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CEPHALOMETRIC ANALYSIS FOR DIAGNOSIS AND TREATMENT OF OBSTRUCTIVE SLEEP APNEA*†

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ABSTRACT

A detailed cephalometric analysis was conducted on lateral x-rays from 30 adult patients with obstructive sleep apnea (OSA) and 12 age- and sex-matched controls. Statistical findings show that OSA patients are different from controls in at least five ways: *1.* Their tongue and soft palate are significantly enlarged. *2.* The hyoid bone is displaced inferiorly. *3.* The mandible is normal in size and position (no micrognathia or malocclusion), but the face is elongated by an inferior displacement of the mandibular body. *4.* The maxilla is retropositioned and the hard palate elongated. *5.* The nasopharynx is normal, but the oropharyngeal and hypopharyngeal airway is reduced in area by an average of 25%, a factor that could produce or enhance OSA symptoms. These data suggest that cephalometric evaluation could be useful when used with head and neck examination, polysomnographic and endoscopic studies to evaluate OSA patients, and to assist with the planning/surgical treatment for improvement of upper airway patency.

Obstructive sleep apnea (OSA) is characterized by recurrent episodes of functional pharyngeal airway obstruction during sleep. The pathophysiological consequences of OSA are those of cardiovascular and pulmonary complications, as well as excessive daytime hypersomnia which may lead to occupational and/or professional disability and adverse behavioral changes. Although there is considerable variation between patients, the site of obstruction involves some part of the pharynx.[1]

The etiology of OSA appears to be a neurogenic failure to preserve the patency of the pharyngeal airway during sleep, but there are indications that other factors may be involved. One factor receiving some attention is that OSA patients show certain craniofacial defects which may influence pharyngeal patency. In their recent study, Riley, *et al.*[2] showed that OSA patients have an elongated soft palate and exhibit a narrowing of the posterior (pharyngeal) airway space. Their measurements, however, were based on a limited number of cephalometric landmarks making it difficult to compare these data with the extensive literature on the interrelationships between the bony- and soft-tissue landmarks of the craniofacial skeleton.[3-6]

Roentgenocephalometric analysis has been used extensively over the last 2 decades to evaluate the growth[7-10] and malformations[11,12] of the dentofacial skeleton. Several cephalometric studies have been performed to analyze the position of the hyoid bone before and after surgery for mandibular osteotomy,[13] during swallowing,[14] following tracheal transection after injury,[15] and to evaluate its influence on pharyngeal airway patency.[2,15]

In the present report, we present a systematic craniometric analysis of OSA patients and age- and sex-matched controls. Each patient and control was evaluated on the basis of angular, linear, and area measurements from lateral x-rays. This procedure allows one to accurately assess the hard- and soft-tissue landmarks at the same time.[16] Measurements are oriented in accordance with the Frankfurt horizontal plane (FH) which is the most widely accepted radiographic plane.

MATERIALS AND METHODS

Roentgenocephalometric measurements were obtained from 30 patients with polysomnographically diagnosed OSA syndrome. There were 27 males and 3 females ranging in age from 42 to 52. Changes in the soft tissues of the oropharyngeal area were recorded during fibro-optic nasopharyngoscopy. For comparison, a control group consisting of 12 nonsnoring individuals (10 males, 2 females) in the same age range were subjected to the same fibro-optic and cephalometric tests.

Severity of OSA was established on the basis of polysomnographic testing according to a modified formula used by Scripps Clinic Sleep Disorder Center. The formula provides a grading and scoring system for hypoxemia, excessive daytime sleepiness (EDS), sleep fragmentation (arousal index), combined apnea hypopnea index, and cardiac event occurrence. Each of these parameters has 4 grades (1-4).

Hypoxemia gradient is calculated as follows:

Grade 1.—Minimum oxygen saturation during sleep higher than 85% and number of desaturation events (greater than 4%) per hour of sleep less than seven.

Grade 2.—Minimum oxygen saturation noted during sleep 80% to 85% and number of desaturation events 7 to 15.

Grade 3.—Minimum oxygen saturation 60% to 80% and number of desaturation events during sleep 15 to 30 per hour.

Grade 4.—Minimum oxygen saturation less than 60% and number of desaturation events greater than 30 per hour.

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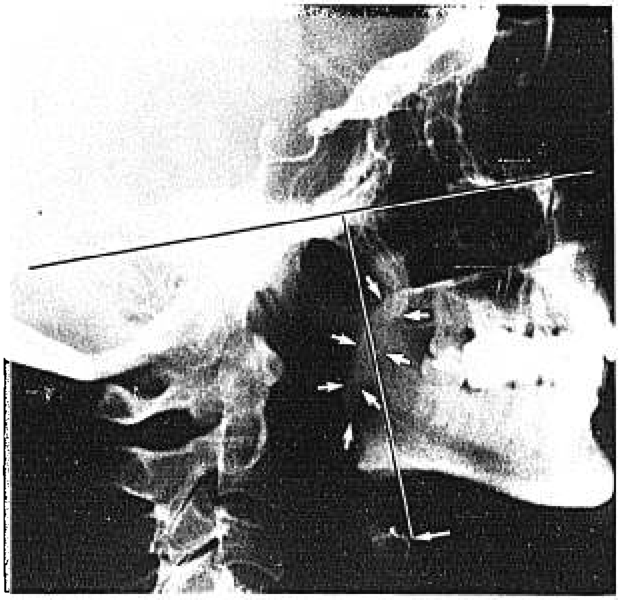


Fig. 1. Lateral x-ray of adult male control. The extent of the soft palate is delineated by the short arrows. Note the position of the Frankfurt horizontal (FH) plane and the relationship between the FH and the hyoid bone (long arrow in figure).

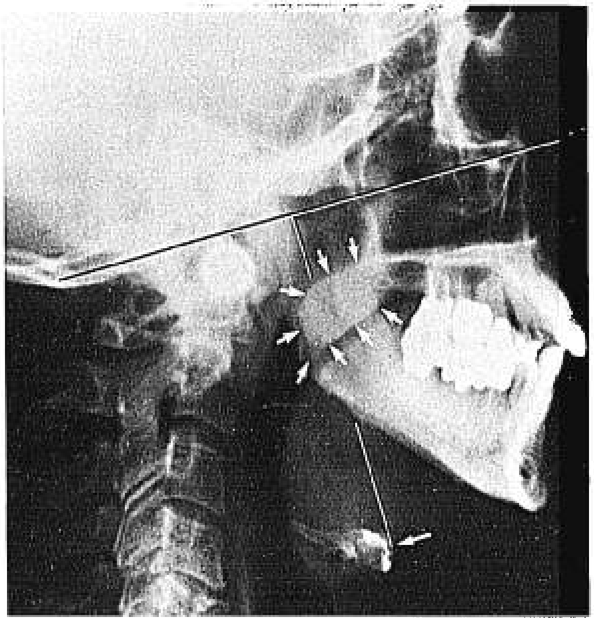


Fig. 2. Lateral x-ray of adult male OSA patient. The enlarged soft palate is shown by the area outlined by the small arrows. Note also the more inferiorly located hyoid bone (marked with long arrow) and enlarged distance between the hyoid bone and the Frankfurt horizontal plane.

EDS is established on the basis of patient's history:

Grade 1. — Patient takes no naps and stays alert throughout the daily activities.

Grade 2. — The patient feels sleepy during the day, but does not fall asleep at inappropriate times.

Grade 3. — Takes naps during the day and falls asleep at inappropriate times (posing social handicap).

Grade 4. — Uncontrollable spontaneous sleep events during eating, driving, and performing work (posing occupational handicap and/or safety hazard).

Sleep fragmentation (arousal index) established on the basis PSG:

Grade 1. — 0 to 6 arousals per hour related to abnormal respiratory events.

Grade 2. — 6 to 12 arousals per hour.

Grade 3. — 12 to 18 arousals per hour.

Grade 4. — Greater than 18 arousals per hour of sleep.

Combined apnea-hypopnea index (adult population age 20 to 60):

Grade 1. — 0 to 7 events per hour.

Grade 2. — 8 to 17 events per hour.

Grade 3. — 18 to 27 events per hour.

Grade 4. — 28 or more events per hour of sleep.

Abnormal cardiac events resulting from apnea episodes are graded as follows:

Grade 1. — Minimal or no rhythm abnormalities.

Grade 2. — Sinus rhythm variability greater than 10 per minute.

Grade 3. — Bradycardia less than 50 per minute, second degree heartblock, atrial tachycardia.

Grade 4. — Significant ventricular irritability (repeated bigeminy, trigeminy and ventricular tachycardia, sinus arrest longer than 2 seconds).

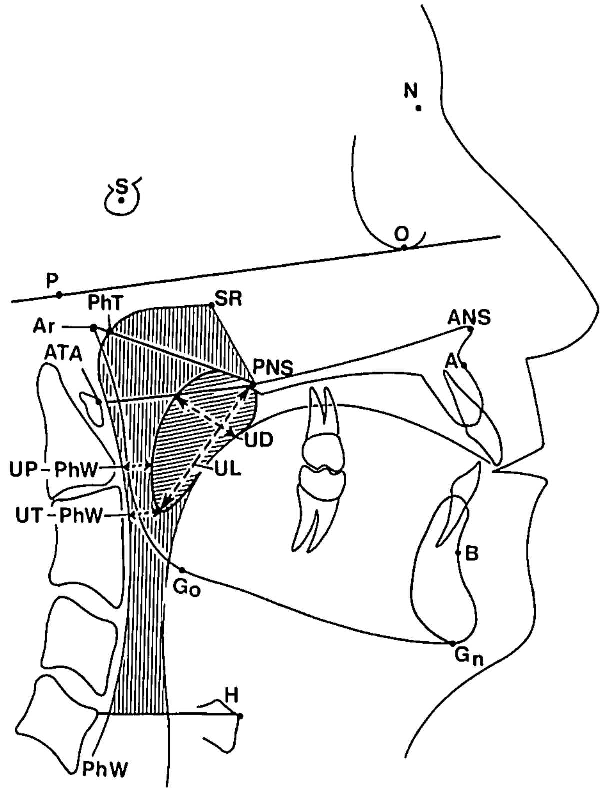
A "Comprehensive Index of OSA" (CIOSA) is arrived at by summing up all grades determined for each category — hypoxemia, EDS, combined apnea-hypopnea index, etc. According to the above-described formula, the patients are divided into three groups of increased OSA severity. *1.* Mild CIOSA: 7 to 12. *2.* Moderate CIOSA: 13 to 18. *3.* Severe CIOSA: 18 to 20.

Lateral x-rays were obtained from patients in a sitting position using a cephalometric head holder which standardizes head and neck position in conjunction with the film holder.[12,17] Before each exposure, the patient was instructed to close the jaw in a natural occlusive position, take a breath and slowly exhale. X-rays were taken during the expiratory phase. The exposure parameters were arranged to maximally observe hard- and soft-tissue landmarks.

Angular and linear measurements were obtained from the x-rays using established anthropological[18-20] and orthodontic landmarks.[2,21-24] The cross-sectional area of the oral cavity, nasal cavity, oropharyngeal and nasopharyngeal airways were obtained from lateral x-rays using a Bioquant Apple II-plus® system.[25] All measurements were collated and subjected to statistical analysis to derive means and standard deviations. Tests for significance were performed using a nonparametric, Mann-Whitney U analysis[26] and significance levels of $p \leq 0.05$.

The following radiographic landmarks of the soft tissue and bony framework of the skull were selected for analysis: *A* — Subspinale: the deepest point on the premaxillary contour between the anterior nasal spine and the central incisors. *ANS* — Anterior nasal spine. *Ar* — Articulare: the intersection of a line along the posterior border of the mandible and the inferior border of the basilar occipital bone. *ATA* — Anterior tubercle of atlas. *B* — Supramentale: the deepest point on the anterior mandibular contour between the gnathion and the central incisor. *DO* — Dental occlusion line. *EA* — Apex of epiglottis. *FH* — Frankfurt horizontal plane: a line joining the superior pole of the external auditory canal and the infraorbital ridge. *G* — Genial tubercle: the most posterior point on the symphysis of the mandible. *Go* — Gonion: the point defining the angle of the mandible (the mandibular plane and the ramus plane form the gonion angle). *Gn* — Gnathion: the most outward and everted point on the mandibu-

TABLE I.
Soft Palate, Nasopharynx, Meso- and Hypopharynx: The Craniometric Measurements for These Anatomical Regions in Controls and OSA Patients are Shown in the Table and are Illustrated by the Insert Figure.†

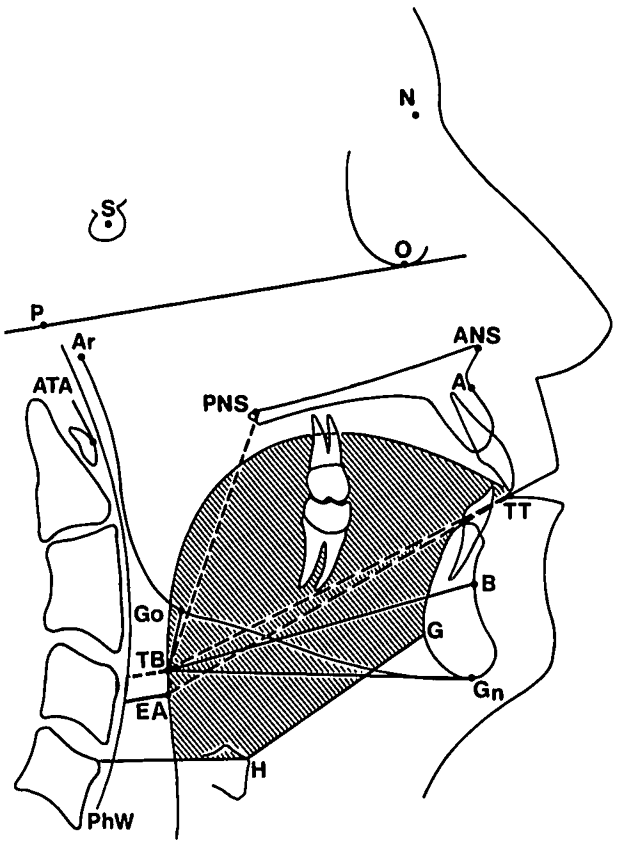


Measurement (distance, angle or area)	OSA Patients $n = 30$ (mean ± *SD*)	Controls $n = 12$ (mean ± *SD*)	Significance (*p* value)
UD (mm)	14 ± 3	10 ± 2	0.000*
UL (mm)	41 ± 6	34 ± 7	0.010*
UP-PhW (mm)	7 ± 4	13 ± 5	0.002*
UT-PhW (mm)	9 ± 3	14 ± 5	0.005*
PNS-PhW (mm)	27 ± 4	30 ± 4	0.104
Ar-PNS (mm)	48 ± 4	45 ± 6	0.104
UV (mm^2)	459 ± 134	251 ± 63	0.000*
Ph-AS (mm^2)	1310 ± 307	1725 ± 370	0.003*
Nph-AS (mm^2)	951 ± 134	915 ± 142	0.461

*Statistically significant differences for controls and OSA patients (*i.e.*, $p \leq 0.05$).

†Special symbols in the insert figure: *dashed lines* denote linear dimensions that are statistically different between controls and OSA patients; *stippling*, angles that are significant; *line shading*, parameters which are different in area. The same method for showing significance between parameters is used in all Tables (I-V; for abbreviations see *METHODS AND MATERIALS*).

TABLE II.
Tongue and Oropharynx: Craniometric Measurements of Tongue Volume in Controls and OSA Patients.†



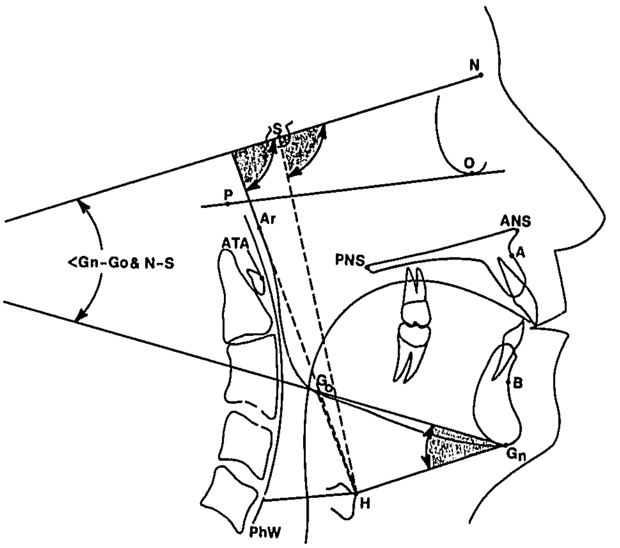
Measurement (distance, angle or area)	OSA Patients $n = 30$ (mean ± *SD*)	Controls $n = 12$ (mean ± *SD*)	Significance (*p* value)
TT-TB (mm)	84 ± 6	77 ± 6	0.003*
PNS-TB (mm)	65 ± 8	55 ± 6	0.000*
TT-ET (mm)	90 ± 7	84 ± 6	0.008*
TB-PhW (mm)	11 ± 4	15 ± 5	0.038*
B-TB (mm)	75 ± 7	70 ± 7	0.088
ET-PhW (mm)	9 ± 4	11 ± 4	0.228
Go-TB (mm)	15 ± 9	11 ± 7	0.126
Gn-TB (mm)	73 ± 7	70 ± 9	0.301
TV (mm^2)	3790 ± 375	3215 ± 471	0.002*

*Statistically significant differences for controls and OSA patients (*i.e.*, $p \leq 0.05$).

†For additional explanation see footnote Table I.

lar symphysis. *H* — Hyoid bone: the most anterosuperior point on the body of the hyoid bone. *N* — Nasion: the most anterior point of the nasofrontal suture. *N-S* — Distance between nasion and midpoint of sella tursica. *NC space* — Nasal cavity area (mm^2) defined as the space obtained by connecting N, SC, SR, PNS, ANS, and N. *Nph-AS* — The area of the nasopharynx defined by the lines connecting PhT, SR, PNS, ATA, and PhT. *OC space* — The area of the oral cavity contained between A, PNS, Go, Gn, and A. *PhT* — Apex of the pharyngeal tubercle. *Ph-AS* — Total area of the oropharyngeal and hypopharyngeal compartments, *i.e.*, the area of the pharynx between the line ATA - PNS and a line through the hyoid bone (H) parallel to the Frankfurt horizontal plane. *PhW* — Posterior pharyngeal wall: soft tissue landmark defining the nasal, oral, and laryngeal limits of the pharyngeal wall. *PNS* — Posterior nasal spine. *PNS-Ar* — Distance from posterior nasal spine to articulare (Ar). *S* — Sella: midpoint of sella tursica. *SC* — Sphenoidal crest. *SR* — Sphenoidal rostrum. *TB* — Tongue base. *TT* — Apex of the tongue. *TV* — Total area of tongue measured at its superior limits and the line contained between TT, G, H and a line parallel to FH up to ET. *UD* — Diameter of the soft palate taken at the widest point. *UL* — Length of soft palate: distance from PNS to UT. *UP* — Soft palate protrusion: greatest posterior convexity of soft palate. *UT* — Apex of soft palate: the lowest point on soft palate. *UV* — Total area of soft palate. *EA-*, *ET-*, *H-*, *PNS-*, *TB-*, *UP-*, *UT-PhW* — Linear distance from the indicated landmark to the posterior pharyngeal wall (PhW) measured along a line parallel to the Frankfurt horizontal.

TABLE III.
Hoid Bone: Craniometric Differences in the Hyoid Bone Position in Controls and OSA Patients.†

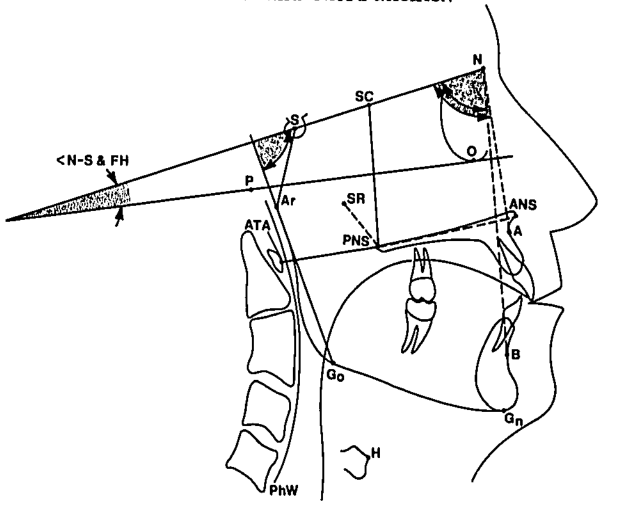


Measurement (distance, angle or area)	OSA Patients $n = 30$ (mean ± *SD*)	Controls $n = 12$ (mean ± *SD*)	Significance (*p* value)
Ar-H (mm)	105 ± 8	91 ± 10	0.001*
S-H (mm)	129 ± 8	116 ± 14	0.009*
Go-H (mm)	41 ± 7	34 ± 10	0.043*
Gn-H (mm)	53 ± 9	52 ± 9	0.687
H-PhW (mm)	34 ± 5	33 ± 6	0.707
< Go-Gn-H (deg)	32 ± 6	20 ± 8	0.000*
< N-S & Ar-H (deg)	83 ± 5	75 ± 9	0.017*
< N-S-H (deg)	93 ± 4	89 ± 5	0.042*
< Gn-Go & N-S (deg)	34 ± 8	32 ± 11	0.672

*Statistically significant differences for controls and OSA patients (*i.e.*, $p \leq 0.05$).

†For additional explanation see footnote Table I.

TABLE IV.
Nasal Cavity: Craniometric Measurements of the Nasal Cavity in Controls and OSA Patients.†



Measurement (distance, angle or area)	OSA Patients $n = 30$ (mean ± *SD*)	Controls $n = 12$ (mean ± *SD*)	Significance (*p* value)
A-N (mm)	69 ± 4	64 ± 6	0.008*
B-N (mm)	110 ± 6	99 ± 7	0.000*
ANS-PNS (mm)	56 ± 5	50 ± 5	0.001*
SR-PNS (mm)	23 ± 5	20 ± 2	0.014*
N-S (mm)	76 ± 4	74 ± 5	0.205
N-SC (mm)	49 ± 4	48 ± 5	0.793
SC-PNS (mm)	52 ± 4	50 ± 4	0.083
Ar-S (mm)	32 ± 4	35 ± 7	0.221
ATA-PNS (mm)	36 ± 4	34 ± 4	0.140
<A-N-S (deg)	83 ± 4	88 ± 6	0.018*
<N-S & Ar-Go (deg)	86 ± 5	79 ± 8	0.032*
<N-S & FH (deg)	10 ± 5	7 ± 3	0.045*
<B-N-S (deg)	78 ± 4	83 ± 8	0.077
<N-S-Ar (deg)	131 ± 7	128 ± 10	0.369
NC Space (mm²)	2956 ± 312	2765 ± 335	0.105

*Statistically significant differences for controls and OSA patients (*i.e.*, $p \leq 0.05$).

†For additional explanation see footnote Table I.

RESULTS

Fifty-eight variables defining the soft- and hard-tissue landmarks of the cranium and upper airway were examined in 30 patients with diagnosed OSA, and in 12 age- and sex-matched controls. The results to be presented below are divided into anatomical regions.

Soft Palate, Nasopharynx, Mesopharynx and Hypopharynx

The soft-tissue landmarks of the nasopharynx in OSA patients show a number of important differences when compared to controls (Figs. 1, 2, Table I). The most obvious are the significantly increased length, width, and area of the soft palate in OSA patients. The enlarged soft palate reduces the size of the nasopharyngeal airway measured as the distance between it and the posterior pharyngeal wall (UT-PhW and UP-PhW). Further, as shown in Table I, OSA patients show a significantly reduced area of the mesopharyngeal and hypopharyngeal airways (area = 1310 ± 307 mm²) when compared to controls (1720 ± 370 mm²). These differences demonstrate that the air passage in the nasal and laryngeal parts of the pharynx are diminished in OSA patients compared to the control group.

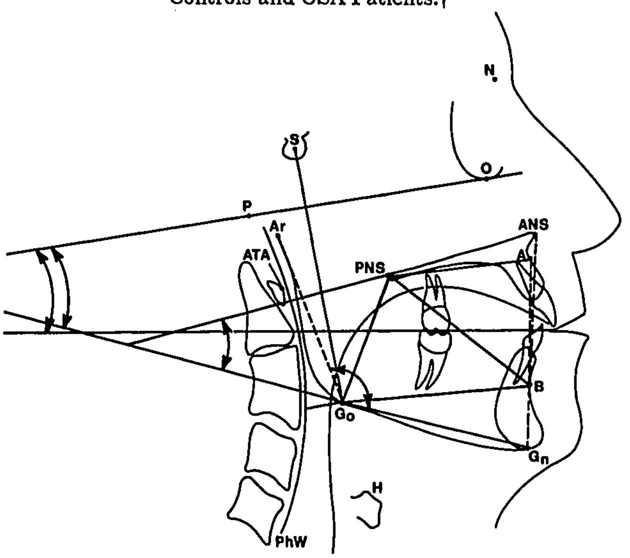
Tongue and Oropharynx

The position of the tongue was determined on the basis of one area and eight linear measurements (Table II). The tongue length and area are significantly larger in OSA patients than in controls. The increased size places the tongue base of the OSA patient in a lower and more posterior position (as indicated by the values or PNS-TB and TB-PhW) which has the effect of reducing the area of the oropharyngeal and hypopharyngeal airway. However, despite the abnormal tongue base position, the position of the epiglottis in the OSA patient is normal (ET-PhW, Table II).

Hyoid Bone

Nine linear and angular measurements were taken to evaluate the position of the hyoid bone of

TABLE V.
Oral Cavity: Craniometric Measurements of Oral Cavity in Controls and OSA Patients.†



Measurement (distance, angle or area)	OSA Patients $n = 30$ (mean ± *SD*)	Controls $n = 12$ (mean ± *SD*)	Significance (*p* value)
A-B (mm)	43 ± 4	36 ± 4	0.000*
ANS-B (mm)	53 ± 6	46 ± 5	0.001*
A-Gn (mm)	67 ± 4	62 ± 5	0.021*
Go-Ar (mm)	68 ± 7	60 ± 9	0.020*
PNS-B (mm)	68 ± 6	64 ± 6	0.060
PNS-A (mm)	54 ± 5	53 ± 5	0.536
Go-S (mm)	91 ± 8	87 ± 13	0.355
Go-PNS (mm)	50 ± 6	49 ± 8	0.690
Go-Gn (mm)	74 ± 7	75 ± 7	0.619
Go-PhW (mm)	12 ± 6	12 ± 6	0.931
B-Go (mm)	72 ± 7	72 ± 5	0.910
< ANS-PNS & Go-Gn (deg)	29 ± 7	26 ± 9	0.387
< Gn-Go-Ar (deg)	130 ± 8	128 ± 7	0.450
< FH & Gn-Go (deg)	27 ± 8	26 ± 9	0.756
< FH & Do (deg)	8 ± 6	8 ± 5	0.862
OC Space (mm²)	3562 ± 404	3560 ± 477	0.989

*Statistically significant differences for controls and OSA patients (*i.e.*, $p \leq 0.05$).

†For additional explanation see footnote Table I.

which six are significantly different in OSA patients compared to controls (Table III). The greatest difference is in the angle between the body of the mandible and the hyoid bone (angle Go-Gn-H), which indicates that the hyoid bone in OSA patients is considerably lower than in controls. The more inferior placement of the hyoid bone in OSA patients is further indicated by the significant increases in the linear dimensions Ar-H, S-H, and Go-H (Figs. 1, 2). The hyoid displacement is strictly vertical, and there are no indications for its misalignment in the anterior-posterior dimension. Note, for example, that the distance between the body of the hyoid and the posterior pharyngeal wall (H-PhW) is virtually identical in both groups (Table III).

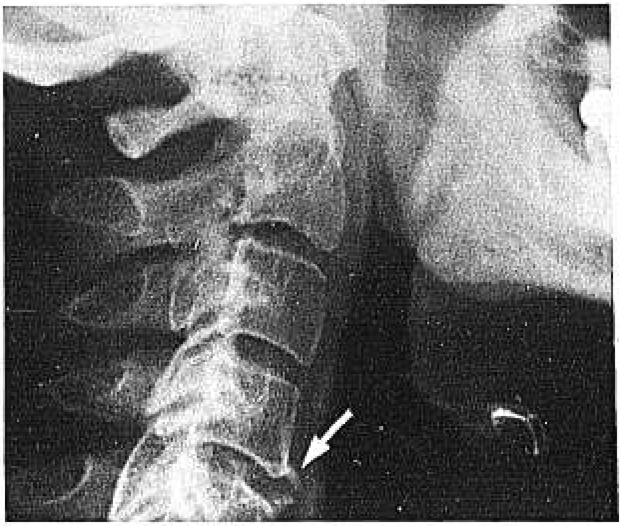


Fig. 3. Lateral x-ray of an OSA patient which shows alterations of the cervical vertebrae. The arrow points to the extra bony bridges on the anterior border of the C4 vertebra. Another bridge is seen on the superior part of the C5 vertebra.

Nasal Cavity

Fifteen measurements were taken to evaluate the nasal cavity of which seven were found to be significantly different in OSA patients (Table IV). Thus, the OSA patient shows: *1.* an increased length of the hard palate measured as the distance ANS-PNS; *2.* a more elongated upper face and corresponding increase in the height of the nasal cavity, *i.e.*, the distance A-N and angle N-S and FH; *3.* an increased width of the nasal choanae, *i.e.*, SR-PNS; and *4.* an overall shortening of the internal nares (Table IV for values of angles A-N-S, N-S, and Ar-Go). The remaining measurements, including the area of the nasal cavity (*i.e.*, NC Space, Table IV), were not significantly different between groups.

Oral Cavity

The oral cavity was evaluated on the basis of 11 linear, 4 angular, and 1 area measurement (Table V). Only 4 out of the 16 parameters were significantly different in OSA patients, but they indicate that the oral cavity of OSA patients is distinguished in, at least, two ways: *1.* OSA patients exhibit a retroposition of the maxilla characterized by a smaller angle A-N-S and *2.* these patients also show an elongation of the lower two thirds of the face anteriorly, as indicated by increased values for A-B, ANS-B, A-Gn, and laterally as shown by the increased length of the vertical ramus of the mandible (Ar-Go), *i.e.*, the body of the mandible is displaced ventrally by approximately 5 to 8 mm compared to controls.

Cervical Vertebral Column

Abnormal growth and pathological changes in the cervical vertebral column are known to influence the

TABLE VI.
Measurements Related to the Soft Palate.*

Severity	UL	UV	UP-PhW
Group 1	100% (5/5)	80% (4/5)	80% (4/5)
Group 2	76% (16/21)	81% (17/21)	48% (10/21)
Group 3	75% (3/4)	100% (4/4)	50% (2/4)

*Values in the table give the percentage and number of patients in each group with cephalometric values greater or less than the control means by 1 *SD*.

TABLE VII.
Measurements Related to the Nasal Cavity.*

Severity	ANS-PNS	A-N	B-N
Group 1	60% (3/5)	40% (2/5)	40% (2/5)
Group 2	62% (13/21)	67% (14/21)	67% (14/21)
Group 3	50% (2/4)	75% (3/4)	75% (3/4)

*Values in the table give the percentage and number of patients in each group with cephalometric values greater or less than the control means by 1 *SD*.

axial posture and can affect the position of the hyoid bone and other related structures in the OSA patient. In our data, 16 out of 30 OSA patients showed distinctive changes in the body of the cervical vertebrae compared to the control group where only 2 out of 12 have similar changes. In all these cases the abnormality appears as a flattening of the body of the fourth vertebra and an extra bony bridge on its anterior border (Fig. 3).

Evaluation of Severity of Obstructive Sleep Apnea

On the basis of described PSG scoring system, the patients were divided into three groups: Group 1: five patients with mild OSA and an average CIOSA index of 9. Group 2: twenty-one individuals with moderate OSA and an average CIOSA of 14.3. Group 3: four individuals with severe OSA and an average CIOSA of 18.2.

Tables VI through IX illustrate presence of cephalometric abnormalities in relationship to the three groups of OSA patients. The values in each table indicate the number of patients having cephalometric values which exceed the control mean by ± *SD*. A close examination of these values document four trends: *1.* All groups have enlarged soft palates and reduced posterior (nasal) airway space but the largest percentage occurred with mild OSA patients (Group 1, Table VI). *2.* The size of the nasal cavity was abnormal in slightly over half of the patients, independent of severity (Table VII). *3.* The enlargement of the tongue and its abnormal position in the hypopharynx becomes an increasing factor with increasing disease severity (Table VIII). *4.* The hyoid bone is abnormally placed anteroinferiorly in 40% of mild, group 1 OSA patients; the frequency of its abnormal position increases with disease severity.

Nasopharyngoscopy Studies

Nasopharyngoscopy studies establish that 24 out of 30 patients displayed abnormal configuration of the upper pharyngeal airway. All five patients in group 1 (mild OSA) displayed positive Müller's maneuver and correspondingly 16 patients in group 2 and three patients in group 3 displayed similar findings. Endoscopic evaluation of lower pharyngeal airway revealed abnormal findings in 1 patient of group 1, 17 patients of group 2, and 4 patients of group 3. During these patient examinations it became convenient to divide arbitrarily the pharyngeal airway into the upper and lower segments by passing a horizontal line along the second cervical vertebra. These two divisions correspond to the cephalometric measurement profiles described in Tables VI, VII (*i.e.*, those related to upper pharyngeal airway and clinically to the area of velopharyngeal sphincter) and Tables XIII and IX, the measurements relating to the hypopharyngeal airway and tongue mass.

DISCUSSION

The present cephalometric analysis indicates that there are a number of differences between OSA patients and the control group in terms of soft- and hard-tissue landmarks of the upper airway. Among the soft-tissue landmarks, the most striking are the enlarged tongue and soft palate in the OSA patient. Our computer-assisted analysis indicates that the additional space occupied by the tongue, soft palate, and redundant pharyngeal mucosa reduces the cross-sectional area of the oropharyngeal airways by an average of 25%. The enlarged soft palate in the OSA patient has been described,[2] and provides the basis for surgical treatment of OSA using the palatopharyngoplasty procedure.[27] Interestingly, the enlarged soft palate has no effect upon the overall area of the nasopharynx (Nph-AS, Table I), but it does limit the size of the inlet connecting the nasopharynx and oropharynx (UP-PhW, UT-PhW, Table I). In addition, the important role of the tongue and the structures of the velopharyngeal sphincter have been confirmed in several studies.[28-30] Our study suggests that it is not only the size of these soft-tissue landmarks but also their relative position in the OSA patient which adversely affect the integrity of the pharyngeal airway.

The altered position of the soft palate and tongue base in the OSA patient results from, at least, three abnormalities of the craniofacial skeleton and hyoid bone. First, the OSA patients exhibit a retroposition of the maxilla. This is evidenced by the larger linear distances between the floor of the cranial vault and the landmarks on the maxilla (*e.g.*, A-N, PNS-Ar) and the reduced angle A-N-S (Table IV). Correspondingly, the hard palate in the OSA patients is significantly longer and is placed more inferiorly than in controls given the increased dimensions ANS-PNS and A-N, respectively. The elongated hard palate places the already enlarged soft palate closer to the posterior pharyngeal wall thereby significantly narrowing the passage between the nasopharyngeal and oropharyngeal airways. This altered anatomy should be considered as one possible expla-

TABLE VIII.
Measurements Related to the Tongue and Its Position.*

Severity	TV	TB-PhW	PNS-TB
Group 1	40% (2/5)	0% (0/5)	80% (4/5)
Group 2	71% (15/21)	57% (12/21)	81% (17/21)
Group 3	100% (4/4)	75% (3/4)	75% (3/4)

*Values in the table give the percentage and number of patients in each group with cephalometric values greater or less than the control means by 1 *SD*.

TABLE IX.
Measurements Related to the Hyoid Bone.*

Severity	<Go-Gn-H	S-H	Go-H
Group 1	40% (2/5)	40% (2/5)	40% (2/5)
Group 2	67% (14/21)	57% (12/21)	76% (16/21)
Group 3	75% (3/4)	75% (3/4)	100% (4/4)

*Values in the table give the percentage and number of patients in each group with cephalometric values greater or less than the control means by 1 *SD*.

nation for the high failure rate (approximately 50%) of palatopharyngoplasty surgery for the treatment of OSA.[31,32]

Second, there is an elongation of the lower and mid-face in OSA patients. The changes in the mid-face result from an increased height of the nasal cavity, *i.e.*, dimensions A-N, SR-PNS (Table IV), but the increase averages only 3 to 5 mm. Changes in the lower face appear to result from the inferior displacement of the mandible which is produced by increased maxillary-mandibular distances anteriorly (A-B, Table V) and an increase in the length of the vertical ramus (Ar-Go, Table V). There is no evidence for micrognathia, as the length of mandibular body in the patients examined is normal (Go-Gn, Table V). A few of the variables examined would indicate a condition of retrognathia (*e.g.*, an enlarged angle N-S and Ar-Go) but the critical measurement for this condition (angle B-N-S) although smaller than normal is not significantly different between groups. Thus, there is a trend in the data towards retrognathia, but this cannot be shown statistically in the present sample of OSA patients. Micrognathia has been previously reported in patients with OSA leading some authors to speculate that these conditions may even precipitate OSA symptoms.[33,34] Some authors have also observed a posterior placement of the mandible and corrected it surgically with beneficial results in patients with OSA.[35,36]

Third, the hyoid bone in the OSA patient is more inferiorly located than in controls as has been reported previously.[2,37] This location produces a significant enlargement of the angle Go-Gn-H and a relocation of the tongue base into the hypopharynx. Thus, the patency of the hypopharyngeal airway, normally preserved by the anterosuperior movement of the tongue mass around its fulcrum-hyoid bone, is adversely affected by the new position of the hyoid bone in OSA patients.

In their recent study, Riley, *et al.*[2] measured a total of eight craniometric landmarks in ten OSA patients and compared these to controls. The present results for angles A-N-S and B-N-S (Table IV) on a larger number (30) OSA patients, are virtually identical to the values they report on the position of the mandible and maxilla. Additionally, our measurement of the length of the soft palate in OSA patients (mean = 41 mm) is comparable to their value of 45 mm (PNS-P, Table II).[2] We did not measure their parameters ANB, N-ANS, or ANS-GN directly, but on geometric reconstruction from the values in Table V; these values are found to be highly comparable.

Two final points should be made with regard to the comparison of the two studies. First, the position of the hyoid bone in our study was measured in relation to three general references: the cranial vault (sella and articulare), the posterior pharyngeal wall (H-PhW), and the mandible. The latter was determined in relation to the gnathion (Gn-H), the gonion (Go-H), and as the angle Go-Gn-H (Table III). A geometric reconstruction of these values produces a value of 29 mm for the distance in the Riley, *et al.*[2] study between the hyoid bone and the mandibular plane (MP-H = 28 mm). Thus, both methods produce identical results and show that the hyoid bone is inferiorly located in comparison to the horizontal ramus of the mandible in the OSA patient. However, the additional number of variables in the present study provide a more accurate position of the hyoid bone which is important in documenting its position independent of interpatient differences in mandibular angle.

Second, we calculate the posterior airway space (TB-PhW) as a line from the tongue base to the posterior pharyngeal wall parallel to the Frankfurt horizontal plane. This value is found to be significantly smaller is OSA patients in the present study compared to controls. Similar conclusions were reached by Riley, *et al.*,[2] but the two measurements are not immediately comparable because they measure the distance differently (*i.e.*, along a line parallel to Go-Gn).

There is no convincing evidence that a specific cephalometric profile, determined statistically, relates to a severity of OSA as reflected by PSG indices — CIOSA. On the other hand, we have observed that as the severity of OSA increases, one finds evidence of increasingly abnormal cephalometric indices. Thus, a representative patient with OSA of mild severity possessed an average 2.4 abnormal cephalometric indices, one in moderate group 2.7, and patients with severe OSA had 3.0 abnormal cephalometric indices. It seems that factors other than cephalometric profile characteristics play an important role in determining the severity of OSA. In the natural history of OSA, time progression of OSA could relate to a degree of competency of protective neurophysiological mechanisms for pharyngeal airway preservation. Although cephalometric indices are unlikely to undergo major changes, a patient with mild OSA may advance to moderate or even severe OSA through a deterioration or loss of appropriate competency of protective neurophysiologic mechanisms. The latter can also be affected by adverse metabolic (weight gain), chemical (intake of CNS depressants), *e.g.*, alcohol, drugs, allergy, and/or deteriorating cardiopulmonary reserve.

The value of cephalometric analysis is that it assists clinical perception of geometry of the pharyngeal airway. It can, therefore, assist in design and planning of surgical procedure. With help of cephalometric evaluation, a case can be made in support of surgical correction of multiple sites of pharyngeal airway obstruction. On the other hand, it may produce evidence that a practical surgical program is not plausible or possible.

CONCLUSIONS

In our opinion, the presented cranioencephalometric profile has an important diagnostic value in the clinical investigation of patients suspected of having OSA, and it should be routinely employed, along with clinical head and neck examination, polysomnographic and endoscopic studies. Such data offers information about the configuration of the pharyngeal airway in each patient and points to specific areas of pharyngeal airway compromise, thus assisting in the planning of corrective surgical procedures. It may also prove to be valuable in identifying individuals at risk for developing OSA and may ultimately explain the familial link in the symptoms of OSA given the inheritability of the mandibulofacial features. Given the number of patients with minimal symptomatology of snoring[38,39] and the reports of inducing OSA following cleft palate or related pharyngeal[40] or maxillofacial surgery (Riley and Powell, personal communication, 1983), we propose that craniometric profiles should be considered for any individual who will undergo an elective procedure which is likely to result in the change of maxillofacial relationships and/or prior to any surgery on the upper aerodigestive tract.

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