage are given in Table 1.

2.3. Measurements

A cephalometric analysis was performed to determine changes in the pharyngeal airway dimensions and position of the hyoid bone. All cephalometric radiographs were digitized and traced by the same person, and 30 landmarks were identified (Figure 1). The X- and Y-axes of all landmarks were coordinated and used to quantify changes between each stage. The line parallel to the Frankfurt line and passing through Point S (Sella) was designated the X-axis. The line passing through Point S and perpendicular to the X-axis was designated the Y-axis. The landmarks were used to perform 20 linear and 17 angular measurements. There were five linear items (D1—D5) for the anteroposterior dimensions of the pharyngeal airway (Figure 2), six linear items (H1—H6) for the position of the hyoid bone (Figure 3), and another 26 items describing the craniofacial morphology (Table 2).

All measurements were performed using the computerized cephalometric analysis software, Winceph (version 7.0; Rise Co., Sendai, Japan). SigmaPlot (version 11.0; Systat Software Inc., San Jose, CA, USA) was used to perform the superimposition of the mean landmarks and profilograms upon the X- and Y-axes between each stage.

Table 2 Measurements for the craniofacial morphology

Linear measurements	Angular measurements
S-N	Facial angle
N-ANS	Convexity
ANS-Me	A-B plane
N-Me	Y-axis
S-Go	SNA
Ar-Go	SNB
Go-Me	ANB
ANS-PNS	Nasal floor to SN
Facial height ratio	GoGn to SN
	Ramus plane to SN
	Gonial angle
	U1 to SN
	L1 to Mandibular plane
	Interincisal angle
	Saddle angle (N-S-Ar)
	Article angle (S-Ar-GoP)
	ANS-PNS-P

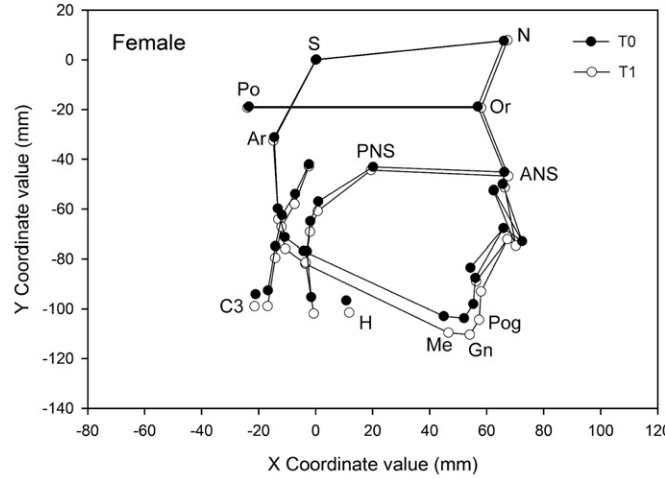

Figure 4 Superimposition of T0 and T1 profilograms of females. T0 = before the bionator treatment; T1 = after the bionator treatment.

2.4. Statistical methods and method error

The mean value and standard deviation were calculated for each measurement. An analysis of variance was used to compare the mean values of each measurement among the four stages (T0, T1, T2, and T3) in both genders. All statistical analyses were performed using SigmaStat (version 2.0, Jandel Corporation, San Rafael, CA, USA), with a 5% level of significance.

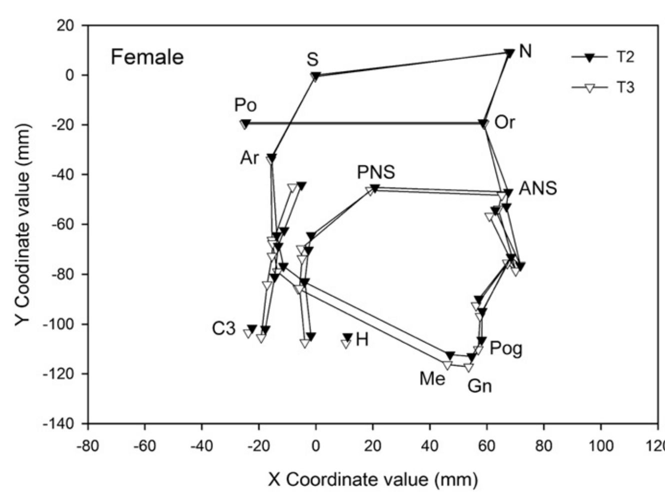

Figure 5 Superimposition of T2 and T3 profilograms of females. T2 = about 2 years after retention; T3 = 4-year follow-up after the bionator treatment.

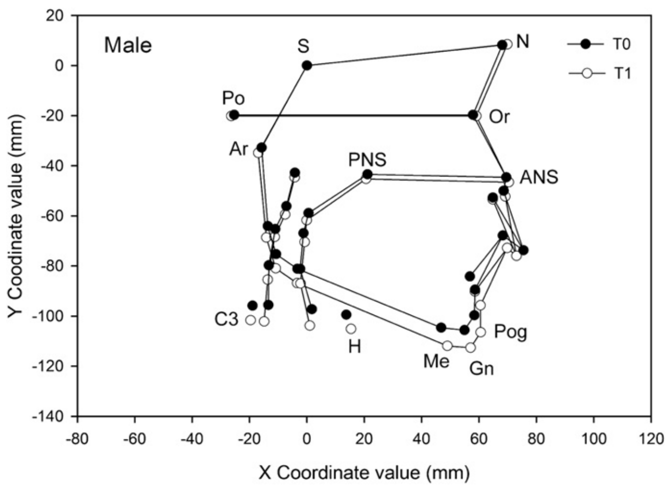

Figure 6 Superimposition of T0 and T1 profilograms of males. T0 = before the bionator treatment; T1 = after the bionator treatment.

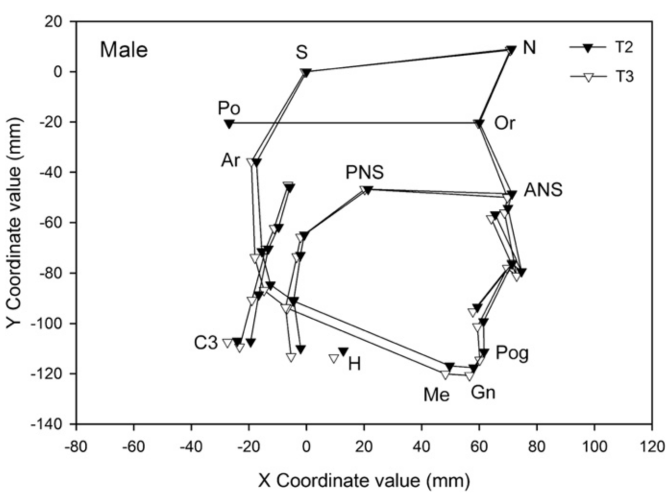

Figure 7 Superimposition of T2 and T3 profilograms of males. T2 = about 2 years after retention; T3 = 4-year follow-up after the bionator treatment.

Ten randomly selected lateral cephalometric radiographs were traced and measured twice 2 weeks later to estimate the error that might have occurred using this method. Statistical significance of the differences was ascertained using a paired *t* test and correlation coefficients. None of the measurements were found to significantly differ.

3. Results

Figures 4–7 show the superimpositions of the mean profilograms of both genders from the T0 to T3 stages. Maxillary incisors were retracted, and axes of the mandibular incisors were maintained through the observation period in both genders. The mandible grew forward and downward during the bionator treatment and achieved a normal anteroposterior relationship with the maxilla.

Table 3 shows the mean values and standard deviations of measurements of the pharyngeal airway in each stage for both genders. Our results indicate that except for a nasopharyngeal dimension (D1) of both genders and a hypopharyngeal dimension (D5) of males, no other measurement (oropharyngeal dimensions) in either gender revealed a significant difference from stages T0 to T3.

Table 4 shows the mean values and standard deviations of measurements of the hyoid bone positions among each stage for both genders. Only H1, H2, and H3 in males and H3 in females significantly increased from stages T0 to T3. H1 and H2 in females remained constant. No significant differences were revealed in H4, H5, or H6 from stages T0 to T3 in either gender.

Table 5 shows the coordinate values of the hyoid bone (H, Landmark 20) and menton (Me, Landmark 13) on the X- and Y-axes in each stage. Horizontally, menton moved slightly forward from Stages T0 to T3, whereas the hyoid bone moved forward from Stages T0 to T1 and moved back to a position more posterior than the original position in stages T1 and T3. Vertically, both the hyoid bone and menton moved downward, but the hyoid bone moved less than menton in each stage.

4. Discussion

Few studies have evaluated the effects of functional appliance treatment on pharyngeal airway dimensions and hyoid bone position in growing patients with an Angle class II malocclusion and a retruded mandible. Ozbek et al[15] compared pharyngeal airway dimensions in 26 children with a Class II skeletal pattern treated with the Harvold-type activator to 15 controls. They found that the pharyngeal airway dimensions significantly increased by functional orthopedic treatment, whereas no significant changes in the pharyngeal airway dimensions were observed in the control group. In contrast to those results, our previous studies[9,16] showed that pharyngeal airway dimensions generally increased with age. In this study, there were no significant increases in oropharyngeal airway dimensions (D2–D4) from stages T0 to T3. Our modified bionator had different influences on the pharyngeal airway in growing patients. During bionator treatment, because of the

Table 3 Mean values and standard deviations of measurements of pharyngeal airway dimensions

Measurement	Sex	Stage								ANOVA
		T0		T1		T2		T3		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
D1 (mm)	Female	22.56	4.49	21.92	4.86	25.82	3.42	27.37	2.08	$p < 0.05$
	Male	25.03	3.17	24.96	3.18	27.20	3.20	26.75	2.93	$p < 0.05$
D2 (mm)	Female	8.92	2.60	9.09	2.52	9.77	3.63	10.29	4.02	NS
	Male	8.48	2.44	9.07	2.84	9.69	2.98	10.01	3.36	NS
D3 (mm)	Female	10.35	2.48	10.29	2.88	10.76	3.23	10.66	3.91	NS
	Male	10.08	2.37	10.83	2.92	11.53	3.10	11.30	2.76	NS
D4 (mm)	Female	11.39	3.34	10.99	2.97	11.30	2.94	11.58	3.69	NS
	Male	11.14	2.95	11.67	2.79	12.47	3.47	12.12	2.09	NS
D5 (mm)	Female	15.54	3.16	16.57	2.73	16.47	2.24	15.61	1.64	NS
	Male	14.89	2.43	16.22	2.75	17.68	2.94	18.35	3.50	$p < 0.05$

ANOVA = analysis of variance; NS = not significant; SD = standard deviation; T0 = before the bionator treatment; T1 = after the bionator treatment; T2 = about 2 years after retention; T3 = 4-year follow-up after the bionator treatment.

Table 4 Mean values and standard deviations of measurements of hyoid bone position

Measurement	Sex	Stage								ANOVA
		T0		T1		T2		T3		
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
H1 (mm)	Female	35.20	5.05	36.30	5.02	36.90	3.16	36.88	3.94	NS
	Male	33.86	5.86	34.62	6.28	37.64	6.07	39.76	5.84	$p < 0.05$
H2 (mm)	Female	32.34	4.06	33.67	3.48	33.98	3.16	34.60	2.62	NS
	Male	33.68	3.74	35.67	3.83	37.28	3.75	37.88	2.21	$p < 0.05$
H3 (mm)	Female	54.73	6.29	58.13	6.21	60.84	3.61	62.01	2.89	$p < 0.05$
	Male	56.84	5.66	60.70	6.00	64.88	5.69	67.82	5.92	$p < 0.05$
H4 (mm)	Female	12.72	2.76	12.71	2.20	13.21	2.05	14.76	2.92	NS
	Male	14.19	2.82	14.93	3.28	15.15	3.30	15.19	1.76	NS
H5 (mm)	Female	−1.76	4.89	−2.65	5.16	−1.70	3.53	−2.10	2.82	NS
	Male	−0.81	4.91	−1.61	4.14	−1.13	3.58	−0.04	5.18	NS
H6 (mm)	Female	10.38	5.76	9.69	5.36	11.52	3.71	10.41	3.56	NS
	Male	9.32	4.95	8.37	4.60	10.35	4.53	10.71	5.49	NS

ANOVA = analysis of variance; NS = not significant; SD = standard deviation; T0 = before the bionator treatment; T1 = after the bionator treatment; T2 = about 2 years after retention; T3 = 4-year follow-up after the bionator treatment.

connection of the lateral wall of the soft palate to the base of the tongue through the palatoglossal arch, mandibular advancement stretched the soft palate and stiffened the velopharynx, which caused the oropharyngeal airway dimension to appear not to have changed during growth.

Ryan et al[17] reported that mandibular-advancement oral appliances increased the lateral dimension of the velopharynx more than the anteroposterior dimension in adult OSAHS individuals. They also demonstrated that the cross-sectional area of the oropharynx did not increase, but there was a tendency for that of the hypopharynx to increase. Zhao et al[18] using magnetic resonance imaging reported that with a mandibular-advancement oral appliance, the pharyngeal airway size increased in the transverse dimension instead of the sagittal dimension. Additionally, Tsuiki et al[19] found that the third cervical vertebra moved anterosuperiorly together with the hyoid bone and concluded that the movement of the third cervical vertebra caused virtually no change in the sagittal dimension of the oropharynx. With regard to the difference in muscular function between wakefulness and sleep, Tangel et al[20] demonstrated a significant decrease in the tonic activity of the masseter muscle during nonrapid eye movement sleep. This indicates that changes observed in masticatory muscle activity could differ between wakefulness and sleep. The mandibular-advancement oral appliance for adult OSAHS patients is used during sleep, whereas our modified bionator was used around-the-clock for growing patients. According to Balter's concept, the bionator stimulates the dorsum part of the tongue to lift.[2] As the tongue is lifted by training with the bionator, the retropalatal and retroglossal pharyngeal airway dimensions may be reduced in the anteroposterior direction. Therefore in this study, it seemed as if mandibular advancement of growing individuals with the modified bionator did not affect the anteroposterior dimension of the oropharynx. Further investigation is needed to determine the effects of mandibular protrusion on the relationship between the anatomy and muscle activity of the upper airway.

Yassaei and Sorush[21] showed short-term results of hyoid bone position changes of 28 Class II, Division 1 children treated with the Farmand functional appliance. The results were coincident with ours from stages T0 to T1, that is, the hyoid bone moved forward during bionator treatment. Tsuiki et al[19] found that the degree of forward movement of the hyoid bone by a mandibular-advancement oral appliance was less than that of the mandible and speculated that some extrinsic tongue muscles, which connect to the hyoid bone and/or the soft palate, the posterior belly of the digastric muscle, and the infrahyoid muscles could restrict anterior movement of the hyoid bone. Other studies showed that the hyoid bone presented initial forward movement after surgical advancement of the mandible.[22] Eggensperger et al[23] also found that the hyoid bone had a significant continuous posterior movement during the following 11 years after the operation. This finding agrees with our finding that the hyoid bone moves backward after Stage T1, namely when bionator treatment is stopped. This may be explained by the strain on the muscles that arises when the mandible and hyoid bone move forward during bionator treatment and the strain force present pulling the hyoid bone back after ceasing to use the appliance.

Table 5 Coordinate values of hyoid bone and Menton at each stage

Coordinate values	Sex	Stage							
		T0		T1		T2		T3	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Coordinate values of hyoid bone									
X-axis	Female	10.74	6.65	11.59	7.71	11.16	7.40	10.81	5.89
	Male	13.74	6.47	15.38	7.03	12.77	6.03	10.00	5.52
Y-axis	Female	−96.62	8.81	−101.67	8.19	−104.97	4.93	−107.02	3.44
	Male	−99.48	7.04	−105.13	8.20	−110.85	7.21	−113.58	7.12
Coordinate values of Menton									
X-axis	Female	44.92	6.68	46.39	8.05	47.08	7.82	46.43	6.99
	Male	46.83	6.08	48.97	6.97	49.70	7.46	48.78	7.83
Y-axis	Female	−102.93	6.62	−109.76	6.47	−112.27	5.22	−115.64	4.60
	Male	−104.62	5.70	−111.91	6.85	−116.85	5.98	−120.10	6.63

SD = standard deviation; T0 = before the bionator treatment; T1 = after the bionator treatment; T2 = about 2 years after retention; T3 = 4-year follow-up after the bionator treatment.

A previous longitudinal study of 50 males and females at 22–42 years of age found that the hyoid bone gradually moved downward.[24] Bench[8] stated that the hyoid bone gradually descends from a position opposite the lower half of the third and the upper half of the fourth cervical vertebra at the age of 3 years to a position opposite the fourth cervical vertebra in adulthood. Sheng et al[9] also found that the hyoid bone moved away from the mandibular plane from the mixed-dentition stage to the young-adult stage. In contrast, our study showed that the distance between the hyoid bone and mandibular plane or C3-menton line remained stable from the beginning of bionator treatment through several years of follow-up. This might have been because the tongue was stimulated by the modified bionator corresponding to Balter's theory and remained in the vertical position.

Previous studies showed that the hyoid bone is upwardly elevated with a mandible-advancing device *in situ*.[25,26] With our modified bionator treatment, it seemed that the hyoid bone can maintain the vertical position during pubertal growth. Further investigation is needed to evaluate whether the modified bionator activates the upper airway dilating and tongue-protruding muscles.

5. Conclusions

The purpose of this study was to determine the effects of treatment with a modified bionator on the anteroposterior dimensions of the pharyngeal airway and position of the hyoid bone in growing patients. Treatment with the modified bionator resulted in

1. Few changes in the anteroposterior pharyngeal dimensions;
2. Few vertical positional changes of the hyoid bone relative to the mandible and third vertebrae;
3. Forward movement of the hyoid bone during treatment; and
4. Backward movement of the hyoid bone after treatment.

References

1. Graber TM, Neumann B. Bionator. In: Graber TM, Neumann B, editors. *Removable Orthodontic Appliances*. 2nd ed. Philadelphia: WB Saunders; 1984. p. 357–75.
2. McNamara Jr JA, Brudon WL. *Orthodontics and Dentofacial Orthopedics*. Ann Arbor: Needham Press; 2001. 63–73.
3. Kirjavainen M, Kirjavainen T. Upper airway dimensions in class II malocclusion. Effects of headgear treatment. *Angle Orthod* 2007;**77**:1046–53.
4. Hoekema A, Hovinga B, Stegenga B, De Bont LG. Craniofacial morphology and obstructive sleep apnoea: a cephalometric analysis. *J Oral Rehabil* 2003;**30**:690–6.
5. Lowe AA, Santamaria JD, Fleetham JA, Price C. Facial morphology and obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 1986;**90**:484–91.
6. Bibby RE, Preston CB. The hyoid triangle. *Am J Orthod* 1981;**80**:92–7.
7. Tsai HH. The positional changes of hyoid bone in children. *J Clin Pediatr Dent* 2002;**27**:29–34.
8. Bench RW. Growth of the cervical vertebrae as related to tongue, face, and denture behavior. *Am J Orthod Dentofacial Orthop* 1963;**49**:183–214.
9. Sheng CM, Lin LH, Su Y, Tsai HH. Developmental changes in pharyngeal airway depth and hyoid bone position from childhood to young adulthood. *Angle Orthod* 2009;**79**:484–90.
10. Pae EK, Lowe AA, Fleetham JA. Shape of the face and tongue in obstructive sleep apnea patients—statistical analysis of coordinate data. *Clin Orthod Res* 1999;**2**:10–8.
11. Hoffstein V. Review of oral appliances for treatment of sleep-disordered breathing. *Sleep Breath* 2007;**11**:1–22.
12. Lin YC, Lin HC, Wang WN, Lee SY, Tsai HH. Treatment of Angle class II malocclusion with a newly modified bionator combined with headgear. *J Dent Sci* 2009;**4**:87–95.
13. Bass NM. The aesthetic analysis of the face. *Eur J Orthod* 1991;**13**:343–50.
14. Rudzki-Janson I, Noachtar R. Functional appliance therapy with the bionator. *Semin Orthod* 1998;**4**:33–45.
15. Ozbek MM, Memikoglu TU, Gogen H, Lowe AA, Baspinar E. Oropharyngeal airway dimensions and functional-orthopedic treatment in skeletal class II cases. *Angle Orthod* 1998;**68**:327–36.
16. Tsai HH. Developmental changes of pharyngeal airway structures from young to adult persons. *J Clin Pediatr Dent* 2007;**31**:219–21.
17. Ryan CF, Love LL, Peat D, Fleetham JA, Lowe AA. Mandibular advancement oral appliance therapy for obstructive sleep apnea: effect on awake calibre of the velopharynx. *Thorax* 1999;**54**:972–7.
18. Zhao X, Liu Y, Gao Y. Three-dimensional upper-airway changes associated with various amounts of mandibular advancement in awake apnea patients. *Am J Orthod Dentofacial Orthop* 2008;**133**:661–8.
19. Tsuiki S, Hiyama S, Ono T, Imamura N, Ishiwata Y, Kuroda T, Lowe AA. Effects of a titratable oral appliance on supine airway size in awake non-apneic individuals. *Sleep* 2001;**24**:554–60.
20. Tangel DJ, Mezzanotte WS, Sandberg EJ, White DP. Influences of NREM sleep on the activity of tonic vs. inspiratory phasic muscles in normal men. *J Appl Physiol* 1992;**73**:1058–66.
21. Yassaei S, Sorush M. Changes in hyoid position following treatment of class II division 1 malocclusions with a functional appliance. *J Clin Pediatr Dent* 2008;**33**:81–4.
22. Gale A, Kilpelainen PV, Laine-Alava MT. Hyoid bone position after surgical mandibular advancement. *Eur J Orthod* 2001;**23**:695–701.
23. Eggensperger N, Smolka K, Johner A, Rahal A, Thuer U, Iizuka T. Long-term changes of hyoid bone and pharyngeal airway size following advancement of the mandible. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005;**99**:404–10.
24. Kollias I, Krogstad O. Adult craniocervical and pharyngeal changes—a longitudinal cephalometric study between 22 and 42 years of age. Part I: morphological craniocervical and hyoid bone changes. *Eur J Orthod* 1999;**21**:333–44.
25. Bonham PE, Currier GF, Orr WC, Othman J, Nanda RS. The effect of a modified functional appliance on obstructive sleep apnea. *Am J Orthod Dentofacial Orthop* 1988;**94**:384–92.
26. Battagel JM, Johal A, L'Estrange PR, Croft CB, Kotecha B. Changes in airway and hyoid position in response to mandibular protrusion in subjects with obstructive sleep apnoea (OSA). *Eur J Orthod* 1999;**21**:363–76.