Cephalometric Evaluation and Measurement of the Upper Airway

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The growth and function of the nasal cavities, the nasopharynx, and the oropharynx are closely associated with the normal growth of the skull. In this respect, knowledge of normal cranial growth has often been gained by recognition and observation of abnormal development. Mouth breathing, which has been associated with specific facial growth patterns, may result from obstruction or restriction of any part of the upper airway. The use of lateral cephalometric radiographs to evaluate the upper airway is somewhat limited as they provide 2-dimensional images of the nasopharynx, which consists of complex 3-dimensional anatomical structures. Not withstanding this observation, some workers have found that a significant correlation exists between the results of posterior rhinoscopy and radiographic cephalometry in the assessment of adenoid size. This article reviews some of the most important cephalometric measurements that have been used to determine the patency of the upper airway. It is an important aim of this review to ensure that there is agreement between the cephalometric measurements used in studies of the upper airway and similar measurements used in physical anthropology and human craniometry. Additionally, one example is given of volumetric radiographic techniques that promise to further elucidate aspects of the normal, and the abnormal, functions of the upper airway. (Semin Orthod 2004;10:3-15.) © *2004 Elsevier Inc. All rights reserved.*

Interpretation of the significance of variations in the growth and function of the nasal cavities, the nasopharynx, and the oropharynx is dependent on an understanding of the normal growth of the skull. In this respect, however, knowledge of normal growth has often been gained by recognition and observation of abnormal cranial function and development. Thus, aberrant respiratory modes such as chronic mouth breathing have been implicated in dentofacial deformities.[1-11] In contrast it should be recorded that not all research workers have reported significant evidence that a relationship exists between mouth breathing and dentofacial form.[12-16] Many current concepts concerning the role of respiration in the etiology of malocclusion are based on subjective impressions and anecdotal reports that form a significant part of the literature on this subject. It is on record that mouth breathing may be associated with all types of malocclusions as well as with normal occlusion.[13,14]

Ricketts[6] used the term respiratory obstruction syndrome to describe the various morphological traits associated with chronic obstruction of the nasal airway in growing children. Other common terms for the syndrome are “adenoidal facies,” “the long face syndrome,” and “vertical maxillary excess.”[1,17] These authors include excessive anterior facial height, incompetent lip posture, protruding maxillary teeth, widely flared external nares, a

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steep mandibular plane, and posterior dental crossbite as features frequently found in patients exhibiting chronic mouth breathing during childhood. Craniocervical posture has been related to upper airway obstruction, to craniofacial morphology, and to malocclusion.[11] There is some acceptance of the observation that subjects with a large mandibular plane inclination are characterized by an extended head posture and forward inclined cervical column, that is, an extended craniocervical posture.[11]

Mouth breathing may result from obstruction or restriction of any part of the upper airway. The mucous membrane that lines the nasal cavity covers the surfaces of all the cartilages and bones forming the nasal tract, and extends into and lines the paranasal sinuses. Irritation of this delicate erectile tissue produces engorgement of its blood vessels resulting in a thickening of the membrane, which, in turn, restricts the normal size of the nasal passages.[18] In the course of a day it is usual for individuals to breathe in a cyclical fashion through their left, their right, or both their nasal passages. This breathing cycle is mostly controlled by temporary changes in the thickness of different areas of the nasal mucosa.

The pharynx is a muscular tube that extends superoinferiorly from the base of the cranium to the level of the inferior surface of the body of the 6th cervical vertebra.[19] The pharynx lies dorsal to the nasal cavity, the oral cavity, and the larynx. The nasal part of the nasopharynx resembles the nasal cavity in possessing a highly vascular mucosa that is rich in lymphoid tissue. The mucosa of the nasal section of the nasopharynx is of the respiratory type, while the posterior part resembles the oropharynx in having a stratified squamous epithelium.[20] The nasal portion of the nasopharynx has bony elements in its wall and is thus rigid, whereas the pharyngeal part is contractile as a result of the muscular nature of its wall. The nasopharynx begins superiorly at the attachment of the superior constrictor muscle to the pharyngeal tubercle on the basilar part of the occipital bone and ends at the level of the soft palate. It should be recorded that this is the widest part of the pharynx and it is in communication with the nasal cavity via the choanae and with the middle ear cavities via the Eustachian tubes.[19]

Definitions of Some Radiographic Cephalometric Landmarks Frequently Used in Studies of the Upper Airway

1. AA. Anterior arch of the atlas. The most anterior (ventral) point on the anterior arch of the atlas (C1) assumed to be in the median sagittal plane.[6]
2. ad. Intersection of the line drawn at right angles to the pterigoid vertical (PTV) and 5 mm above posterior nasal spine (PNS) and the posterior nasopharyngeal wall.
3. ad1. Intersection of the line PNS-ba (basion) and the posterior nasopharyngeal wall.[51]
4. ad2. Intersection of the line PNS-midpoint of sella (so) and the posterior nasopharyngeal wall.[51]
5. ba (also Ba). Basion line. The most posterior limit of the lowest point in the midline on the anterior margin of the foramen magnum (this is external basion or ectobasion).
6. C2 (cv2p[11]). The most posterior point on the inferior margin of the outline of the body of the second cervical vertebra (axis).
7. C3 (cv3p[11]). The most posterior point on the inferior margin of the outline of the body of the third cervical vertebra.
8. C4 (cv4p[11]). The most posterior point on the inferior margin of the outline of the body of the 4th cervical vertebra.
9. C2c (cv2c[11]). The anteroposterior midpoint on the inferior margin of the body of the second cervical vertebra (axis).
10. C3c, C4c, C5c. These radiographic cephalometric points correspond to the position of C2c on their respective cervical vertebrae.
11. ho (also Ho). Homerion. The most posterior contact point of the vomer with the body of the sphenoid bone. It is assumed to lie in the midsagittal plane, between the alae of the vomer.[22,52] On a lateral cephalometric radiograph hormion is that point where the posterior border or choanal crest of the vomer meets the pharyngeal outline of the

cranial base, and this is assumed to be in the median plane.

12. hy. Hyoidale. The most superior point on the anterior surface of the outline of the body of the hyoid bone.[53] This point is assumed to lie in the median sagittal plane of the hyoid bone.
13. in. The inferior end of the perpendicular from sos to the line that joins PNS to AA.
14. od. Odontoid. This is the most superior point on the tip of the odontoid process as seen on a lateral cephalometric radiograph.
15. op. Opisthion external. The most anterior limit of the lowest point, assumed to be in the midline, on the posterior margin of the foramen magnum.
16. PNS. This is a constructed, radiographic, lateral cephalometric point, located at the intersection of the continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose. It is assumed to mark the posterior limit of the maxilla.[54]
17. rgn. Retrognathion. The most inferior point on the posterior surface of the symphysis of the mandible, assumed to be in the median plane.
18. so. Midpoint of the sella-basion line.[51]
19. sos. Spheno-occipital synchondrosis. The most inferior point in the anteroposterior middle of the spheno-occipital synchondrosis as seen on a lateral cephalometric radiograph.
20. TMJ. A constructed point on the bony contour of the glenoid fossa. It is located where the extension of the line that joins gnathion to the most posterior, superior point of the left condyle intersects the outline of the glenoid fossa.[33,34]
21. cv2tg. The most posterior midline point on the superior curvature of the tip of the odontoid process.

Some Reference Lines Used in Radiographic Cephalometric Studies of the Upper Airway

1. Cervical axis. The line od-C5c.
2. Frankfurt plane. The line formed by joining the left porion with the left orbitale. This line may be extended in either direction.
3. Odontoid tangent. The line that passes through cv2p and is tangent to the posterior surface of the outline of the odontoid process.
4. Palatal line. On a lateral cephalometric x-ray the palatal plane is represented by a line joining the posterior, and the anterior nasal spines (PNS-ANS). The palatal line may be extended in either direction.
5. Pterygoid vertical (PTV). This line passes through the pterygomaxillary fissure and is perpendicular to the Frankfurt plane.

Anatomically, the Skeletal Limits of the Nasopharynx Are:

1. Anteriorly, the bony structures constituting the choanal openings usually taken to be the dorsal border or choanal crest of the vomer.
2. Superoposteriorly, the pharyngeal surface of the body of the sphenoid bone and of the basilar part of the occipital bone.
3. Posteriorly, the cranial half of the anterior

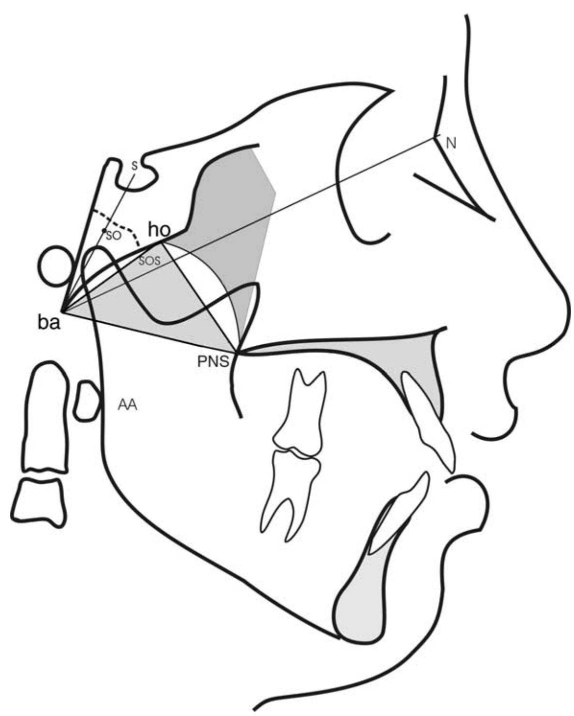

Figure 1. The cephalometric bony nasopharynx is usually defined by the lines that join the landmarks PNS, ho, and ba.

surface of the anterior arch of the atlas (C1), while Tobias[21] includes the ventral surface of the axis (C2) as part of the "bony background" of the nasopharynx.
4. Caudally, the nasopharynx is defined osteologically by a straight line that joins the posterior nasal spine to the most anterior point, AA, on the anterior arch of the atlas.[6]

Geometrically the roof of the bony nasopharynx in the median sagittal plane is shaped like a gable (Fig 1).[22] The anterior part of the gable is formed by a line joining the posterior nasal spine to hormion, ie, the vomer's dorsocaudal point of contact with the sphenoid bone. In humans this line lies in a plane that approximates to the main direction of the pterygoid processes, ie, the choanal plane.[23] A line joining hormion and basion forms the posterior part of the gable. This line is used by convention,[6,22] although it excludes the region between basion and AA, which contributes to the posterior wall of the nasopharynx. The bony roof of the nasopharynx is made up of the inferior aspect of the clivus that is formed by midline portions of the sphenoid and occipital bones.

Linear Measurements (Fig 2) Commonly Used in Studies of the Upper Airway Are:

1. The length of the (presellar) anterior cranial base (S-N).
2. The length of the postsellar part of the posterior cranial base (ba-S).
3. The total or effective cranial base length (ba-N).
4. The length of the palate (floor of the nasal cavity). The distance between PNS and ANS.
5. The posterior height of the nasal cavity (S-PNS).
6. The vertical diameter of the choanal openings (ho and PNS).
7. The length of the pharyngeal clivus (ba to ho).[22]
8. The length of the floor of the nasopharynx (AA to PNS).[6,42]
9. The total depth of the nasopharynx. The distance from ba to PNS.[22]
10. The effective length of the maxilla (TMJ to ANS).
11. The upper anterior facial height (N and ANS).
12. The distance from so to in.

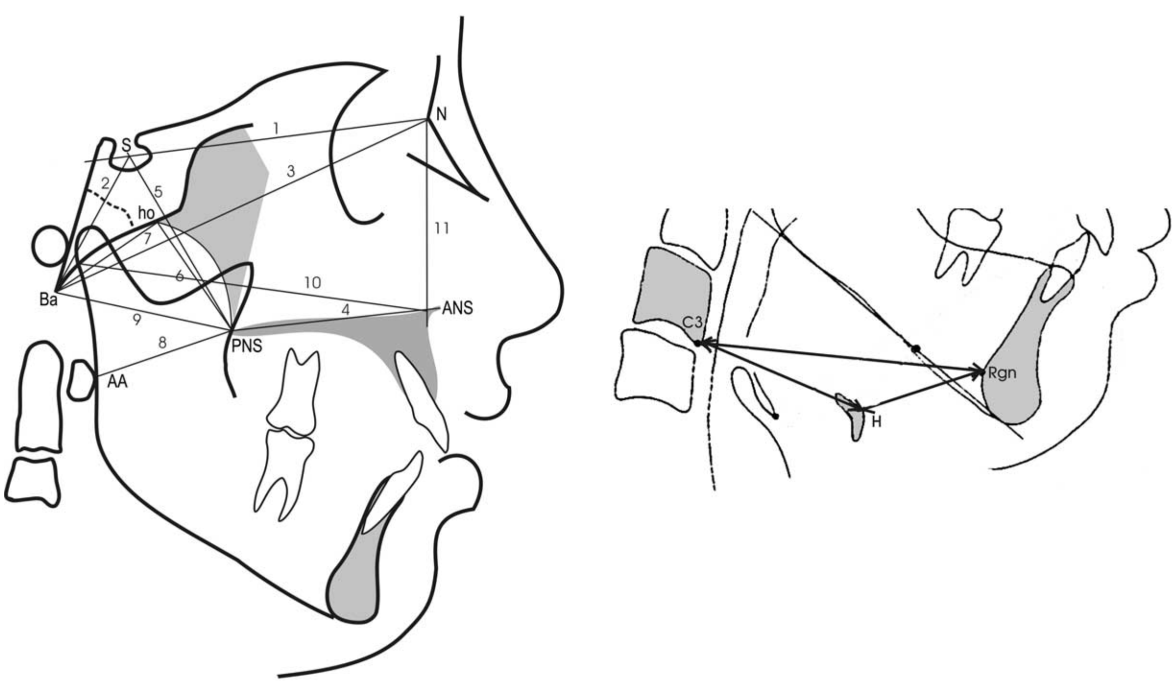

Figure 2. Some important linear measurements used in radiographic cephalometric studies of the upper airway. The hyoid triangle is shown.

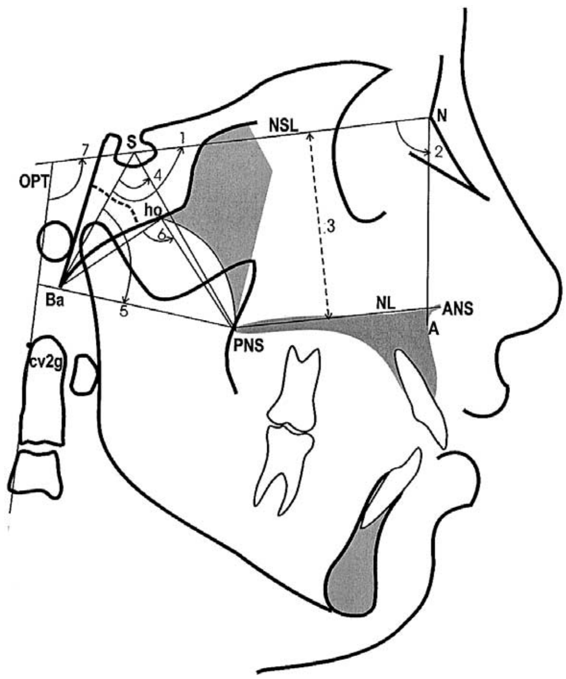

Figure 3. Some important angular measurements used in radiographic cephalometric studies of the upper airway.

13. The distance from AA to hy.
14. The distance from hy to rgn.

Angular Measurements (Fig 3) Commonly Used in Studies of the Upper Airway Include:

1. The saddle angle included between the lines joining ba to S and S to N (ba-S-N).
2. The angle between the anterior cranial base and point A on the maxilla.
3. The angle between the palatal lane (PNS-ANS) and the anterior cranial base (S-N).
4. The angle of nasopharyngeal depth. The included angle ba-S-PNS.
5. The vertical angle of the nasopharynx. The included angle PNS-ba-S.
6. The roof angle of the nasopharynx. The included angle ba-ho-PNS.[22]
7. The craniocervical angle included between the superior extension of the tangent to the posterior surface of the odontoid process, and the posterior extension of the line ba-S.

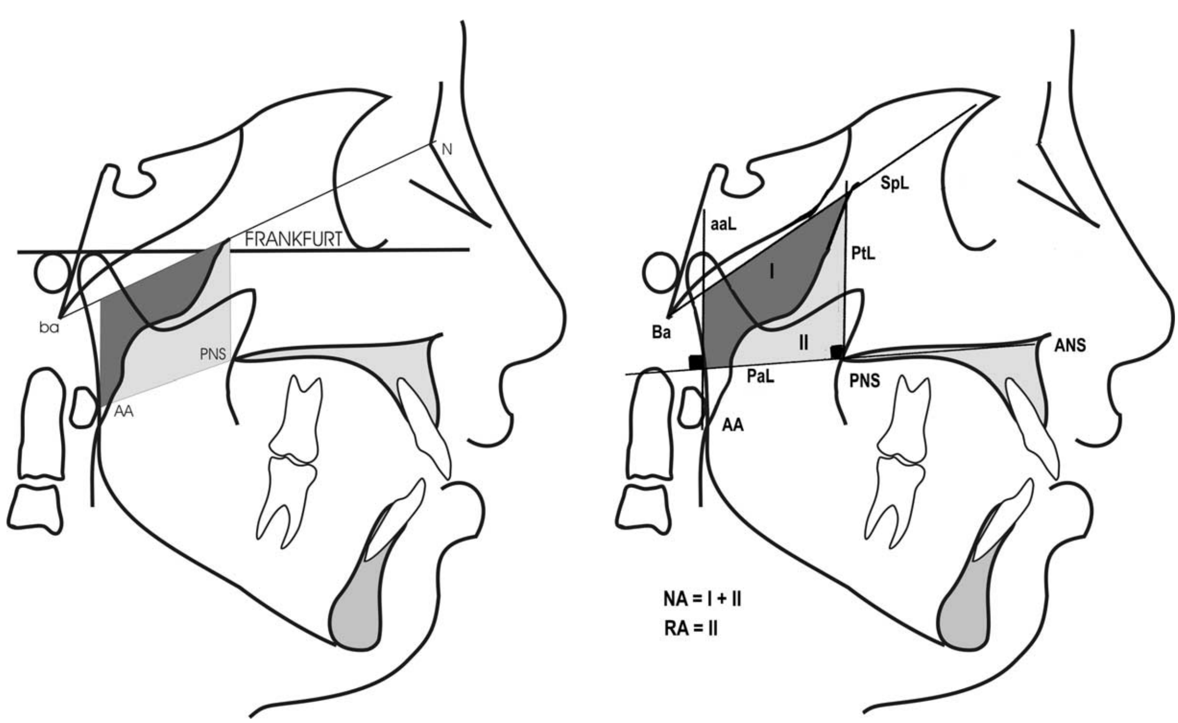

Figure 4. Two techniques that have been used to measure the adenoid (NA) and the respiratory (RA) areas.[41,42]

Some Area Measurements (Fig 4) Used in Radiographic Cephalometric Studies of the Upper Airway Are:

1. The area of the bony nasopharynx frequently defined as a trapezoid demarcated by the following lines: AA-PNS; the pterygoid vertical between PNS and the intersection of this vertical line and the ba-N line; a line drawn through AA, parallel to the pterygoid vertical and extended to intersect the ba-N line; the section of the ba-N line between the pterygoid vertical and the vertical erected through point AA.
2. The area of the adenoid tissue contained within the trapezoid that depicts the nasopharynx.

Some Percentages and Ratios (Figs 4 and 5) Used in Radiographic Cephalometric Studies of the Upper Airway Are:

1. The adenoid percentage: percentage of the bony nasopharynx area occupied by the area of adenoid tissue.[41]
2. The percentage of the so-in line covered by adenoid tissue.[27]

The flow of inspired air is subject to the physical constraints of fluid-flow dynamics, which deals with factors that result in resistance to the flow of a medium such as air. For practical purposes constriction, anywhere in the upper airway, is the main cause of resistance to nasal airflow. In this respect the liminal valve, at the entrance to the nasal air passages, as well as the turbinates and the mucosa covering them, may contribute substantially to the obstruction of inspired air. More posteriorly the relative size of the nasopharynx has a bearing on whether the mode of breathing is predominantly nasal or oral.

Invasion of lymphoid tissue into the palatine, posterior pharyngeal, adenoid, and lingual tonsillar regions takes place during the 3rd to 5th intrauterine month. These lymphoid masses encircle the upper part of the oropharynx to form an incomplete ring (Waldeyer's ring) of immunodefensive tissue that grows markedly postnatally to bulge into the oropharynx.[24] The ade-

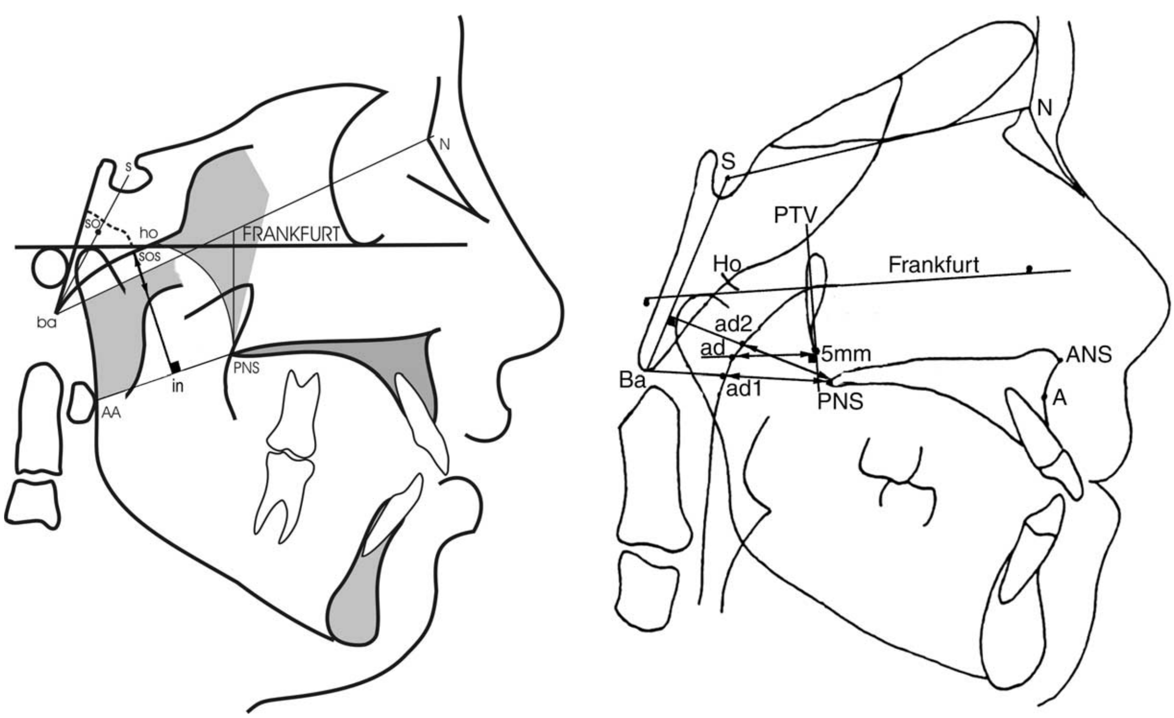

Figure 5. Four linear measurements used to determine the thickness of the adenoidal tissue. The distance to the nearest adenoidal tissue on the line SOS-in, ad, ad1, and ad2.

noidal tissue is thought to hypertrophy during the period shortly before puberty.[25,26] This enlargement of lymphoid tissue enhances the chances of the nasopharyngeal airway being constricted, and, in consequence, the relationship between the size of the adenoids and that of the bony nasopharynx is important.[2,27-30] An association that was noted between adenoid enlargement and mouth breathing formed the basis for some of the earliest explanations of the etiology of the adenoidal facies.[1]

Tomes,[31] who reported that children with enlarged adenoids display V-shaped dental arches, proposed a compression theory. The narrowing of the upper arch is ascribed to a low tongue position in combination with an unbalanced compressive force on the maxillary arch buccal segments.[1,2,32-34] Solow and his coworkers[9,11] focused more on the relationships that exist between modes of breathing, cranial posture, muscle tension, and those craniofacial features that are displayed on a lateral cephalometric radiographic film. At least one study[35] points out that all of the clinical trials of adenoidectomy tested the efficacy of these surgical procedures in children, in whom the indications for this procedure were questionable. Another study[36] notes that the results of tonsillectomy and adenoidectomy are not striking and that only some reduction in mouth breathing may be expected following these operations.

The use of lateral cephalometric radiographs to evaluate the upper airway is somewhat limited as they provide 2-dimensional images of the nasopharynx, which consists of complex 3-dimensional anatomical structures.[15] Not withstanding this observation, Linder-Aronson[28] found a high level of correlation between the results of posterior rhinoscopy and radiographic cephalometrics in the assessment of adenoid size. This observation was made also by previous authors[37-39] who found that lateral skull radiographs provide a good picture of the size of the nasopharyngeal airway in children of all ages. The functional adequacy of the upper airway should always be evaluated fully, making use of all of the appropriate diagnostic means.

Linder-Aronson and Henrikson[40] set out to determine the average anteroposterior size of the nasopharyngeal airway in children from 6 to 12 years of age. They measured the length of the posterior cranial base (ba-S), the depth of the nasopharynx (ba-PNS), and the size of the airway. The size of the airway was determined by measuring the distance between the adenoid and the posterior nasal spine, on 2 previously defined radii. The results showed that when planning orthodontic therapy, a clinical record of the mode of breathing could be supplemented with radiocephalometric data on the anteroposterior size of the nasopharyngeal airway. The standard values obtained in the study showed that an otological examination of the nasopharyngeal space should be recommended, if certain distances were less than the mean minus 1 standard deviation, for patients in the appropriate age group.

The dimensions of the nasopharynx, the adenoid, and the nasopharyngeal airway were analyzed in 12 subjects selected from the longitudinal growth study of the Child Research Council of Denver.[41] Four skeletally determined lines that circumscribe a trapezoid were used to define the nasopharyngeal area. The trapezoid was divided into 2 parts of which the first contains the adenoid and the second represents the available airway space. Handelman and Osborne[41] studied the growth of the nasopharynx from 9 months to 18 years and found that a sexual dimorphism exists in the growth pattern of this anatomical region. They also concluded that the growth of the nasopharyngeal area corresponds to the descent of the palate from the sphenoid, a movement that increases the nasopharyngeal height.[21] Restriction of the nasopharyngeal airway frequently occurs during the early school years, due to an adenoid hypertrophy that exceeds the usual increase in nasopharyngeal volume. The nasophryngeal airway tends to increase during early adolescence due to a concurrent increase in nasopharyngeal area and adenoid involution.

Four linear measurements of the nasopharynx, found to be significantly correlated with airway patency, were used to measure the effective nasopharyngeal airway[30,42] (Fig 5 and Table 1). Two of the measurements used were those employed by Linder-Aronson and Henrikson,[40] a third was derived from the study of Handelman and Osborne,[41] while the final dimension measured the distance to the nearest adenoid tissue, from a point on the pterygoid vertical, 5 mm above the posterior nasal spine.[6,43] As a result of his study Schulhof[42] suggested that sur-

Table 1. Mean data presented by Schulhof (1978) for the percentage of airway area relative to the nasopharyngeal area, and three linear measurements of airway patency

		Male		Female	
Measurement		*6 Yr*	*16 Yr*	*6 Yr*	*16 Yr*
Airway %	Mean	50.55	63.96	50.99	62.68
	SD	15.85	12.80	13.49	16.09
D-AD1: PNS	Mean	20.66	26.48	14.74	26.32
	SD	5.50	5.45	5.69	4.28
D-AD2: PNS	Mean	15.89	22.44	14.93	21.78
	SD	3.53	4.26	3.52	4.67
D-PTV: AD	Mean	7.07	14.59	7.02	14.56
	SD	3.85	6.10	3.87	4.70

The data were obtained from the Foundation for Orthodontic Research and applies to white American children.

geons could perform either complete or partial adenoidectomies in selected patients.

In a longitudinal study the areas of the nasopharynx and its contents were measured on the lateral cephalometric radiographs of 41 normal children who had been examined at yearly intervals, for a minimum of 12 years, between the ages of 3 and 19 years.[44] Observations on consecutive tracings of individual children show that the outline of the soft tissue and the airway varies from year to year. During development the inferior margin of the adenoid tissue outlined against the airway is convex and with maturity it becomes concave. Jeans and coworkers[44] suggest that linear measurements of the soft tissues of the nasopharynx are unreliable, and that measurements of areas are more meaningful in studies of the upper airway (Fig 5). They also found that growth of the bony nasopharynx, in the sagittal plane, measured on lateral radiographs is mainly in height (0.8-1.0 mm per annum). In boys the area of nasopharyngeal soft tissue is constant after the age of 6 years, while in girls this area decreases slowly from 9 to 19 years of age. In boys the increase in the size of the bony nasopharynx, and the standstill in soft tissue size, was thought by Jeans and coworkers[44] to account for a progressive increase in the size of the airway from the age of 5 years onward.

During the past 50 years a number of researchers used a variety of radiographs to study the spatial and morphological relationships that exist between the adenoidal tissue and the nasopharyngeal airway. The data from the Foundation for Orthodontic Research® were used to study facial form in relation to the functional anatomy of the upper airway[27,42] while Linder-Aronson[28] analyzed in excess of 200 craniofacial measurements for the same purpose. Ten years later Poole and Engel[30] evaluated a similar number of cephalometric measurements to define some of the craniofacial features that are common to patients with nasopharyngeal obstruction. They found that, whereas no single cephalometric dimension is adequate to diagnose an adenoid problem, a combination of measurements could be used effectively in this regard.

The size and shape of the nasopharynx may be described in terms of its height, width, and depth. Previous studies agree that in growing children both the height and width of the nasopharynx are closely dependent on age.[26] There is, however, some difference of opinion as to the relationship that exists between age and the sag-

Figure 6. A Newtom™-generated image of the palate and a portion of the nasopharynx of a patient.

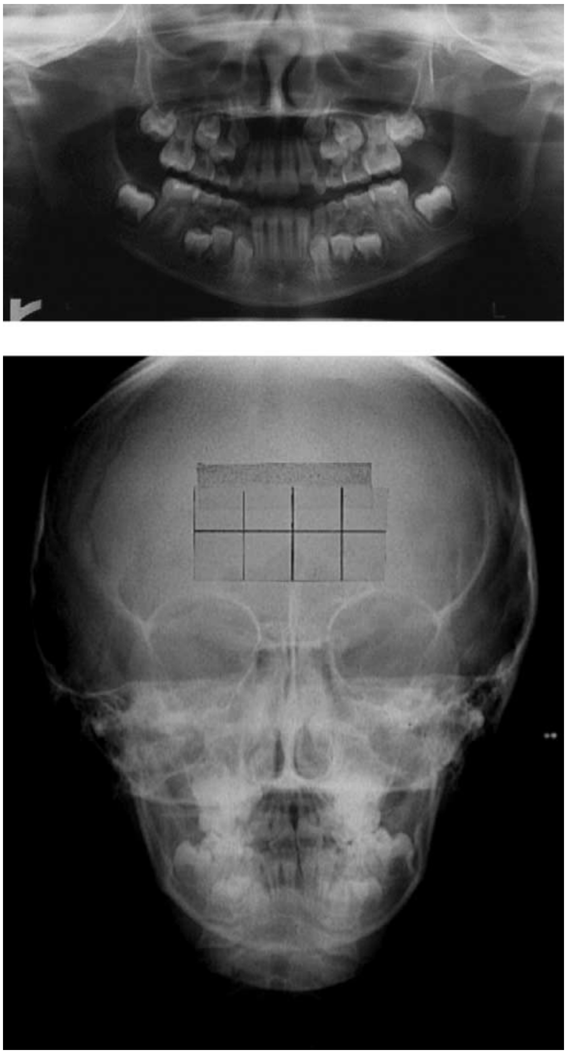

Figure 7. Newtom™-generated panoramic and posteroanterior images of a patient with predominantly oral breathing. Both of these images indicate that the patient has a deviated nasal septum.

ittal depth of the nasopharynx.[41,45-48] The above studies were based on the chronological ages of the subjects studied and this fact may have affected the findings.[49] Studies dealing with the growth of the upper airway should preferably be

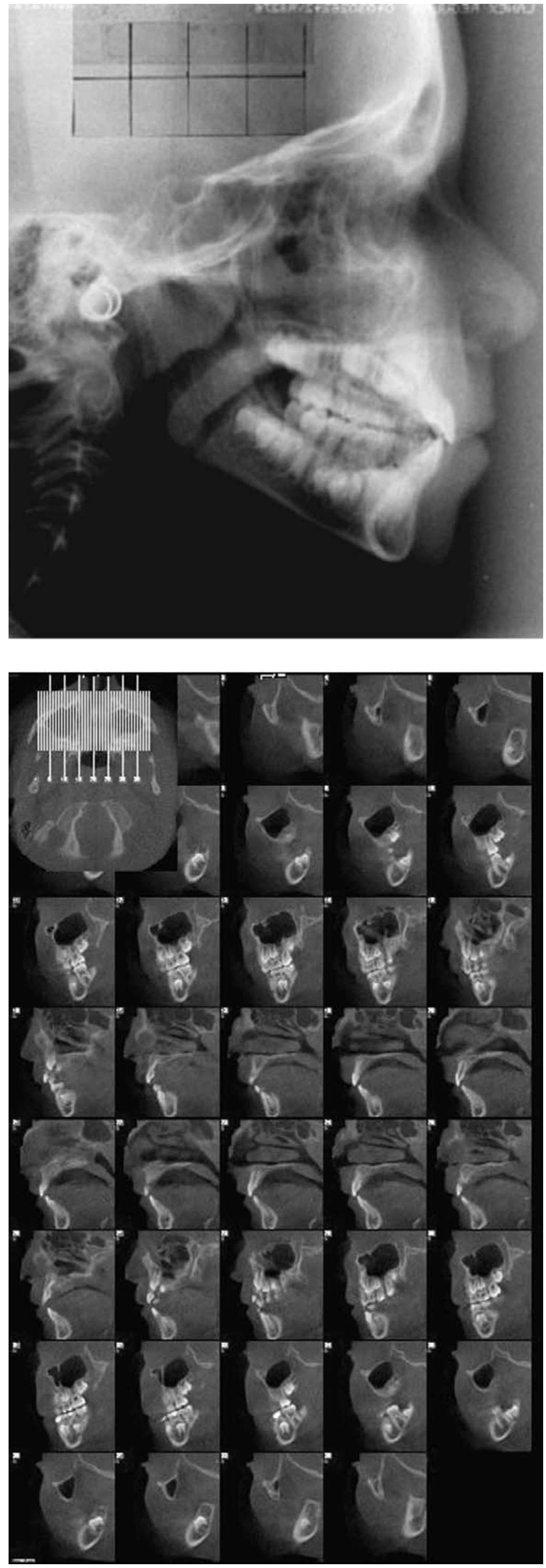

Figure 8. Newtom™-generated midsagittal plane lateral cephalometric image, and images of 3-mm-thick sagittal plane slices of the face of the same patient shown in Figures 6, 7, and 9. The latter slices provide anatomical data that give a good insight into the patency of the nasal airway and nasopharynx of this patient. Images of slices in other cranial planes can be provided with little effort other than software manipulation of the original Newtom™-generated data file.

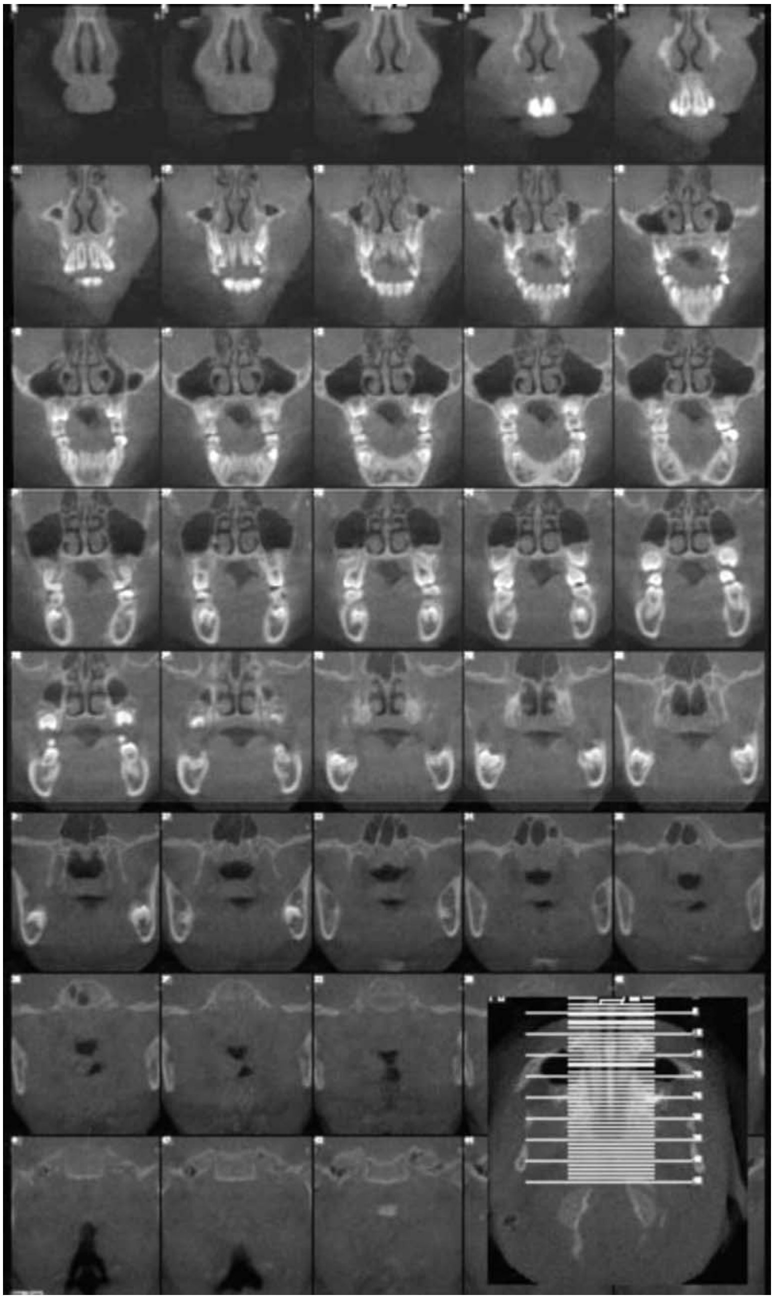

Figure 9. Newtom™-generated images of 3-mm-thick coronal plane slices of the face of the same patient shown in Figures 6, 7, and 8.

performed by relating the skeletal maturation of the subjects being studied to the skeletal maturation of children on whom specific maturational standards are based.[49]

In a technical sense it is recommended that cephalometric radiographs, taken to evaluate the upper airway, are exposed while the subjects maintain their natural head position, and preferably without the use of a cephalostat.[7,8,34,50,51]

The total posterior facial height is usually taken as the distance from point sella to the angle of the mandible.[53,54] In studies of the upper airway the distance from sella to the posterior nasal spine is used to represent the upper posterior facial height.[49] Bergland[22] divided the upper posterior facial height into 2 parts. The first extended from sella to hormion and represented the approximate dimension of the body of the sphenoid bone. The second extended from hormion to the posterior nasal spine and gave an approximate expression for the length of the pterygoid processes or the vertical diameter of the choanal openings.

The calcified tissues that support the pharynx have been studied radiographically in live human samples.[9,22,26,41,46,47] Previously the nasopharynx was studied craniologically,[23,52,55-59] and more recently in studies related to vocalization.[60] Growth studies of the soft tissues of the pharynx have also been performed by means of cephalometric radiographs.[15,49] The problems associated with an x-ray cephalometric study of the upper airway can roughly be divided into 2 groups. In the first group are those problems that result from difficulties encountered in landmark identification. A second group of problems results from the fact that conventional x-rays yield 2-dimensional pictures of 3-dimensional structures. Certainly, the problems associated with estimating the 3-dimensional size of adenoidal tissue from a cephalometric radiograph, which essentially provides information in 2 planes, remains a very real one. Vig[15] made an eloquent appeal for researchers to base claims that link predominant respiratory mode and facial form on sound evidence based research.

During the past few years a number of manufacturers have produced x-ray equipment that specifically produces volumetric radiographs of the craniofacial structures. In this regard the Newtom™ provides a good example of equipment that is dedicated to computed tomography of the skull. During tomography the Newtom™ machine creates a data file of coordinates located in 3 dimensions on the *x*, *y*, and *z* axes of the skull being radiographed. These coordinates represent the respective anatomical points located in the craniofacial skeleton. The coordinates are recorded and stored according to their darkness on a continuous white to black scale that, just as in a regular x-ray, reflects the radiopacity of the tissue point being imaged. The data files produced by the Newtom™ are manipulated with separate computer software capable of producing an almost endless variety of radiographs that give a 3-dimensional insight into craniofacial structures (Figs 6, 7, 8, and 9).

Notwithstanding the considerable attention given to the growth of the pharynx, the statement of Scott[64] (1955) that "less is known about the growth of the pharyngeal region than any other part of the face" is still largely true. With new technology and equipment it is becoming feasible to obtain 3-dimensional knowledge of the craniofacial morphology of orthodontic patients. This article shows 1 example of such equipment designed specifically for use in dental offices. This article also strives to standardize the definitions of some of the landmarks and dimensions used to study the upper airway.

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