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The cephalometric morphology of patients with obstructive sleep apnoea (OSA)

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SUMMARY This prospective study analysed the lateral cephalometric radiographs of 59 dentate, white, Caucasian males. Thirty-five patients with proven obstructive sleep apnoea (OSA) formed the experimental group, while 24 subjects with no history of respiratory disease acted as controls. Radiographs were traced and digitized, and both hard and soft tissue features were compared between the groups. The pooled data were then subjected to discriminate analysis.

Although conventional cephalometric measurements did not differ between the two groups, significant reductions were found in the lengths of the mandibular body and cranial base and in cranial base angulation in OSA subjects. The width of the oropharynx was significantly narrower in this group, particularly in the post-palatal region. The area of the soft palate was increased although that of the tongue was not. Intermaxillary space length (the distance between the posterior pharyngeal wall and the tip of the lower incisor) was decreased, and thus the area in which the tongue had to function was smaller in OSA subjects.

From the discriminant analysis, two four-variable models were derived, both of which provided 100 per cent discrimination between the OSA and normal subjects. For the first model the entire OSA group was used: for the second, only obese OSA subjects (those a body mass index >25) were chosen.

The combination of a short mandible and intermaxillary space, with an enlarged soft palate but decreased pharyngeal airway has relevance to the effective management of OSA. In selected patients, advancement of the lower jaw by a nocturnal mandibular repositioning splint may be indicated. The orthodontist would seem to be in a unique position to assist in both the identification and treatment of these subjects.

Introduction

Obstructive sleep apnoea (OSA) is a potentially life-threatening condition in which periodic cessation of breathing occurs during sleep in the presence of inspiratory effort. This affects not only the quality of life but also has a significant morbidity. The reduction in blood oxygen saturation may give rise to hypertension, cardiac arrhythmias, nocturnal angina and myocardial ischaemia (Klitzman and Miller, 1994; Rapoport, 1994). Impaired sleep quality leads to reduced concentration and the risk of falling asleep during the day.

The aetiology of this condition would appear to be a blend of anatomical and physiological features (Anch *et al.*, 1982; Haponik *et al.*, 1983; Rivlin *et al.*, 1984; Lowe *et al.*, 1986a; Rodenstein *et al.*, 1990). During sleep, the combination of a reduction in lingual and pharyngeal muscle tone, alterations in breathing control, the supine position and reduced pharyngeal space may lead to airway occlusion in susceptible subjects.

Lateral cephalometric radiographs have been used by several investigators in an attempt to identify morphological parameters that might be characteristic of OSA. However, their value as a routine diagnostic tool is uncertain, as a true assessment of the airway dimensions requires a three-dimensional recording technique such as computerized tomography (CT) scanning or magnetic resonance imaging (MRI) (Lowe *et al.*, 1986b; Rodenstein *et al.*, 1990).

The dimensions of the pharynx are consistently reported to be reduced, whether the subject has been investigated in the upright or supine position (Yildirim *et al.*, 1991) and independently of the assessment technique (Rojewski *et al.*, 1982; Haponik *et al.*, 1983; Lowe *et al.*, 1986a; de Berry-Borowiecki *et al.*, 1988; Suto *et al.*, 1993).

The soft palate is longer (Jamieson *et al.*, 1986; Bacon *et al.*, 1988; Partinen *et al.*, 1988; Lyberg *et al.*, 1989), larger and in contact with a wider area of the tongue in OSA subjects (Lyberg *et al.*, 1989). Data on the tongue are ambiguous: whilst Lyberg *et al.* (1989) found no difference in tongue size in OSA subjects, de Berry-Borowiecki *et al.* (1988) found it to be significantly larger than in controls. Pracharktam *et al.* (1994) concluded that although the tongue was no larger in their OSA group, the space in which it had to function was reduced.

Variable skeletal differences have been reported. The cranial base may be short (Bacon *et al.*, 1988) and the cranial base angle reduced (Jamieson *et al.*, 1986). Bimaxillary retrusion (Lowe *et al.*, 1986a; de Berry-Borowiecki *et al.*, 1988) or retrognathia of the mandible alone have also been reported (Jamieson *et al.*, 1986; Tsuchiya *et al.*, 1992). Whilst a decrease in mandibular body length was described by Rivlin *et al.* (1984), Bacon *et al.* (1990) did not find any such reduction. In the vertical plane, the lower face height was typically increased with a concomitant elevation of the maxillo-mandibular plane angle (Lowe *et al.*, 1986a; Bacon *et al.*, 1990; Tsuchiya *et al.*, 1992).

Hyoid position has been found to be more inferior than normal in relation to the mandibular plane (Jamieson *et al.*, 1986; de Berry-Borowiecki *et al.*, 1988; Partinen *et al.*, 1988; Tsuchiya *et al.*, 1992). Evaluation of the cranio-cervical angle revealed this to be increased (Solow *et al.*, 1993).

Discriminate analysis is a multivariate technique which aims to segregate as widely as possible two groups of individuals drawn from the same population (Dillon and Goldstein, 1984; Norusis, 1986). Despite its potential diagnostic capabilities, the approach has been applied with only limited success in orthodontics. Kowalski *et al.* (1974, 1975) attempted to separate the facial characteristics of different American ethnic groups, whilst Bacon *et al.* (1983) carried out a similar study on white Caucasians resident in Europe. Kerr and Ford (1986) and Kerr and Hirst (1987) sought to compare facial form in European males, whilst Bacon *et al.* (1988) attempted to identify which craniofacial factors contributed most to OSA. These authors derived a three-variable model which correctly identified 80 per cent of their combined OSA and normal sample. Eight controls and five OSA patients were misclassified and the authors concluded that other factors should be considered in the design of a more satisfactory model.

The results of previous cephalometric studies are not exhaustive and lack unanimity. Furthermore, there is little information on the role of the tongue, particularly in relation to its functional space. These discrepancies may be due to differences in measurement selection, the relatively small number of parameters investigated and the difficulty in obtaining adequate controls. The present study was therefore undertaken in an attempt to clarify some of these matters.

Thus the aims of the investigation were two-fold. Firstly, to examine in detail the craniofacial and pharyngeal anatomy of a group of OSA subjects as revealed by lateral cephalometry, and to compare these with values from a group of normal individuals matched for sex, age and ethnicity. Secondly, the study sought to determine whether it was possible to identify the patient with OSA from a combination of cephalometric and demographic data. If the condition could be thus demonstrated, the potential patient could be referred for appropriate medical screening and treatment before medical complications ensued.

Subjects

The material for this study comprised the lateral cephalometric radiographs of 59 dentate, male, white Caucasians, recorded with the mandible in the position of maximal intercuspation. Thirty-five subjects, with a diagnosis of OSA confirmed by polysomnography at the Department of

Table 1 Demographic data.

	Control group (n = 24)		OSA group (n = 35)			
	Mean ± SD	Range	Mean ± SD	Range	Difference	Significance of difference
Age (years)	41.8 (9.0)	25.9 – 60.5	50.9 (11.4)	26.0 – 73.5	−9.1	$P = 0.000$
Height (cm)	178.7 (5.5)	170.2 – 188.0	174.7 (7.2)	161.0 – 188.5	4.0	NS
Weight (kg)	79.1 (6.1)	67.0 – 90.0	93.0 (17.8)	65.5 – 133.5	−13.9	$P = 0.000$
BMI	24.5 (2.2)	21.0 – 28.4	30.6 (5.9)	22.0 – 44.5	−6.1	$P = 0.000$

Thoracic Medicine, Prince Charles Hospital, Brisbane, formed the experimental group. The remaining 24 individuals acted as controls: none snored, exhibited any history of respiratory disorders or suffered from daytime somnolence. The absence of snoring was confirmed by a second person wherever possible. No attempt was made to restrict the control group to individuals with normal occlusions.

Height and weight were recorded for all subjects and the body mass index (BMI) calculated (Table 1) (BMI = weight in kilograms divided by height in meters^2).

The severity of the OSA was recorded using the respiratory disturbance index (RDI) [this registers the number of episodes of apnoea (total cessation of airflow for 10 seconds or more) per hour of sleep]. The lowest oxygen saturation and the mean oxygen desaturation were also noted (Table 2).

Methods

Radiography

Lateral cephalograms were taken following a standardized procedure. With the subject positioned in the cephalostat, the midline of the tongue was painted with a thin layer of barium sulphate contrast medium to aid in the identification of its contour. In order to fix the hyoid in a consistent position, the patient was requested to breathe slowly in and then exhale, holding the latter position whilst the film was exposed. This procedure was practised several times before the film was actually taken.

Cephalometric analysis

Radiographs were traced, orientated with the maxillary plane horizontal and 25 conventional hard and soft tissue points identified (Fig. 1). Twenty-two additional points relating to the cervical vertebrae, oropharynx, epiglottis, soft palate and tongue were recorded (Fig. 2). Definitions of the additional landmarks and of those conventional points not conforming to British Standards (BSI, 1983) are given in the accompanying legends. Points were digitized twice in a predetermined sequence to a tolerance of 0.2 mm and the mean value taken. The soft tissue outlines of the tongue and soft palate were recorded.

Table 2 Severity of OSA (n = 35).

	Mean ± SD	Range
Respiratory disturbance index	28.3 ± 23.8	5.0–97.0
Mean oxygen desaturation	6.8 ± 5.3	2.8–19.4
Nadir oxygen saturation	76.1 ± 12.7	45–91

Films were automatically realigned to the maxillary horizontal and a vertical reference line dropped from Sella. All calculations were made with this orientation. Forty angular, linear and proportional measurements were calculated, together with the areas of the intermaxillary space, soft palate and tongue (Fig. 3, Table 3). To take into account the varying magnifications of the cephalostats, all measurements were converted to life size.

Method error

Duplicate tracings of 20 films were made and random method error assessed as described by Dahlberg (1940). Systematic error was determined as suggested by Houston (1983). Errors

Table 3a Comparison between facial dimensions for control and sleep apnoea (n = 35) patients. Skeletal and dental measurements.

Variable	Control (n = 24) Mean ± SD	Control (n = 24) Range	OSA (n = 35) Mean ± SD	OSA (n = 35) Range	Difference (control – OSA)	Significance of difference
Cranial base						
BaSN (deg)	132.4 ± 5.1	121.5 – 141.0	128.6 ± 5.2	119.5 – 139.2	3.7	P = 0.010
S–N (mm)	72.4 ± 3.0	67.4 – 78.0	70.0 ± 2.6	63.7 – 74.9	2.4	P = 0.001
Maxilla						
SNA (deg)	80.6 ± 3.9	72.4 – 87.5	81.6 ± 3.8	71.5 – 88.4	-1.0	NS
Point A to S (vertical mm)	69.8 ± 5.8	56.2 – 79.6	67.8 ± 4.8	53.6 – 77.1	1.9	NS
Mandible						
SNB (deg)	78.6 ± 4.2	70.8 – 86.1	79.2 ± 4.1	71.0 – 88.1	–0.6	NS
Gonial angle (deg)	125.0 ± 6.0	112.7 – 138.3	128.6 ± 7.1	115.4 – 148.2	–3.6	NS
Gonion to menton (mm)	75.6 ± 6.9	62.7 – 91.5	69.7 ± 5.7	54.5 – 79.8	5.9	P = 0.002
Gonion to point B (mm)	72.8 ± 5.5	59.4 – 83.9	67.2 ± 5.9	49.9 – 79.7	5.6	P = 0.002
Point B to S (vertical mm)	64.9 ± 7.9	44.9 – 79.9	62.5 ± 8.1	40.4 – 77.3	2.4	NS
Intermaxillary						
ANB (deg)	1.9 ± 2.7	-3.5 – 5.6	2.1 ± 2.8	–3.0 – 7.6	–0.2	NS
Max.-mand. plane angle (deg)	24.2 ± 7.0	12.7 – 43.0	26.5 ± 7.9	13.0 – 47.3	–2.7	NS
Upper anterior face height (mm)	54.4 ± 3.3	46.1 – 60.5	52.7 ± 3.3	43.6 – 59.4	1.7	NS
Lower anterior face height (mm)	69.2 ± 5.5	59.8 – 80.1	67.6 ± 7.2	51.6 – 86.7	1.6	NS
Lower anterior face height (%)	55.9 ± 1.7	51.7 – 59.1	56.0 ± 2.5	51.7 – 62.2	–0.1	NS
Intermaxillary space length (mm)	80.4 ± 6.2	66.7 – 93.7	74.7 ± 5.8	61.3 – 87.0	5.7	P = 0.001
Intermaxillary space area (cm^2)	42.4 ± 5.3	32.3 – 57.9	38.3 ± 6.3	26.5 – 51.1	4.1	P = 0.035
Dental						
$\underline{1\|1}$ to maxillary plane (deg)	108.9 ± 10.2	92.0 – 127.3	110.0 ± 5.1	93.2 – 117.1	1.1	NS
$\overline{1\|1}$ to mandibular plane (deg)	90.9 ± 8.5	72.5 – 102.6	89.1 ± 7.9	73.7 – 105.8	1.8	NS
Overjet (mm)	3.0 ± 1.6	0.0 – 6.9	3.4 ± 3.0	–6.9 – 9.7	–0.4	NS
Overbite (mm)	3.6 ± 2.2	0.7 – 10.2	3.4 ± 2.5	–2.6 – 10.3	0.1	NS

ranged from 0.37 cm^2 for the area of the soft palate to 2.12 mm for its length. The errors tended to be larger for those measurements for which the definitions of the points were least precise or, as in the case of the soft palate, where the exact tip of the uvula was difficult to define. No systematic errors were detected.

Statistical evaluation

Data were analyzed using SPSS PC+ (Norusis, 1986). Means, standard deviations and ranges were calculated for each variable for both sleep apnoea and control groups. Because of the highly significant disparity in the ages of the final groups, an analysis of variance, incorporating age as a covariate, was used to examine the differences between them (Table 3).

Both demographic and cephalometric data were subjected to a discriminant analysis run under SPSS. Using the stepwise method of Wilks, all eligible variables were entered into the analysis. From the factors selected, the number of elements was progressively reduced by sequentially excluding those measurements which contributed least to the overall model. The aim of this procedure was to achieve 100 per cent separation of the OSA and control subjects with as few discriminating parameters as possible.

Once variable selection was complete, a model was generated comprising a number of factors, each with its own coefficient and a constant. A discriminant score was then calculated for each individual and from this subjects were automatically allocated to either the OSA or control groups. If the model was 100 per cent successful, no subject would be misclassified.

Results

Demographic data (Tables 1 and 2)

In the OSA group the age of the patients varied from 26.0 to 73.5 years with a mean of 50.9 years. The age range in the control group was

Table 3b Comparison between facial dimensions for control and sleep apnoea patients. Measurements relating to the lips, spine, hyoid, pharynx, soft palate and tongue.

Variable	Control (n = 24)		OSA (n = 35)		Difference (control – OSA)	Significance of difference
	Mean ± SD	Range	Mean ± SD	Range		
Soft tissue						
Upper lip thickness (mm)	17.8 ± 2.1	11.8 – 21.8	17.4 ± 2.2	13.7 – 22.5	0.4	NS
Upper lip length (mm)	23.3 ± 3.0	16.2 – 29.6	23.5 ± 3.2	18.7 – 32.4	–0.2	NS
Ls to aesthetic line (mm)	–7.6 ± 3.1	–12.5 – 0.5	–7.9 ± 4.0	–13.9 – 4.2	–0.3	NS
Lower lip thickness (mm)	20.2 ± 2.8	15.4 – 25.5	20.7 ± 3.1	13.7 – 28.3	–0.5	NS
Lower lip length (mm)	49.8 ± 3.9	43.4 – 57.7	49.1 ± 5.3	40.3 – 71.2	0.7	NS
Li to aesthetic line (mm)	–5.5 ± 2.6	–10.2 – –0.1	–6.2 ± 4.0	–12.8 – 3.8	–0.7	NS
Cervical spine and hyoid						
Spinal inclination (deg)	7.8 ± 10.1	–14.4 – 26.6	14.5 ± 10.4	–2.2 – 40.9	–6.7	P = 0.038
C2 (pt 1) to sella vertical (mm)	33.5 ± 4.9	25.0 – 42.29	29.9 ± 4.4	17.2 – 39.4	3.6	P = 0.003
Hyoid (pt 16) to ANS (horiz) (mm)	64.5 ± 8.9	47.6 – 83.5	60.6 ± 9.0	47.1 – 81.6	3.9	NS
Hyoid to point B (horiz) (mm)	52.2 ± 6.0	41.9 – 63.8	48.9 ± 6.2	40.1 – 65.7	3.3	P = 0.042
Hyoid (pt 16) to maxill. plane (vert) (mm)	72.9 ± 5.8	62.7 – 82.2	73.5 ± 5.2	57.7 – 82.3	–0.6	NS
Hyoid (pt 16) to mandib. plane (mm)	23.3 ± 5.8	11.3 – 34.9	25.9 ± 4.8	18.7 – 36.5	–2.6	NS
Oral and pharyngeal						
Palatal angle (ANS–PNS–pt12) (deg)	126.9 ± 5.0	113.8 – 137.9	125.9 ± 6.2	110.5 – 136.7	–1.0	NS
Pharynx: retro-palatal 1 (pts 3–9) (mm)	19.7 ± 3.6	13.3 – 26.5	12.8 ± 4.0	6.1 – 21.6	6.9	P = 0.000
Pharynx: retro-palatal 2 (pts 5–10) (mm)	9.9 ± 3.1	4.7 – 15.0	6.3 ± 2.7	0.5 – 11.7	3.4	P = 0.000
Pharynx: retro-palatal 3 (pts 6–11) (mm)	9.6 ± 3.4	3.6 – 17.3	5.7 ± 2.8	0.1 – 10.7	3.9	P = 0.000
Pharynx: retro-palatal 4 (pts 7–12) (mm)	11.5 ± 3.5	5.1 – 19.5	8.8 ± 2.9	4.3 – 14.7	2.7	P = 0.005
Pharynx: retro-lingual (pts 8–13) (mm)	12.4 ± 3.3	5.8 – 18.9	10.9 ± 4.4	4.0 – 19.7	1.5	P = 0.036
PNS to tip of soft palate (mm)	40.9 ± 5.5	27.8 – 49.1	42.6 ± 6.9	23.0 – 55.1	–2.3	NS
PNS to uvula (pt 12) (horiz) (mm)	24.4 ± 4.7	14.6 – 29.8	24.7 ± 5.3	14.0 – 34.4	–0.3	NS
Soft palate area (cm^2)	4.1 ± 0.7	2.8 – 5.5	4.9 ± 1.2	3.1 – 8.5	–0.8	P = 0.014
Tongue area (cm^2)	41.2 ± 3.9	34.8 – 49.1	41.0 ± 4.8	33.1 – 51.4	0.2	NS
Tongue proportion (%)	98.2 ± 11.2	66.4 – 116.7	108.6 ± 14.5	86.2 – 161.5	–10.4	P = 0.019

Intermaxillary space length: the distance between the posterior pharyngeal wall (point 4) and the lower incisor at the level of the occlusal plane.
Spinal inclination: the angle between a line drawn between the sixth and second cervical vertebrae and a vertical through sella.
Tongue proportion: the tongue area as a percentage of the intermaxillary space area.

25.9–50.5 years with a mean of 41.8 years (Table 1).

Whilst there was no statistical difference between the heights of the two groups, the mean weight of the OSA subjects was almost 14 kg greater than that of the controls. The mean BMI of the controls was within normal limits (24.5), whereas the OSA subjects tended to be obese (mean BMI 30.6) (Table 1).

In subjects with sleep apnoea, the respiratory disturbance index varied widely: from 5 (mild OSA) to 97 (very severe OSA) with a mean of 28.3 (Table 2).

Cephalometric findings

Radiographs of OSA and control group subjects with very similar facial characteristics, but grossly different airway dimensions are shown in Figures 4 and 5.

Standard cephalometric variables (Table 3a)

None of the standard cephalometric parameters showed any significant differences between the OSA and control groups, and matched those of a normal population. SNA, SNB, ANB, the maxillo-mandibular plane (MM) angle and lower anterior face height were the same in both groups.

Dentally there were no differences between the position of the teeth in the OSA and control categories. Overjet, overbite and the axial inclination of both upper and lower incisors to their respective planes were normal. Although

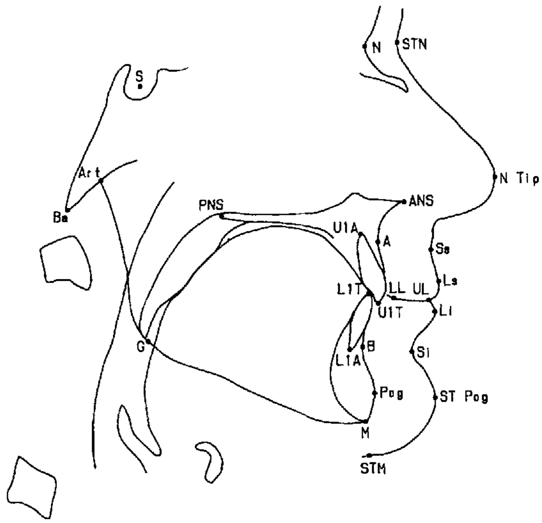

Figure 1 The cephalometric points recorded. Except where listed below, points, lines and planes conformed to British Standard definitions (BSI, 1983). Hard tissue: A, point A; ANS, anterior nasal spine; Art, articulare; B, point B; Ba, basion; G, gonion (the point where the bisector of the angle between the posterior and lower mandibular border tangents meets the mandibular angle); L1A, lower incisor apex; L1T, lower incisor tip; M, menton (the point of intersection of the lower mandibular border and the symphysial outline); N, nasion; PNS, posterior nasal spine; Pog, pogonion; S, sella; U1A, upper incisor apex; U1T, upper incisor tip. Soft tissue: N tip, the tip of the nose; Li, labrale inferioris (the most prominent point on the soft tissue outline of the lower lip); LL, lowest point on the upper lip; Ls, Labrale superioris. The most prominent point on the soft tissue outline of the upper lip; Si, sulcus inferioris (the deepest point of the concavity on the soft tissue outline of the lower lip); STM, soft tissue menton; STN, soft tissue nasion; Ss, sulcus superioris (the deepest point of the concavity on the soft tissue outline of the upper lip); ST Pog, soft tissue pogonion; UL, highest point on the lower lip. Measurements of lip length and thickness: upper lip thickness, the horizontal distance between point A and sulcus superioris; upper lip length, the vertical distance between subnasale and the most inferior point on the upper lip; lower lip thickness, the horizontal distance between point B and sulcus inferioris; lower lip length, the vertical distance between soft tissue menton and the most superior point on the lower lip.

the ranges of these values varied, they did so equally in both OSA and control subjects.

Other measurements of the face and cranium (Table 3a)

Here, significant differences were seen. The cranial base angle (BaSN) was significantly smaller (3.7 degrees) in OSA subjects and the length of the anterior cranial base was reduced (2.4 mm). This indicates a shortening of the anterior–posterior dimension of the cranium and thus a more retruded face.

Mandibular body length (gonion to menton) was reduced by 5.9 mm in the OSA group (P = 0.002). Recording this distance in the horizontal plane, to take into account variations in mandibular plane inclination, the same differences were found. Gonion to menton was 6.6 mm shorter and gonion to point B 5.6 mm less in apnoeic individuals.

Intermaxillary space length—the distance between the posterior pharyngeal wall and the lingual aspect of the lower incisor at the level of the occlusal plane (Fig. 2)—was 5.7 mm shorter in OSA subjects (P = 0.001). The intermaxillary space area (the trapezium outlined in Fig. 3) was also reduced, by 4.1 cm^2, indicating a lack of vertical compensation for the diminished antero-posterior development.

Soft tissue measurements (Table 3b)

No differences were found in any of the soft tissue measurements recorded. The position, length and thickness of the lips showed no statistical differences between the OSA and control groups.

The cervical spine and hyoid (Table 3b)

The distance from the C2 to a perpendicular dropped from sella was significantly smaller (3.6 mm) in OSA subjects.

Despite examining hyoid position in the horizontal, vertical and oblique directions, the only difference between the two groups was in the measurement hyoid to point B (3.3 mm shorter in OSA subjects). This is as likely to be a reflection of the short mandible as of any characteristic position of the hyoid bone itself.

Oral and pharyngeal measurements (Fig. 2, Table 3b)

Oropharynx. Measurements taken at all four levels of the post-palatal airway, from the upper limit of the oropharynx to the tip of the uvula, showed high degrees of statistical difference between the two groups. These differences were greatest (P = 0.000) where the soft palate was at its thickest (Fig. 2, points 3–9), at the level of the lower incisor tip (points 5–10) and at the zone of maximal protrusion of the soft palate into the

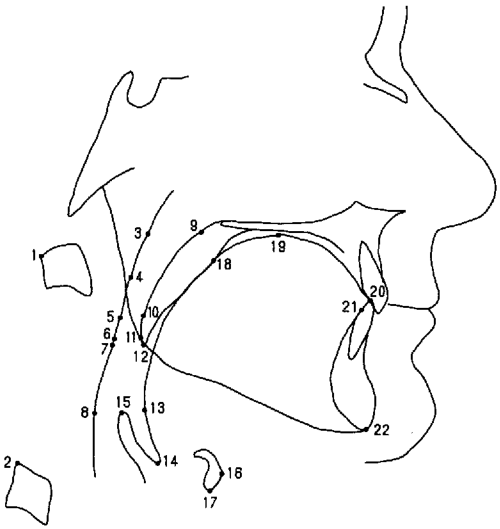

Figure 2 1, Most postero-superior point on the second cervical vertebra; 2, most postero-superior point on the sixth cervical vertebra; 3, the point on the posterior pharyngeal wall at the same horizontal level as point 9; 4, the point of intersection of the occlusal plane with the posterior pharyngeal wall; 5, the point on the posterior pharyngeal wall at the same horizontal level as the lower incisor tip; 6, the point on the posterior pharyngeal wall at the same horizontal level as the most posterior point on the soft palate (point 11); 7, the point on the posterior pharyngeal wall at the same horizontal level as the tip of the soft palate (point 12); 8, the point on the posterior pharyngeal wall at the same horizontal level as the most posterior point on the tongue contour (point 13); 9, most postero-superior point on the soft palate, determined by eye; 10, the point on the posterior aspect of the soft palate at the same horizontal level as the lower incisor tip; 11, the most posterior point on the contour of the soft palate; 12, the tip of the soft palate (uvula); 13, the most posterior point on the contour of the tongue; 14, the deepest point of the vallecula; 15, the tip of the epiglottis; 16, the most anterior point on the hyoid bone; 17, the most inferior point on the hyoid bone; 18, a point on the oral surface of the soft palate where the palatal width is at its maximum; 19, the most superior point on the tongue; 20, the tip of the tongue; 21, the point of intersection of the occlusal plane with the lingual contour of the lower incisor; 22, the most inferior point on the bony chin. (this did not invariably coincide with menton as defined in this study).

airway (points 6–11). For all measurements the mean airway dimensions in OSA subjects were approximately 66 per cent of those in the control individuals. Considerable interindividual variation was seen in both groups. Minimum readings in the OSA group, however, were less than 1 mm for two out of the four levels recorded.

In the post-lingual area, by contrast, the difference in airway size between the two groups was very much smaller.

Soft palate and oral cavity (Table 3b). The area of the soft palate was increased by 0.8 cm^2 (or 15 per cent) in OSA patients but there were no differences in palatal length or in the horizontal distance between PNS and the tip of the uvula.

The area of the tongue showed no differences between the two groups. Its size in relation to the intermaxillary space (the tongue proportion) however, was significantly greater (10.4 per cent, $P = 0.019$) in OSA subjects. As with the oropharyngeal airway, there was marked intra-group variation and considerable overlap between measurements within each group.

Results of the discriminant analysis

The whole sample (Table 4). A four-variable discriminant model was generated (Table 4) which provided 100 per cent correct discrimination between the OSA and control groups. The variables selected were BMI, the sella to nasion distance, the width of the oropharynx where the soft palate was at its thickest and the area of the soft palate. All measurements showed highly significant differences between the two groups (Tables 1 and 3).

Whilst obesity is a frequent finding in OSA subjects, not all individuals are overweight. In view of this, a further discriminant analysis was run, excluding the 10 OSA individuals whose BMIs were <25.

The sample excluding OSA subjects with BMI <25: the overweight group (Table 5). Using a slightly different four-variable model, all OSA and control subjects were again identified correctly (Table 5). Three of the four parameters were the same but the sella–nasion distance was replaced by the length of the intermaxillary space. Because different subjects were involved in generation of the model, the coefficients assigned to each variable and the accompanying constant differed from those in the first analysis.

Discussion

Validity of the control group

In any comparative study, the composition of

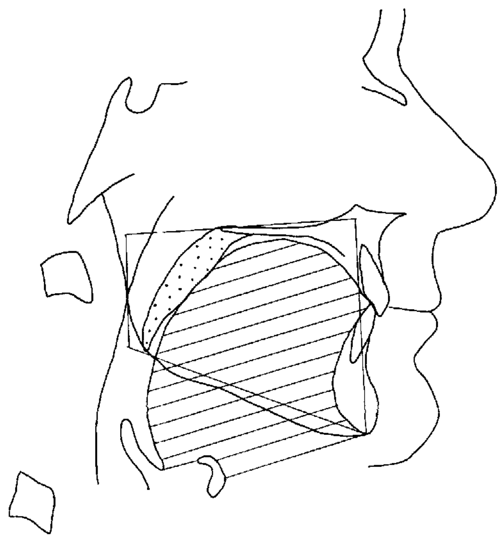

Figure 3 The intermaxillary space. This space is delineated by the trapezium drawn through the maxillary and mandibular planes, the posterior pharyngeal wall and the lingual gingival aspect of the lower incisor.

the control group is central to the interpretation of the results. Bacon *et al.* (1988) selected controls from a group of medical students but many authors have failed to consider this adequately. The current study was restricted to dentate, white, Caucasian males, with the control group comprising dental and medical colleagues of the authors. Whilst every effort was made to match the two groups for age, this proved difficult as many older individuals who agreed to be radiographed were found to snore. Since facial growth continues throughout life (Forsberg, 1979; Behrents, 1985), this age difference could be relevant and was responsible for the decision to include age as a covariate in the analysis of variance. However, as Bacon *et al.* (1988) pointed out, any differences will tend to be underestimated using a younger population.

Apart from their age, the controls were lighter and had a smaller BMI than their OSA counterparts. As increased fat deposits around the pharynx have been reported in OSA subjects (Horner *et al.*, 1989b), the difference in obesity between the groups could perhaps be responsible for some of the variations in lumen of the pharyngeal airway.

Cephalometric findings

Skeletal morphology. This study failed to demonstrate any differences in the positional relationships of the mandible and maxilla between OSA and control groups. This held true for both vertical and antero-posterior dimensions and is in contrast to other work.

In the antero-posterior dimension, this conflict may be more apparent than real. Whilst mandibular retrognathia was reported by Jamieson *et al.* (1986), Sériès *et al.* (1992) and Hochban and Brandenberg (1994), other studies found no evidence of this (de Berry-Borowiecki *et al.*, 1988; Zucconi *et al.*, 1992). Tsuchiya *et al.* (1992), categorizing OSA patients by cluster analysis, found retrognathia in one subgroup only. Furthermore, a normal antero-posterior relationship of the jaws is compatible with bimaxillary retrusion, provided that anterior cranial base length is also reduced, as it was in this study (Lowe *et al.*, 1986a). This would concur with the findings of bimaxillary retrusion (Lowe *et al.* 1986a; Bacon *et al.* 1988; de Berry-Borowiecki *et al.*, 1988) and is in keeping with the other data suggesting an overall antero-posterior shortness of the face.

The reduction in length of the body of the mandible (both gonion to menton and gonion to point B) and the intermaxillary space support this contention. Jaw length has not often been examined but a decrease was reported by Rivlin *et al.* (1984). Although Bacon *et al.* (1988) failed to demonstrate such a difference, this may have been because mandibular length was measured as an oblique distance from condyle to chin.

The hyoid. Because of the attachments of the lingual musculature, considerable attention has been paid in the literature to the position of the hyoid. However, this data may not be uniformly reliable as few studies have indicated whether the hyoid was stabilized before exposing the radiographs.

The tongue and intermaxillary space. The intermaxillary space length and area and their relationship to tongue size were first described by Vig and Cohen (1974). They were incorporated in this study in an attempt to investigate any differences in the working space for the tongue.

Table 4 Four-variable discriminant analysis generated by SPSS for the group of 59 individuals: 35 OSA and 24 control subjects.

Predictive variables	Associated coefficients
BMI	–0.17743
Sella–nasion length	0.13867
Width of pharynx where soft palate thickest (retro-palatal 1)	0.25512
Soft palate area	–0.20875
(Constant)	–7.84986

Classification results		Predicted group membership	
Actual group	No. of cases	1 (OSA)	2 (control)
Group 1 (OSA)	35	35 100.0%	0 0.0%
Group 2 (Control)	24	0 0.0%	24 100.0%

Per cent of grouped cases correctly classified	100.0%
Mean discriminant scores for each group	
OSA	–1.4167
Control	2.0606
Critical score	0.2220

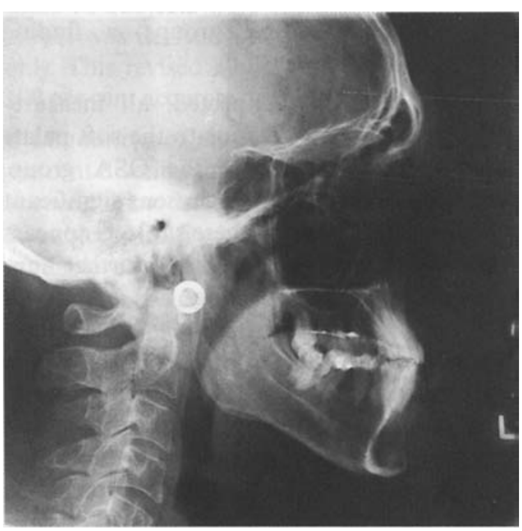

Figure 4 Lateral cephalometric radiograph of a subject with OSA. Vertical and antero-posterior skeletal relationships appear normal but the soft palate is enlarged with consequent reduction in the post-palatal airway, particularly at its narrowest point.

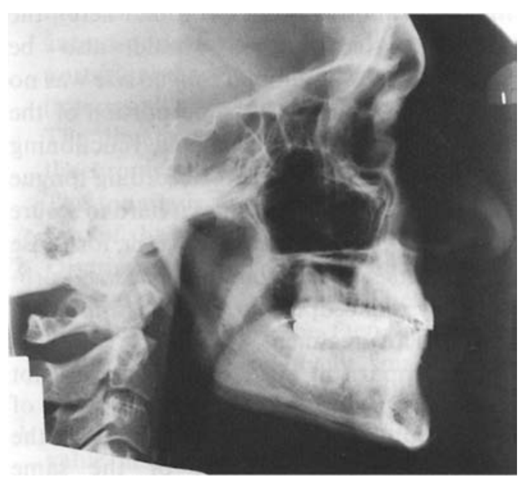

Figure 5 Lateral cephalometric radiograph of a control subject. Skeletal relationships are essentially normal, the soft palate is smaller than in the previous film and the pharyngeal airway, particularly behind the soft palate, is increased.

Table 5 Four-variable discriminant analysis generated by SPSS for the group of OSA subjects with a BMI equal to or greater than 25 and the control group: 25 OSA and 24 control subjects.

Predictive variables		Associated coefficients	
Body mass index		0.25631	
Width of pharynx where soft palate thickest (retro-palatal 1)		−0.15639	
Intermaxillary space length		−0.07704	
Area of soft palate		0.27559	
(Constant)		−0.03010	
Classification results		**Predicted group membership**	
Actual group	No. of cases	1 (OSA)	2 (Control)
Group 1 (OSA)	25	25 100.0%	0 0.0%
Group 2 (Control)	24	0 0.0%	24 100.0%
Per cent of grouped cases correctly classified		100.0%	
Mean discriminant scores for each group			
OSA		1.9180	
Control		−1.9180	
Critical score		0.0	

As mandibular body length was short, it might be anticipated that the intermaxillary space length would also be reduced. In the presence of normal vertical dimensions (as found here), the intermaxillary space area would also be decreased. Thus even though tongue size was no different in OSA subjects, the proportion of the tongue in relation to its available, functioning space was significantly larger. Recording tongue area is notoriously difficult since it hard to secure a consistent tongue position. However, for those OSA subjects whose tongue space is proportionately reduced, this could have important implications for treatment.

Exact comparison with other work is not possible since no other cephalometric study of OSA and control groups has used either the intermaxillary space concept or the same landmarks for recording tongue size. Whereas Lyberg *et al.* (1989) found no differences in tongue area in OSA subjects, de Berry-Borowiecki *et al.* (1988), using a similar outline, and Tsuchiya *et al.* (1992) found this to be larger. Relating tongue proportion to 'oral space', Lyberg *et al.* (1989) could find no differences, noting that the tongue occupied more than 90 per cent of the oral area in both OSA and control groups—a finding confirmed in the present study.

The oropharynx. As expected, all measurements of the airway posterior to the soft palate were markedly reduced in the OSA group. Despite the differing levels chosen, significant retro-palatal narrowing in these subjects appears to be a universal finding. This is further supported by studies employing CT and MRI techniques (Haponik *et al.*, 1983; Suratt *et al.*, 1983; Lowe *et al.*, 1986b; Crumley *et al.*, 1987; de Berry-Borowiecki *et al.*, 1988; Horner *et al.*, 1989a; Lyberg *et al.*, 1989). Because a reduction in the post-palatal airway occurs in the supine position in apnoeic individuals, evaluation of the oropharyngeal airway dimensions in this position will be of considerable importance when planning treatment (Yildirim *et al.*, 1991).

The discriminant analysis

General composition of the models. The model produced by a discriminant analysis is not influenced by the operator except in the choice of variables submitted. However, if the eventual outcome is not to be prejudged, all probable variables should be submitted: thus parameters which show highly significant differences between the groups are most likely to be useful. All measurements eventually selected showed this distinction. Variables which describe the same condition must not be duplicated: thus if BMI is included, weight and height must be removed. The decision to include BMI is in line with the suggestions of Bacon *et al.* (1988) whose discriminant model correctly identified only 80 per cent of a similar, mixed sample using cephalometric variables alone. These authors indicated that any non-cephalometric factors which might have a bearing on the disease should improve the discrimination.

BMI was a prominent contributor to both final models. Attempts to remove it or to replace it by weight or cephalometric variables always reduced the discriminating power of the equation. Because of the apparent importance of BMI, it was considered that those OSA individuals in whom this variable was normal, might be influencing the results by diluting the study sample. Therefore these 10 subjects were excluded and a separate model was derived for the overweight subjects only. This revised model also proved capable of 100 per cent accurate prediction.

Limitations of the models. Despite their 100 per cent discriminating capacity, a serious limitation of the models presented is the small number of subjects from which they were derived. Since available data are currently limited, this restriction had to be accepted. Ideally the model should be tested on another group of Caucasian subjects at risk for OSA to see whether they are identified correctly. It is probable, however, that hundreds of subjects would need to be studied before a truly robust model was derived. Furthermore, it is possible that the inclusion of ear, nose and throat data obtained from examination of the nasal and pharyngeal airways might further refine the discriminating process.

The relevance of this study to orthodontics

It would appear that subjects with OSA may have several structural, predisposing factors which could encourage airway occlusion during sleep. The combination of a restricted post-palatal air space and retrusive face with an enlarged soft palate and increased tongue proportion must necessarily reduce the oro-pharyngeal area.

The orthodontist may have a dual role in the management of OSA. Firstly, the ready availability of the lateral cephalogram may help to identify the patient at risk who can then be referred for further investigation. In addition, treatment options for the subject with OSA may involve the provision of mandibular advancement splints (similar to functional appliances but worn at night only) and the orthodontist is uniquely placed to provide these. Finally where maxillo-facial surgery is recommended, the orthodontist will be involved in the pre-surgical co-ordination of the occlusion.

Conclusions

1. Subjects with OSA have morphological abnormalities of both skeletal and soft tissue elements of the face, oral cavity and pharynx. (i) The body of the mandible is short but the jaw relationships appear normal because the entire face is reduced in depth antero-posteriorly. (ii) The distance between posterior pharyngeal wall and lower incisor (intermaxillary space length) is reduced. (iii) The dimensions of the retro-palatal area of the oropharynx are markedly reduced. (iv) The tongue is proportionately large. (v) The area of the soft palate is increased.
2. Discriminate models correctly identified all OSA and control subjects. The models are, however, limited by the fact that they were derived from a relatively small group of subjects.
3. Lateral cephalometric radiography may be of value in the identification of subjects with OSA.
4. Orthodontists may therefore find themselves in a position to assist in the early identification of patients with OSA. Prompt diagnosis and treatment will minimize the medical complications of this disorder.

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