Soft tissue growth of the oropharynx

Michael Taylor, DDS, MSD; Mark G. Hans, DDS, MSD; Kingman P.Strohl, MD, MPH; Suchitra Nelson, PhD; B. Holly Broadbent, DDS

The orthodontic literature is full of reports on hard tissue growth of the craniofacial complex, giving orthodontic clinicians an appreciation for the usual pattern of bony change in this area. However, with the exception of studies of the tonsils and adenoids, little information has been published on the usual pattern of growth and development of oropharyngeal soft tissues.

Recently there has been renewed interest in the soft tissues of the oral and nasal pharynx. This increased interest stems from a potential relationship between the size and shape of the oral/nasal airway and sleep disordered breathing (SDB).[3-5] In the last 5 years there has been an enormous increase in the number of individuals diagnosed with SDB. A recent study in the *New England Journal of Medicine* reported that up to 10% of the adult male population may suffer from SDB,[6] and socially disruptive snoring is a common occurrence in the adult population.[7]

The relationship between SDB and craniofacial anatomy is not fully understood. However, cephalometric analyses of patients in an upright, standing position have demonstrated that patients with SDB differ from healthy controls. Specifically, the SDB subject has an enlarged tongue and a soft palate that is positioned posteriorly

Abstract

The purpose of this study was to describe the pattern of bony and soft tissue growth of the oropharynx in a sample of healthy, orthodontically untreated children. The sample consisted of 16 males and 16 females with lateral cephalograms at 6, 9, 12, 15, and 18 years of age, for a total of 160 lateral cephalometric radiographs. All subjects were enrolled in the Broadbent Bolton Study[1] and their radiographs were used to produce the Bolton Standard Templates.[2] Each radiograph was traced by hand and the tracings were paired and averaged to create a standard template for pharyngeal tissues at each age. In addition, all 160 tracings were digitized and means and standard deviations were calculated for 29 hard and 7 soft tissue measurements. Four linear (Ar-H,S-H,Go-H, Gn-H) and three angular (N-S-H, SN-ArH,GoGn-H) measurements demonstrated that the hyoid bone descends and moves slightly anteriorly up to age 18. The soft palate (PNS-P) increased 1 mm in length and 0.5 mm in thickness every 3 years after age 9. The distance between the anterior border of the atlas (ATA) and PNS did not change after age 12, while two soft tissue measurements (PNS-pharyngeal wall [PhW2] and posterior soft palate to pharyngeal wall [psp-PhW3]) increased. In general, two periods of accelerated change (6-9 years and 12-15 years) and two periods of quiescence (9-12 years and 15-18 years) were identified for the pharyngeal soft tissues. Further studies are needed to determine if soft tissues in the oropharynx continue to change after age 18.

Key Words

Soft tissue • Cephalometrics • Growth • Oropharynx

Submitted: November 1994 **Revised and accepted:** June 1995 Angle Orthod 1996;66(5):393-400.

Figure 1
Landmarks used for assessment of airway structures.

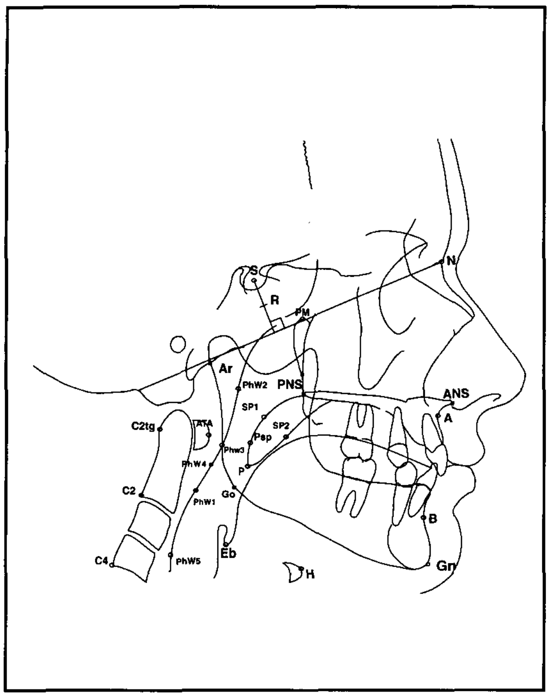

Figure 1

and inferiorly.[7-9] A correlation between total posterior displacement of the mandible (relative to both size and position) and the number of apneic episodes per sleep hour has also been reported.[9] Although there is disagreement with regard to the size, shape, and position of the maxilla and mandible, there is general agreement that in subjects with SDB the oropharynx and hypopharynx airway are often reduced in area while the nasopharynx airway is often normal.[7-9] Another consistent finding is that the hyoid bone is displaced inferiorly in individuals with SDB.[5,10,11] Jamieson et al. hypothesized that acute cranial base flexure (<NSBa) leads to abnormal development of the hypopharyngeal soft tissues associated with lower position of the hyoid bone.[11]

Since these craniofacial characteristics have been shown to be associated with SDB, it is important to determine the normal pattern of growth for these structures. Previous studies have shown that although hyoid bone position is associated with head posture, there is a regular pattern of downward and slightly anterior descent of the hyoid throughout the growth period.[13-18]

Changes in adenoid tissue mass have also been reported.[19,20] This tissue develops rapidly after birth, reaches its maximum size in early childhood, begins to regress around 8 to 10 years, and is usually completely atrophied by 12 to 14 years.[21] However, similar studies on the effect of growth on soft palate length or oropharyngeal dimensions have not been reported for a noncleft sample.

In order to characterize growth related changes in craniofacial hard and soft tissues, investigators need longitudinal standards for comparison. Since the Bolton Sample has been used to characterize "normal" hard tissue anatomy, it is logical that this sample may provide some basis for comparison of soft tissue anatomy as well. The purpose of this study was to evaluate the relationship between dentofacial skeletal growth and growth of the surrounding pharyngeal soft tissues in the Bolton Sample. Using the same methodology that was used to create the Bolton Standards, soft tissue standard templates for pharyngeal tissues were produced. In particular, changes in the soft palate and the posterior pharyngeal wall were characterized.

Materials and methods

The sample consisted of 160 lateral cephalometric radiographs obtained from the Bolton Study archives at Case Western Reserve University. There were 16 males and 16 females chosen for each age group (6, 9, 12, 15, and 18 years). The sample was drawn from the sample used to develop the Bolton Standard Templates for dentofacial development.[2] The soft tissue template for each age was constructed following published procedures.[2] Each radiograph was traced and 37 cephalometric measurements were taken. (See Figure 1 and Table 1.) Individuals were grouped according to age and sex for statistical analysis. Paired *t*-tests were used to detect differences based on sex. Because of the multiple testing problem, Bonferroni correction was applied and a P-value of 0.0135 was used to assign statistical significance. No differences between males and females were found at 6, 9, or 12 years of age, so these groups were combined to increase the size of the sample to 32. Means and standard deviations were calculated for pooled groups and are reported in Table 1. Some differences were found at 15 and 18 years. The means and standard deviations for males and females are reported separately in Table 2. To force the initial value for the graphs (Figures 2 to 4) through the origin, all values were normalized by subtracting the initial value at age 6 from the value at each of the subsequent ages (i.e., value at age 9 minus value at age 6, value at age 12 minus value at age 6, etc.).

Results

The average soft and hard tissue tracings at each age, superimposed on the Bolton plane and registered at R point, are compared two at a time

Table 1
Means and standard deviations for all variables measured

Age Variable	6 Mean	 S.D.	9 Mean	 S.D.	12 Mean	 S.D.	15 Mean	 S.D.	18 Mean	 S.D.
N-A(mm)	48.3	2.3	53.0	2.6	56.2	2.5	59.2	3.7	61.0	4.1
N-B(mm)	80.1	4.0	86.0	3.4	91.3	4.1	96.1	5.0	98.8	6.0
S-N(mm)	64.8	2.4	67.5	2.7	69.6	2.7	71.6	3.2	72.7	3.9
PM-PNS(mm)	22.6	1.7	24.9	1.8	26.7	2.1	28.7	2.5	29.7	2.3
ANS-PNS(mm)	47.3	1.8	50.4	1.6	52.9	2.2	55.4	2.6	56.7	3.0
ATA-PNS(mm)	31.1	3.0	32.4	3.4	33.0	3.6	33.0	3.9	32.7	4.2
ANS-B(mm)	38.0	3.4	39.7	2.7	41.8	3.6	43.4	3.8	44.9	4.2
A-B(mm)	32.2	3.2	33.2	2.4	35.4	2.6	37.1	2.9	38.0	3.2
A-GN(mm)	48.6	3.0	50.7	3.1	53.7	3.0	57.3	3.7	58.8	4.0
GO-PNS(mm)	34.5	2.3	37.2	2.4	39.5	2.8	42.5	3.7	45.1	4.2
GO-B(mm)	60.9	2.4	65.6	2.9	68.5	3.3	72.4	3.8	73.5	4.0
PNS-B(mm)	52.9	2.6	56.1	2.4	59.9	2.6	63.9	2.8	65.5	3.8
GO-H(mm)	26.7	4.4	29.8	4.8	32.9	4.8	35.4	6.3	37.6	6.0
GN-H(mm)	37.0	4.8	41.5	5.2	42.8	5.1	47.2	5.3	49.0	4.7
PhW5-H(mm)	24.6	2.7	25.5	2.7	27.5	2.8	30.1	3.7	31.1	4.7
AR-H(mm)	59.7	4.8	65.7	5.3	72.5	5.2	79.4	7.9	84.6	7.9
S-H(mm)	80.3	5.3	88.9	6.2	96.7	5.7	105.5	8.0	111.8	9.4
PNS-PhW2(mm)	19.3	4.8	23.4	3.4	23.6	3.7	25.3	3.1	25.6	3.3
PNS-AR(mm)	32.3	2.8	34.8	2.4	36.1	2.4	37.4	2.8	38.6	3.4
SP1-SP2(mm)	7.8	1.2	8.1	1.2	8.6	1.1	9.2	1.6	9.8	1.4
PNS-P(mm)	28.4	2.9	28.8	3.8	30.7	2.4	31.9	3.2	32.9	3.0
Psp-PhW3(mm)	8.2	2.4	9.5	2.3	9.6	2.2	10.5	3.0	11.1	2.9
P-PhW4(mm)	9.8	2.5	10.6	2.4	10.7	2.0	11.7	3.0	12.2	2.9
GO-GN(mm)	61.8	2.6	67.8	3.0	71.3	3.1	76.2	3.9	78.3	4.5
AR-GO(mm)	36.4	2.2	38.8	2.0	42.5	3.1	46.9	3.1	49.8	3.6
S-GO(mm)	61.4	3.0	66.7	3.5	71.9	4.4	77.9	4.4	81.8	5.8
GO-PhW1(mm)	5.2	3.2	5.0	3.4	5.1	3.1	5.4	3.0	5.5	3.3
S-N-A(deg)	82.3	3.3	82.0	3.1	82.3	2.5	83.1	2.7	83.8	2.4
S-N-B(deg)	78.5	2.9	78.8	2.7	79.2	2.5	80.6	2.4	81.1	2.6
S-N:AR-GO(deg)	82.8	4.2	83.4	4.2	83.5	4.2	84.0	4.3	84.1	4.3
ANS-PNS:GO-GN(deg)	25.2	3.3	23.9	3.0	22.8	3.3	21.7	3.6	20.4	4.1
GO-GN-H(deg)	10.0	7.0	14.1	6.3	16.1	6.2	18.6	7.0	21.0	7.6
N-S-H(deg)	83.7	3.1	85.9	3.1	86.1	2.8	86.8	3.3	86.7	3.3
S-N:GO-GN(deg)	32.4	3.3	31.6	3.0	31.1	3.2	30.0	3.2	28.8	3.7
S-N:AR-H(deg)	67.5	3.8	69.6	4.0	70.0	3.8	71.6	4.2	72.3	4.3
AR-GO-GN(deg)	129.6	3.8	128.2	4.2	127.5	4.4	126.0	4.4	124.7	4.3

in Figures 5 to 8. These drawings graphically illustrate the relative changes in hard and soft tissues from 6 to 18 years of age.

The results of the quantitative analysis showed that the majority of skeletal linear measurements increased with time. The rate of increase usually slowed between 15 and 18 years. The exception was the measurement between the anterior border of the atlas (ATA) and the posterior nasal spine (PNS). This measurement showed a slight decrease in distance after 12 years (see Figure 3). Most of the linear measurements that included the hyoid bone demonstrated patterns similar to those reported for fixed skeletal points, i.e., an increase in distance from 6 to 12 years followed by a gradual reduction in the rate of increase between 15 and 18 years (see Figure 3).

Measurements that included the posterior pharyngeal wall showed patterns that were different than those seen for skeletal measures.

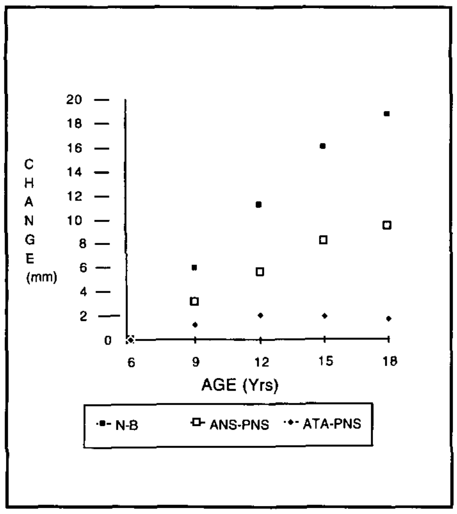

Figure 2

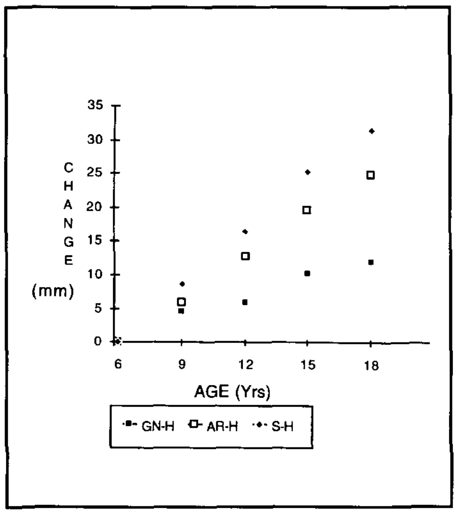

Figure 3

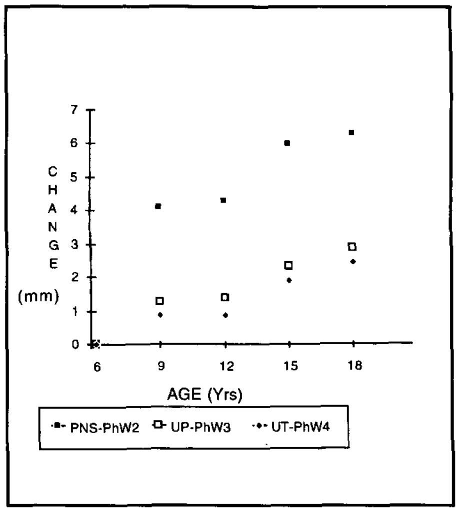

Figure 4

Figure 2
Graph comparing means for selected linear cephalometric measurements.

Figure 3
Change in hyoid position with time.

Figure 4
Graph comparing the measurements through the posterior pharyngeal wall.

Posterior pharyngeal wall measurements showed an increase between the ages of 6 to 9 years and 12 to 15 years. These same measures showed very little change between 9 to 12 years and 15 to 18 years (see Figure 4).

Discussion

After age 12, the mean values for the measurement from atlas (ATA) to posterior nasal spine (PNS) did not increase (Figure 2 and Table 1). This may be due to continued increase in the length of the palatal plane (ANS-PNS) and the increase in size of the atlas after age 12. This finding indicates that the bony pharynx may not increase in dimensions after the pubertal growth spurt.

The change in position of the hyoid bone relative to various cephalometric points over time can be directly related to bony skeletal growth. The graphic pictures of these two phenomena coincide extremely well. Both show an increase in the distance between various cephalometric points continuing through age 18. These results confirm those of previous studies on hyoid position.[14,16,22] There is a downward and slightly forward descent of the hyoid even though the mandibular plane angle decreases. Forward translation of the mandible probably contributes to the forward positioning of the hyoid bone, while growth of the cervical vertebrae contributes to hyoid bone descent. Because the hyoid is anatomically suspended between the mandible and cervical vertebrae, hyoid position moves forward and downward. These results highlight the importance of using age-matched controls for comparison of hyoid bone position between sample groups.

In Figure 4, the changes that occurred over time for three soft tissue measurements (PNS-PhW2, Psp-PHW3, P-PhW4) show a great deal of similarity. All three increase from 6 to 9 years, level off between 9 and 12 years, increase again between 12 and 15 years, and increase only slightly between 15 and 18 years. Each of these measurements is represented at one end by a point that intersects the posterior pharyngeal wall. These measurements are affected by growth and atrophy of the tonsils and adenoids as well as by surgical removal of these structures. The adenoids develop rapidly after birth, begin to involute at about 8 to 10 years, and have usually completely atrophied by 12 to 14 years.

The cephalometric point PhW2 is created by the intersection of the posterior pharyngeal wall with a line drawn through ANS and PNS, which puts it in the same area as the adenoid mass. The cephalometric points PhW3 and PhW4 are usually very close to one another along the posterior pharyngeal wall and are located distal to the adenoid mass. The measurements to PhW3 and PhW4 originate from the distal portion of the soft palate adjacent to the palatine tonsils. Eleven of the 32 subjects had tonsils and adenoids removed prior to age 6, seven others reported missing tonsils and adenoids by age 9, and six more had surgery by age 15.

Using the information above, the graphic patterns in Figure 4 may be interpreted as follows. Three factors alone or in combination may account for the increase in airway size from 6 to 9 years (PNS - PhW2). First, the surgical removal of adenoid tissue; second, the continued growth of the pharynx; and third, the onset of adenoidal regression around age 8. In addition, the increased linear dimension between 6 and 9 years could be explained by a prepubertal growth spurt often seen around age 7.[21] There is a slight

Table 2
Male and female descriptive statistics

Age	15				18			
Gender	Female		Male		Female		Male	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N-A(mm)	56.8*	2.8	61.6*	3.0	58.2*	2.7	63.8*	3.4
N-B(mm)	93.5*	4.0	98.6*	4.7	94.8*	3.9	102.8*	5.0
S-N(mm)	69.7*	2.2	73.6*	2.7	70.0*	3.0	75.4*	2.7
SR-PNS(mm)	28.1	2.2	29.2	2.8	29.1	1.5	30.3	2.9
ANS-PNS(mm)	54.2*	2.4	56.6*	2.3	55.0*	2.9	58.4*	2.1
ATA-PNS(mm)	31.9	3.3	34.1	4.3	31.2*	3.6	34.2*	4.3
ANS-B(mm)	42.8	4.3	44.0	3.3	43.5	3.8	46.3	4.3
A-B(mm)	36.9	2.9	37.3	3.0	36.7*	2.0	39.3*	3.7
A-GN(mm)	56.3	3.1	58.4	3.9	56.7*	2.9	60.8*	3.9
GO-PNS(mm)	41.3	3.4	43.7	3.6	42.9*	3.4	47.3*	3.9
GO-B(mm)	70.6*	3.1	74.2*	3.5	70.9*	3.0	76.2*	3.1
PNS-B(mm)	63.1	2.8	64.8	2.7	63.3*	3.0	67.7*	3.2
GO-H(mm)	32.2*	5.6	38.5*	5.5	33.9*	4.7	41.3*	4.8
GN-H(mm)	47.9	4.8	46.4	5.8	48.5	5.6	49.4	3.8
PhW5-H(mm)	27.4*	2.0	32.7*	3.2	27.6*	2.5	34.6*	3.7
AR-H(mm)	75.5*	7.3	83.3*	6.6	78.7*	4.7	90.6*	5.8
S-H(mm)	100.9*	6.4	110.1*	6.9	104.9*	5.6	118.7*	7.1
PNS-PhW2(mm)	25.1	3.3	25.5	3.0	25.2	3.2	26.0	3.3
PNS-SR(mm)	28.1	2.2	29.2	2.8	29.1	1.5	30.3	2.9
PNS-AR(mm)	35.7*	1.4	39.1*	2.9	36.7*	2.0	40.6*	3.5
SP1-SP2(mm)	8.6*	1.5	9.8*	1.5	9.2*	1.5	10.4*	1.0
PNS-UT(mm)	32.0	3.7	31.8	2.7	32.1	2.5	33.7	3.3
UP-PhW3(mm)	9.8	3.1	11.3	2.8	10.7	2.6	11.5	3.2
UT-PhW4(mm)	10.9	3.1	12.5	2.8	11.7	2.5	12.8	3.3
GO-GN(mm)	74.3*	3.1	78.1*	3.7	75.4*	3.7	81.2*	3.1
AR-GO(mm)	46.0	3.2	47.7	2.8	47.5*	2.7	52.1*	2.8
S-GO(mm)	75.8*	3.9	79.9*	4.1	78.0*	4.4	85.5*	4.7
GO-PhW1(mm)	5.7	2.6	5.1	3.4	5.4	2.8	5.5	3.8
S-N-A(deg)	83.0	2.1	83.1	3.2	83.8	1.9	83.7	2.8
S-N-B(deg)	81.1	1.8	80.2	2.9	81.2	1.9	80.9	3.2
S-N:AR-GO(deg)	84.1	3.9	83.8	4.8	84.2	3.8	83.9	4.9
ANS-PNS:GO-GN(deg)	21.7	3.2	21.6	4.1	21.0	2.8	19.8	5.1
GO-GN-H(deg)	17.0	6.9	20.2	6.9	18.5	6.8	23.5	7.8
N-S-H(deg)	87.3	2.7	86.3	3.9	87.2	3.2	86.3	3.4
S-N:GO-GN(deg)	29.7	2.6	30.3	3.7	29.0	2.8	28.6	4.4
S-N:AR-H(deg)	72.5	3.5	70.8	4.8	72.7	4.5	71.9	4.2
AR-GO-GN(deg)	125.5	4.2	126.5	4.7	124.8	4.3	124.7	4.4

* P<=0.05 for males and females

increase in the mean value for this linear measurement from 9 to 12 years, followed by another significant increase in mean value from 12 to 15 years.

The increase from 12 to 15 years is probably due to a combination of three factors. First, and probably most important, this time period encompasses the pubertal growth spurt. Second, it is during this time period that one sees complete adenoid regression. Third, 24 of the 32 individuals studied had tonsillectomies and adenoidectomies by age 15. The increase from 12 to 15 years was followed by a more subtle increase from 15 to 18 years.

The other two measurements, one from the posteriormost point on the soft palate (Psp) to posterior pharyngeal wall (PhW3) and one from the tip of the soft palate (P) to the posterior pharyngeal wall (PhW4), do not fall in the direct vi-

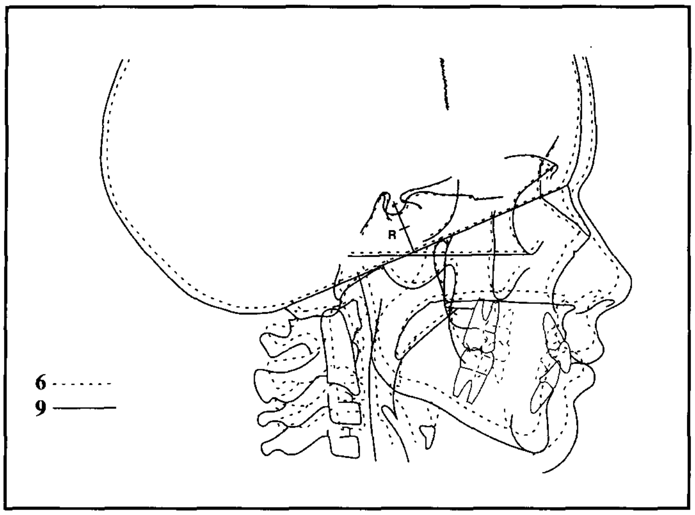

Figure 5

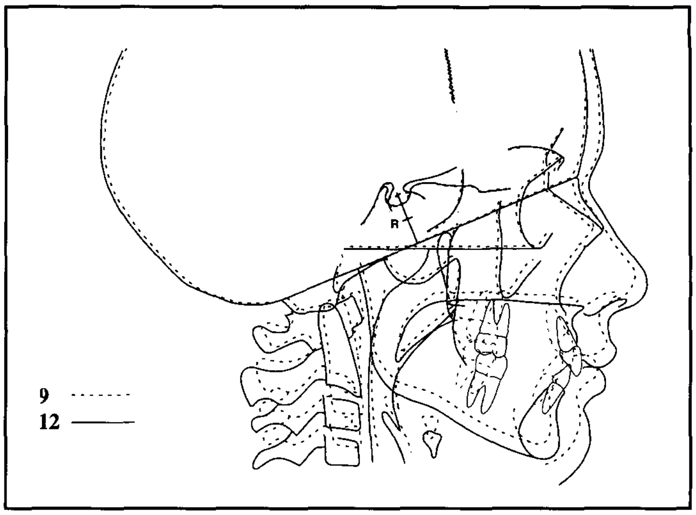

Figure 6

Figure 5
Averaged tracings for 6 and 9 years, superimposed on the Bolton plane and registered at R point.

Figure 6
Averaged tracings for 9 and 12 years, superimposed on the Bolton plane and registered at R point.

cinity of the adenoid tissue, so it is interesting to find increases between ages 6 and 9 years as well as between 12 and 15 years. It is likely that such increases are the result of normal growth in the oropharyngeal area during these time periods. The mean values for the measurements from Psp to PhW3 and from P to PhW4 also show a leveling between 9 and 12 years and between 15 and 18 years. This pattern is similar to that seen for measurements of the nasopharynx.

Limitations of the study findings

The findings of this study are limited because over half of the children in the sample had their tonsils and adenoids removed during the study. Therefore, some of the changes in soft tissue morphology of the posterior pharyngeal wall are likely to be due to surgical intervention. The other major limitation of all cephalometric studies is the representation of three-dimensional structures on a two-dimensional radiograph. However, if these two limitations are kept in mind the clinician can still use the data presented to estimate normal soft tissue anatomy.

Summary and conclusions

1. The results of the linear measurements from one fixed skeletal point to another were similar to those from previously published data.[2,23]

2. The distance from the atlas (ATA) to the posterior nasal spine (PNS) did not increase after age 12.

3. The measurements to the hyoid bone (H) showed increasing distances between the hyoid and various cephalometric skeletal points over time.

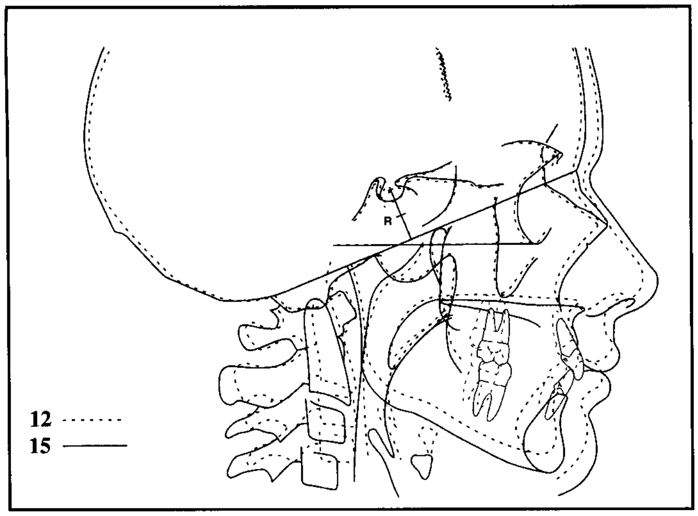

Figure 7

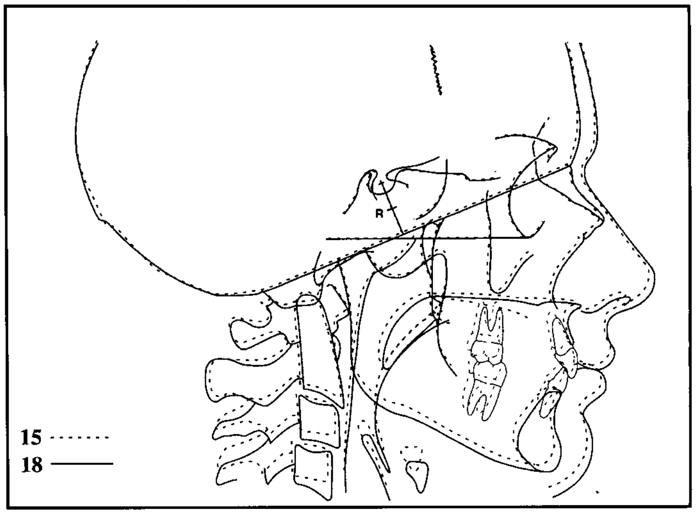

Figure 8

4. The hyoid has a somewhat predictable descent relative to various cephalometric points throughout the growth period.

5. The soft tissue measurements through the posterior pharyngeal wall showed a greater rate of change between 6 to 9 years and 12 to 15 years compared with those observed from 9 to 12 and 15 to 18 years.

Author Address

Mark G. Hans, DDS, MSD
Department of Orthodontics
School of Dentistry
Case Western Reserve University
10900 Euclid Avenue
Cleveland, OH 44106-4905

Based in part on a thesis submitted by Michael Taylor, DDS, MSD, in partial fulfillment of the degree of master of science in dentistry, Case Western Reserve University, Cleveland, Ohio.

Michael Taylor is in the private practice of orthodontics in Roswell, New Mexico.

Mark G. Hans is an associate professor and graduate program director, Department of Orthodontics, and Associate Director of the Bolton-Brush Growth Study Center, School of Dentistry, Case Western Reserve University, Cleveland, Ohio.

Kingman P.Strohl is a professor of medicine, Case Western Reserve University, Ohio.

Suchitra Nelson is a visiting assistant professor in the Department of Orthodontics, School of Dentistry, Case Western Reserve University, Cleveland, Ohio.

B. Holly Broadbent is a clinical professor in the Department of Orthodontics and director of the Bolton-Brush Growth Study Center, School of Dentistry, Case Western Reserve University, Cleveland, Ohio.

Figure 7
Averaged tracings for 12 and 15 years, superimposed on the Bolton Plane and registered at R point.

Figure 8
Averaged tracings for 15 and 18 years, superimposed on the Bolton Plane and registered at R point.

References

1. Hans MG, Broadbent BH, Nelson S. Broadbent-Bolton growth study–past, present, and future. Am J Orthod Dentofac Orthop 1994;106:598–603.
2. Broadbent BH Sr, Broadbent BHJr, Golden W. Bolton standards of normal dentofacial development. Philidelphia: Mosby, 1975.
3. Hans MG, Pracharktam N, Nelson S. The orthodontist's role in obstructive sleep apnea. LaRevue d'Orthopédie Dento-Faciale 1994;28:455–471.
4. Pracharktam N, Nelson S, Hans MG, Broadbent BH Jr, Redline S, Rosenberg C, Strohl KP. Cephalometric assessment of obstructive sleep apnea. Am J Orthod Dentofacial Orthop 1994; In Press.
5. Pracharktam N, Hans MG, Strohl KP, Redline S. Upright and supine cephalometric evaluation of obstructive sleep apnea syndrome and snoring subjects. Angle Orthod 1994; 64(1):63-74
6. Young T, PM, Dempsey J, Skatrud J, Weber S, Badr S. The occurrence of sleep-disordered breathing among middle aged adults. New Engl J Med 1993;328:1230-1235.
7. DeBerry-Borowiecki B. Cephalometric analysis for diagnosis and treatment of obstructive sleep apnea. Laryngoscope 1988;98: 226.
8. Lowe AA. The tongue and airway. Otolaryngol Clin North Am 1990;23(4):677-98.
9. Strelzow V. Cephalometric airway analysis in obstructive sleep apnea syndrome. Laryngoscope 1988;98: 1149
10. Pae EK. A comparative study of the relationship between airway size, tongue activity, and body position. Vancouver, B.C.: University of British Columbia, 1989.
11. Tsuchiya M, et al. Obstructive sleep apnea subtypes by cluster analysis. Am J Orthod Dentofac Orthop 1992;101(6):533-542.
12. Jamieson A, GC, Partinen M, Quera-Salva MA. Obstructive sleep apnea patients have craniomandibular abnormalities. Sleep 1986;9(4): 469.
13. King E. A roentgenographic study of pharyngeal growth. Angle Orthod 1952;22(1): 23-37.
14. Bibby RaCP. The hyoid triangle. Am J Orthod 1981;80:92-97.
15. Rocabado M. Biomechanical relationship of the cranial, cervical, and hyoid regions. J Craniomandib Prac 1983;1:61-66.
16. Stepovich M. A cephalometric positional study of the hyoid bone. Am J Orthod 1965;51:882-900.
17. Graber L. Hyoid changes following orthopedic treatment of mandibular prognathism. Angle Orthod 1978;48:33-38.
18. Tallgren AaBS. Long-term changes in hyoid bone position and craniocervical posture in complete denture wearers. Acta Odontol Scand 1984;42:257–267.
19. Goldman JaAB. Soft tissue roentgenography of the nasopharynx for adenoids. Transcripts from the American Laryngology, Rhinology, and Otolaryngology Society, 1958:692-717.
20. Adamidis P, SM. The effects of lymphadenoid hypertrophy on the position of the tongue, the mandible, and the hyoid bone. Eur J Orthod 1983;5:287.
21. Butler G, McKie M, Ratcliffe S. The cyclical nature of prepubertal growth. Annals of Human Biology 1990;17(3):177-198.
22. Tallgren A, Solow B. Hyoid bone position, facial morphology, and head posture in adults. Eur J Orthod 1987;9:1-8.
23. Riolo ML, Moyers RE, McNamara JA Jr, Hunter WS. An atlas of craniofacial growth; cephalometric standards from the University School Growth Study. Ann Arbor: University of Michigan Center for Human Growth and Development, Craniofacial Growth Series, Monograph No. 2, 1974.