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A cephalometric comparison of subjects with snoring and obstructive sleep apnoea

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SUMMARY This prospective study analysed the upright lateral cephalometric radiographs of 115 dentate, Caucasian males. Forty-five subjects exhibited proven obstructive sleep apnoea (OSA), 46 were simple snorers, and the remaining 24 subjects, who had no history of respiratory disease and did not snore, acted as controls. Radiographs were traced and digitized, and comparisons were made of the dento-skeletal, soft tissue, and oropharyngeal features of the three groups. Differences were also sought between the snoring and OSA subjects.

Of the hard tissue measurements, only the cranial base angle and mandibular body length showed significant inter-group differences ($P < 0.001$ and $P < 0.05$, respectively). When the airway and associated structures were examined, both snorers and OSA subjects exhibited narrower airways, reduced oropharyngeal areas, shorter and thicker soft palates, and larger tongues than their control counterparts. Comparison of the two sleep disordered breathing groups showed no differences in any of the skeletal or dental variables examined. However in OSA subjects, the soft palate was larger and thicker ($P < 0.05$), both lingual and oropharyngeal areas were increased ($P < 0.01$ and $P < 0.05$, respectively) and the hyoid was further from the mandibular plane ($P < 0.05$).

Thus, whilst the dento-skeletal patterns of snorers resembled those of subjects with OSA, some differences in soft tissue and hyoid orientation were apparent. There was not, however, a recognizable gradation in size of the airway and its associated structures from control through snoring to OSA subjects. This suggests that there may be a cephalometrically recognizable predisposition towards the development of sleep disordered breathing, but that this is only one facet of the condition.

Introduction

Sleep-related breathing disorders are increasingly being recognized as conditions for which accurate diagnosis and treatment are required. Snoring is a very common complaint, affecting a large proportion of the adult population. Ohayon *et al.* (1997), in a telephone survey, reported that 40 per cent of the UK population snored. Studies in Italy and the USA have recorded a lower prevalence, with males being twice as likely to snore as females (Cirignotta *et al.*, 1989; Young *et al.*, 1993). The condition not only causes appreciable inconvenience to the snorers' partners, but may also have serious health implications. Snoring can be exacerbated by anatomical abnormalities, obesity, or excessive alcohol consumption. Subjects may complain that their sleep is unrefreshing (Ulfberg *et al.*, 1996) and that they feel excessively tired during the day. These patients may be 'simple snorers' or may have varying degrees of obstructive sleep apnoea (OSA), and thorough investigation is required before appropriate treatment can be offered. Investigations include polysomnography to determine the severity of sleep apnoea and sleep nasendoscopy to ascertain the anatomical level of obstruction. This may be at single or multiple levels (at the naso-, oro-, or hypopharynx) and can be appropriately graded (Pringle and Croft, 1993).

In the aetiology of OSA both anatomical and pathophysiological factors seem implicated (Anch *et al*., 1982; Haponik *et al*., 1983; Rivlin *et al*., 1984; Brown *et al*., 1985; Lowe *et al*., 1986a; Battagel and L'Estrange, 1996; Smith *et al*., 1998), and thus the radiographic examination of the face and airway has received considerable attention. Both lateral cephalometric radiographs and three-dimensional scanning techniques (Lowe *et al*., 1986b; Rodenstein *et al*., 1990) have been employed in this context. Whilst the cephalometric view provides a necessarily limited two-dimensional picture, it has the merit of being simpler and more readily available than computed tomography (CT) scanning or magnetic resonance imaging (MRI) techniques. Although earlier work indicated that there was a 'typical' skeletal morphology found in OSA subjects (de Berry-Borowiecki *et al*., 1988), more recent studies suggest that this is an overly simplistic view (Hochban and Brandenburg, 1994; Battagel and L'Estrange, 1996; Lowe *et al*., 1996).

In OSA, skeletal differences have been reported in both horizontal and vertical planes. Antero-posteriorly, both the face and anterior cranial base tend to be retruded (Lowe *et al*., 1986a, 1996; Bacon *et al*., 1988; de Berry-Borowiecki *et al*., 1988; Tsuchiya *et al*., 1992) and the cranial base angle reduced (Jamieson *et al*., 1986). This skeletal arrangement leads to a reduction in the space available for the airway. Additional mandibular retrusion may also occur. Jamieson *et al*. (1986) described a Class II pattern, but more recently, a wide range of skeletal presentation has been confirmed (Battagel and L'Estrange, 1996; Lowe *et al*., 1996; Ono *et al*., 1996). Even in the absence of skeletal disharmony, where the entire face is retropositioned, the body of the mandible may be short (Rivlin *et al*., 1984; Battagel and L'Estrange, 1996). In the vertical plane, increases in lower face height and maxillo-mandibular planes angle have been reported (Lowe *et al*., 1986a, 1996; Bacon *et al*., 1990; Tsuchiya *et al*., 1992).

Both hyoid position and oropharyngeal dimensions are also atypical in OSA individuals. The hyoid is more inferiorly placed than normal in relation to the mandibular plane (Jamieson *et al*., 1986; de Berry-Borowiecki *et al*., 1988; Partinen *et al*., 1988) and the pharyngeal lumen is reduced (Haponik *et al*., 1983; Lowe *et al*., 1986a; de Berry-Borowiecki *et al*., 1988; Yildirim *et al*., 1991) with structural encroachment by the soft palate (Jamieson *et al*., 1986; Partinen *et al*., 1988; Bacon *et al*., 1988; Lyberg *et al*., 1989) and tongue (Pracharktam *et al*., 1994; Battagel and L'Estrange, 1996).

Although snoring and OSA are described as two aspects of the same basic disorder, sleep-related narrowing of the upper airways (Lugaresi *et al*., 1988; Bennett *et al*., 1998), the relationship between the two conditions is not entirely clear. Clinically, it has been suggested that subjects who snore may eventually develop OSA as they grow older or their body mass increases (Nelson and Hans, 1997). This suggests that snoring and OSA share a common underlying predisposition, and differ only in severity (Lugaresi, 1988; Maltais *et al*., 1991; Zucconi *et al*., 1992). Schafer *et al*. (1989), and Andersson and Brattström (1991) reinforced this suggestion, pointing out that the craniofacial anomalies present in OSA subjects also existed in simple snorers. Pracharktam *et al*. (1994) suggested that anatomical factors might predispose some snorers to develop OSA, but their study was very small.

The cephalometric data available tend to support the concept of both craniofacial and soft tissue abnormalities, but the results are not consistent. Variations in sample size, statistical analysis, and the cut-off points selected to distinguish between snoring, and OSA subjects may contribute to this discrepancy. Dento-skeletally, the two groups appear rather alike with similar reductions in cranial base angle having been reported in both snoring and OSA subjects (Maltais *et al*., 1991; Zucconi *et al*., 1992; Frohberg *et al*., 1995; Pracharktam *et al*., 1996). The hyoid to mandibular plane distance is greater in OSA subjects than in snorers, with the hyoid being more postero-inferiorly placed (Maltais *et al*., 1991; Zucconi *et al*., 1992; Frohberg *et al*., 1995; Pracharktam *et al*., 1996).

Reduced pharyngeal airway dimensions appear common to both groups (Andersson and

Brattström, 1991; Maltais *et al*., 1991; Frohberg *et al*., 1995; Pracharktam *et al*., 1996), but whilst acoustic reflectance studies support this finding, they also reveal differences in airway compliance and behaviour (Brown *et al*., 1985; Bradley *et al*., 1986).

It would therefore appear that data concerning the craniofacial characteristics of subjects who snore, but do not exhibit OSA are limited and thus the present study was undertaken in an attempt to gain further information in this area. The aims of the investigation were 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 groups of both snoring and normal individuals matched for sex and ethnicity.

Subjects

The material for this study comprised the lateral cephalometric radiographs of 115 dentate, male Caucasians, recorded with the mandible in the position of maximal inter-cuspation. Forty-five subjects with a diagnosis of OSA and 46 simple snorers formed the experimental group. All had been diagnosed following overnight polysomnography at the Royal National Throat Nose and Ear Hospital in London. The remaining 24 individuals acted as controls. None had histories of snoring or respiratory disorders, or suffered from excessive daytime sleepiness.

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 m^2). The distinction between snorers and OSA subjects was made on the basis of a clinical evaluation of each subject's overnight polysomnography supplemented by his apnoea/hypopnoea index (AHI; Table 1). The AHI sums the number of episodes of apnoea (total cessation of airflow for 10 seconds or more) and hypopnoea (50 per cent reduction in airflow accompanied by a 4 per cent or greater drop in blood oxygen saturation) per hour of sleep. A cut-off value of 9.9 was considered as the upper limit for simple snoring and a minimum value of 15 taken as the lower limit for the OSA group. Subjects with an AHI between these points and individuals with upper airways resistance syndrome were excluded in an attempt to distinguish the two groups more clearly.

Three of the OSA subjects had previously undergone surgery [uvulo-palato-pharnygo-plasty (UPPP)] to reduce the size of their soft palates. This data was excluded from all calculations involving the soft palate and its associated airway.

Methods

Radiography

Standardized lateral cephalograms in the natural head position were taken as part of the normal protocol for evaluation of the sleep disordered breathing subjects. Control individuals were recruited personally by the authors and had given their informed consent to the radiographic procedure. With the subject carefully positioned in the cephalostat, the tongue was painted with barium sulphate contrast medium to aid in the identification of its contour. In order to fix the

Table 1 Demographic data

	Controls		Snorers		OSA		Significance of differences		
	mean (SD)	range	mean (SD)	range	mean (SD)	range	Control	Snorers	OSA
Age (years)	41.8 (9.0)	25.9–60.5	51.4 (9.5)	33.9–77.4	52.3 (9.1)	34.5–74.2	***	NS	NS
BMI (Wt/Ht^2)	24.5 (2.2)	21.0–28.4	26.5 (2.9)	20.7–33.1	27.6 (3.2)	19.9–34.1	***	NS	NS
AHI	n/a	n/a	6.2 (2.8)	1.0–9.8	32.5 (14.8)	15.3–78.0	n/a	***	***

Significance: ***$P < 0.001$.
BMI, body mass index; AHI, apnoea/hypopnoea index.

hyoid in a consistent position, the patient was requested to breathe in slowly and then exhale, holding the latter position while the film was exposed. This procedure was practised several times and the head position checked before the film was actually taken. All films were taken at the same magnification by radiographers familiar with the protocol.

Cephalometric analysis

The radiographs were traced by a single examiner (AJ), orientated with the maxillary plane horizontal and 15 conventional hard tissue points identified (Figure 1). Thirteen additional points relating to the cervical vertebra, oropharynx, epiglottis, soft palate, and tongue were recorded (Figure 2). Definitions of the additional landmarks and of those conventional points not conforming to British Standards Institution (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 soft palate, tongue, and oropharynx were recorded. Films for the sleep disordered breathing subjects were traced in a random order, whereas those of the control group were recorded on a separate occasion.

Films were automatically realigned to the maxillary horizontal, a vertical reference line dropped from the sella and all subsequent calculations made with this orientation. Twenty-three angular, linear, and proportional measurements were calculated, together with the areas of the intermaxillary space, soft palate, oropharynx, and tongue (Figure 2, Table 2). All measurements were converted to life size.

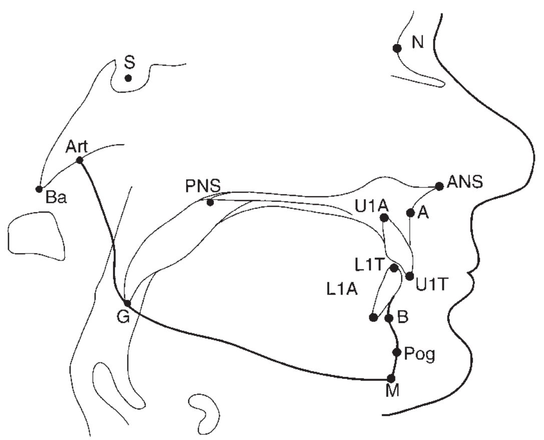

Figure 1 The cephalometric points recorded. Except where listed below, points, lines and planes conformed to British Standard definitions (British Standard Institution, 1983). Hard tissue: A, point 'A'; ANS, anterior nasal spine; Art, articulare; B, point 'B'; Ba, basion; G, gonion, the point where the 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.

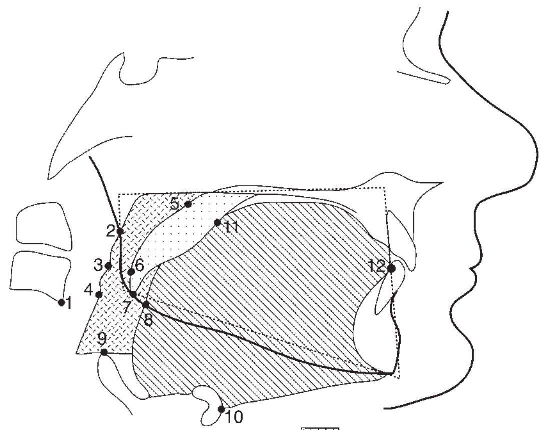

Figure 2 (1) Most antero-inferior point on the third cervical vertebra. (2) The point of intersection of the occlusal plane with the posterior pharyngeal wall. (3) The point on the posterior pharyngeal wall where the post-palatal airway is at its narrowest. (4) The point on the posterior pharyngeal wall where the post-lingual airway is at its narrowest. (5) The point on the nasal surface of the soft palate where the soft palate is at its thickest. (6) The point on the posterior surface of the soft palate where the post-palatal airway is at its narrowest. (7) The tip of the soft palate. (8) The point on the posterior surface of the tongue where the post-lingual airway is at its narrowest. (9) The tip of the epiglottis. (10) The most anterior point on the hyoid bone. (11) The point on the oral surface of the soft palate where the soft palate is at its thickest. (12) The point of intersection of the occlusal plane with the lingual contour of the lower incisor. Minimum airway behind soft palate: point 3 to point 6. Minimum airway behind tongue: point 4 to point 8. Soft palate length: PNS to point 7. Soft palate thickness: point 5 to point 11. Intermaxillary space: the area enclosed by the trapezium drawn through the maxillary and mandibular planes, the posterior pharyngeal wall, and the lingual contour of the lower incisor.

Method error

Duplicate tracings of 20 films were made and random method error assessed as described by Dahlberg (1940) and Houston (1983). Systematic error was determined as suggested by Houston (1983) using paired *t*-tests and a significance level of 10 per cent. Dahlberg errors varied between 0.32 and 2.33 mm, from 0.41 to 2.21 degrees, and from 0.19 to 0.38 cm^2. Houston's coefficient of reliability ranged from 87.7 to 99.2 per cent: only mandibular body length exhibited a value of less than 90 per cent. Errors tended to be larger for those measurements where the associated points were difficult to define. The largest error (2.47 per cent) was associated with tongue proportion, which was based on two other parameters. Where systematic errors were detected, the second recording tended to be greater than the first. This would suggest some bias either at the tracing stage or when the points were identified.

Statistical evaluation

Data were analysed using SPSS for Windows, version 6.1 (SPSS Inc, Chicago, Illinois). Means, standard deviations and ranges were calculated for each variable. Because the control group

Table 2 (a) Comparison between facial dimensions for control, snoring and OSA patients: skeletal and dental measurements.

Variable	Control		Snorer		OSA		ANOVA[a]	*t*-test[b]
	mean (SD) (*n* = 24)	range	mean (SD) (*n* = 46)	range	mean (SD) (*n* = 45)	range		
Cranial base								
Ba-S-N (°)	132.6 (5.2)	121.5–140.8	127.7 (6.2)	114.7–137.3	126.2 (5.4)	116.2–141.3	***	NS
Maxilla								
SNA (°)	80.8 (3.9)	73.2–87.9	80.3 (4.2)	71.7–88.5	81.6 (3.7)	69.8–87.8	NS	NS
Mandible								
SNB (°)	78.6 (4.2)	71.0–86.3	78.0 (4.3)	68.9–86.6	78.2 (3.7)	69.0–88.4	NS	NS
Gonial angle (°)	125.1 (5.7)	113.1–138.8	127.5 (7.0)	110.7–146.9	127.5 (7.4)	115.7–143.5	NS (age)	NS
Mand. body length (mm, G–M)	73.2 (5.6)	61.4–81.5	69.6 (5.1)	61.6–80.9	69.1 (5.1)	59.1–81.8	*(age)	NS
Intermaxillary								
ANB (°)	1.9 (2.7)	–3.7–5.9	2.4 (3.2)	–4.9–9.6	3.2 (2.1)	–3.1–7.7	NS	NS
Max.–Mand. planes angle (°)	23.9 (6.6)	12.5–43.0	27.8 (7.2)	12.6–42.2	28.6 (7.9)	14.7–46.4	NS (age)	NS
Lower anterior face height (%)	56.0 (1.7)	51.6–59.0	56.5 (2.1)	51.5–61.1	56.1 (2.5)	50.5–60.5	NS (age)	NS
Lower posterior face height (%)	46.1 (4.7)	34.1–54.7	44.7 (4.6)	30.7–52.7	44.3 (5.5)	29.8–57.6	NS (BMI)	NS
Intermaxillary space length (mm)	79.0 (6.0)	65.9–92.3	74.0 (5.5)	62.2–87.0	74.1 (6.4)	63.3–91.9	**	NS
Dental								
1/1 to maxillary plane (°)	108.8 (10.1)	92.0–127.0	105.2 (11.0)	68.8–125.5	105.8 (10.3)	73.9–124.6	NS	NS
1/1 to mandibular plane (°)	91.6 (8.0)	73.5–103.2	89.2 (9.6)	69.9–108.2	91.4 (9.5)	66.5–109.7	NS (age)	NS
Overjet (mm)	2.9 (1.5)	0.7–6.9	4.5 (2.8)	0.0–15.1	4.8 (2.5)	1.6–11.4	NS (age)	NS
Overbite (mm)	3.0 (2.6)	–3.4–9.7	3.8 (2.8)	–0.4–11.0	3.6 (2.5)	–2.2–12.4	NS (age)	NS

Significance: *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$.
[a]Significance (other effects).
[b]Significance between snorers and OSA.

Table 2 (b) Comparison between facial dimensions for control, snoring and OSA patients: measurements relating to the spine, hyoid, pharynx soft palate, and tongue.

Variable	Control		Snorer		OSA		ANOVA[a]	*t*-test[b]
	mean (SD) (*n* = 24)	range	mean (SD) (*n* = 46)	range	mean (SD) (*n* = 45)	range		
Hyoid								
Hyoid to point 'B' (horiz, mm)	51.1 (5.9)	41.3–62.5	47.8 (5.9)	34.5–61.8	51.5 (5.7)	38.2–66.5	**	** O from S
Hyoid to C3 (horiz, mm)	35.9 (3.1)	28.0–40.0	34.6 (4.9)	21.6–44.2	37.2 (5.7)	26.3–51.5	NS (BMI)	NS
Hyoid to Max. plane (vert, mm)	71.2 (5.3)	61.9–80.7	71.8 (6.6)	59.5–87.7	74.4 (7.5)	61.8–93.9	NS	NS
Hyoid to Mand. plane(vert, mm)	22.5 (5.7)	11.3–34.5	23.3 (5.9)	11.3–36.8	26.3 (6.6)	12.2–39.2	*	* O from S
Hyoid to gonion (vert, mm)	33.4 (7.6)	17.9–48.9	36.5 (7.4)	17.7–53.3	38.9 (9.2)	22.4–57.0	NS	NS
Airway								
Minimum airway behind soft palate (mm)	8.7 (3.0)	3.9–15.0	5.3 (2.9)	0.1–12.7	5.4 (3.5)	0.1–15.0	**	NS
Minimum airway behind tongue (mm)	10.8 (3.1)	6.2–18.0	8.4 (3.8)	1.0–17.8	8.9 (4.4)	1.7–21.6	*	NS
Area of oro-pharynx (cm^2)	8.3 (2.3)	4.7–12.6	5.4 (2.0)	2.2–9.9	6.3 (2.4)	2.5–13.1	***	* O from S
Soft palate and tongue								
Soft palate length (mm)	40.6 (4.5)	31.4–48.3	38.1 (4.0)	31.0–47.8	38.4 (5.1)	27.3–47.1	*	NS
Soft palate thickness (mm)	10.4 (1.3)	8.0–12.6	11.5 (1.5)	8.3–14.6	12.4 (1.9)	9.0–17.8	*** (BMI)	* O from S
Soft palate area (cm^2)	4.0 (0.7)	2.6–5.3	4.3 (0.7)	3.2–6.8	4.6 (0.8)	2.8–7.6	NS (BMI)	* O from S
Tongue area (cm^2)	39.9 (3.9)	33.2–47.8	39.8 (4.0)	32.1–47.9	42.5 (4.5)	33.8–52.6	** (BMI)	** O from S
Tongue proportion (%)	98.0 (10.1)	76.4–118.9	105.1 (10.3)	88.9–130.5	110.9 (12.0)	87.1–136.0	***	* O from S

Intermaxillary space length: the distance between the posterior pharyngeal wall (point 2) and the lower incisor at the level of the occlusal plane.
Tongue proportion: the tongue area as a percentage of the intermaxillary space area.
Significance: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[a]Significance (other effects).
[b]Significance between snorers and OSA.

was significantly younger and less obese than the treated subjects, an analysis of variance, incorporating age and BMI as co-variates, was used to examine the differences between the three groups (Tables 2 and 3). To investigate further the differences between the snoring and OSA groups, unpaired *t*-tests were employed. Values of *P* equal to or less than 0.05 were considered to be statistically significant.

Additionally, both demographic and cephalometric data for all patients were subjected to a discriminant analysis (Norusis, 1986). Using the stepwise method of Wilks, all eligible variables were entered into the analysis. The number of elements was progressively reduced by sequentially excluding those measurements that contributed least to the overall model. Once variable selection was complete, a model was generated comprising a number of factors, each with its own coefficient, and a constant, allowing discriminant scores to be calculated for each individual. This score automatically allocated

Table 3 A summary comparison of significant facial dimensions in OSA, snoring and control subjects.

Measurement	Control	Snorer	OSA
Cranial base angle	Normal	↓	↓
Mandibular body	Normal	↓	↓
Intermaxillary space length	Normal	↓	↓
Minimum palatal airway	Normal	↓	↓
Minimum lingual airway	Normal	↓	↓
Soft palate length	Normal	↓	↓
Hyoid to mandibular plane	Normal	Normal	↑
Hyoid to point 'B'	Normal	↓	Normal
Soft palate thickness	Normal	↑	↑↑
Soft palate area	Normal	↑	↑↑
Tongue area	Normal	Normal	↑
Tongue proportion	Normal	↑	↑↑
Oropharyngeal area	Normal	↓↓	↓

↑ = Increased; ↑↑ = greater increase in this group;
↓ = reduced; ↓↓ = greater reduction in this group.

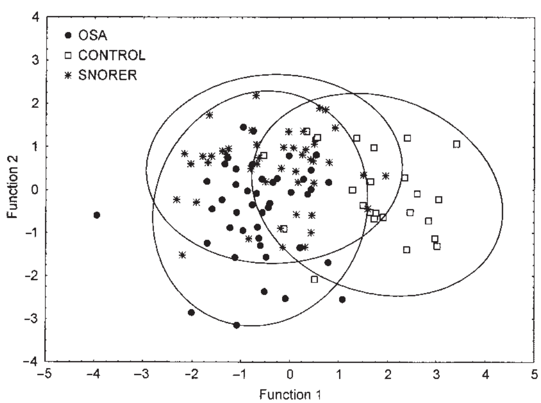

Figure 3 Plot of discriminant function scores, showing considerable overlap between the three groups, particularly between the OSA and snoring subjects.

individuals to one of the three groups and these are represented diagrammatically in Figure 3.

Results

Demographic data (Table 1)

The ages of the snoring and OSA groups were well matched: 51.4 and 52.3 years, respectively. Subjects in the control group, at 41.8 years, were approximately 10 years younger (Table 1).

Both sleep disordered breathing groups exhibited statistically significantly higher BMIs than the control subjects. BMI for the control subjects was within normal limits at 24.5 (normal values 20–25), snorers exhibited a mean of 26.5 (range 20.7–33.1), and for the OSA subjects the value was 27.6 (range 19.9–34.1). Although, on average, the sleep disordered breathing subjects were overweight, this was not universal.

The mean AHI for snorers was 6.2 and that for OSA subjects 32.5, with a range of 15.2–78.0.

Cephalometric findings: dentoskeletal (Table 2a)

All groups. Few statistically significant differences were found between the cephalometric measurements for the control, snoring, or OSA groups. Only the cranial base angle (BaSN), mandibular body length and the intermaxillary space length differed between the three groups: all were significantly larger in the control group. The differences in cranial base angle were highly significant ($P < 0.001$). Mandibular body length was shorter in the snoring and OSA groups by 3.6 mm and 4.1 mm respectively ($P < 0.05$) with intermaxillary space length being reduced by 5 mm in snorers and 4.9 mm in OSA subjects ($P < 0.01$).

Snoring versus OSA subjects. There were no differences between the snoring and OSA subjects for any of the dento-skeletal measurements in Table 2a. For the three parameters listed in the previous paragraph, the values for the two treatment groups showed remarkable similarity.

Cephalometric findings: the hyoid (Table 2b, Figure 4)

Significant differences in antero-posterior hyoid position were found between the three groups. The distance from hyoid to point B was similar in the OSA and control groups, but almost 3 mm shorter in the snoring subjects ($P < 0.01$). Comparison of the snoring and OSA groups confirmed this difference. The distance of the hyoid to the mandibular plane showed differences significant at the 5 per cent level between the three groups analysed together, and also when the snoring and OSA subjects were compared separately. The inter-relationships between

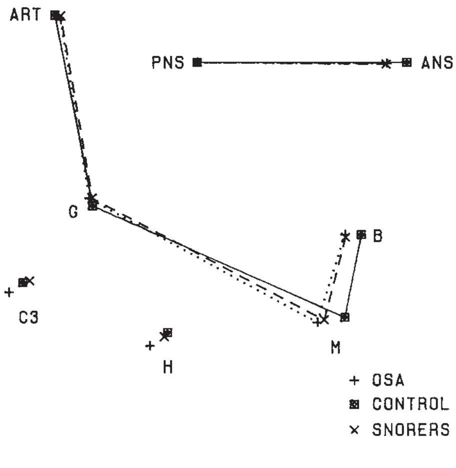

Figure 4 Diagrammatic representation of the relationship of hyoid and C3 to the mandible and maxillary plane, superimposed on the ANS–PNS line, registered at PNS. Solid line: controls; dashed line: snorers; dotted line: OSA subjects.

the hyoid, C3, and the mandible are shown in Figure 4.

Cephalometric findings: the airway (Table 2b)

The airway was recorded at its narrowest dimensions behind both the soft palate and tongue, and by the area of the oropharynx. All measurements exhibited significant inter-group differences. Behind the soft palate the airway measured 8.7 mm in the control group, 5.3 mm in snorers, and 5.4 mm in OSA individuals ($P < 0.01$).

Post-lingually, the same pattern of behaviour was seen, although the disparity between control and sleep disordered breathing subjects was less marked. Minimum dimensions for the controls were 10.8 mm, and for snorers and OSA individuals 8.4 and 8.9 mm, respectively ($P < 0.05$). No significant differences could be shown at either level between the snoring and OSA subjects.

Comparison of the oropharyngeal areas revealed highly significant differences between the three groups ($P < 0.001$). The difference between the two sleep disordered breathing groups was also significant ($P < 0.05$).

Cephalometric findings: the soft palate and tongue (Table 2b)

The soft palate. Soft palate length did not vary between the two treatment groups, but was approximately 2 mm longer in the control group. Soft palate thickness exhibited significant differences between all three groups ($P < 0.001$). The thinnest palates were seen in the controls (10.4 mm) and the thickest ones in the OSA subjects (12.4 mm), with dimensions of the snorers' palates mid-way between (11.5 mm).

Although there appeared to be a similar gradation in the soft palate area from control through the snorers to the OSA subjects, the analysis of variance showed that the differences were insignificant. When snorers and OSA subjects were compared directly, the soft palate areas in the latter were 0.3 cm^2 larger and this was significant at the 5 per cent level.

The tongue. Tongue area showed significant differences between the three groups ($P < 0.01$). Whereas control and snoring subjects had tongues of approximately equal area, tongue size was approximately 2.6 mm^2 larger in the OSA individuals. Tongue proportion, however, did not follow the same pattern. Proportionately, the tongue occupied least space in the mouths of the control subjects (98 per cent); in the snorers the percentage was 105 and in the OSA subjects, 111 per cent.

Cephalometric findings: body mass

For five measurements, lower posterior face height, hyoid to C3, soft palate area, and thickness and the area of the tongue, the BMI contributed to the significance of the inter-group differences. That is, subjects with a lower BMI had statistically significantly lower values of the variable in question than did those with higher BMI values.

Discriminant analysis (Figure 3)

It was not possible to refine a model that permitted 100 per cent discrimination between the control, snoring, and OSA groups. The final model, giving an overall success rate of 64 per

Table 4 Results of discriminant analysis.

Actual group	No. in group	Predicted to be in control group	Predicted to be in snoring group	Predicted to be in OSA group
Control	24	18 (75.0%)	4 (16.7%)	2 (8.3%)
Snoring	46	4 (8.7%)	30 (65.2%)	12 (26.1%)
OSA	45	3 (6.7%)	17 (37.8%)	25 (55.6%)

Overall number of subjects identified correctly: 64 per cent.

cent, contained six variables: age, cranial base angle, oropharyngeal area, minimum post-palatal airway, soft palate thickness, and tongue area. Fifty-six per cent of OSA subjects, 65 per cent of snorers, and 75 per cent of controls were identified correctly (Table 4).

The scatterplot (Figure 3) derived from the discriminant analysis scores allocated to each subject, illustrates the degree of overlap between the three groups. Ellipses have been drawn around each group centroid at the 95 per cent confidence interval. Whilst control subjects (on the right) have some overlap with both the snoring (upper left) and OSA (lower left) groups, the inter-relationship between the two sleep disordered breathing groups is much closer.

Discussion

Cephalometric differences between snoring and OSA subjects (Table 3)

The OSA subjects in this study demonstrated the craniofacial characteristics normally associated with this group. A number of these features were present in the snoring subjects, but certain differences were also apparent. Wherever differences were found, measurements were smaller in the snoring individuals.

The hard tissues

Snorers presented the same acute cranial base angles as reported for OSA subjects (Jamieson *et al.*, 1986; Battagel and L'Estrange, 1996) and this is in agreement with existing data for snorers (Frohberg *et al.*, 1995; Pracharktam *et al.*, 1996). Both snorers and OSA subjects showed reductions in mandibular body length, and this supports the work of Andersson and Brattström (1991). These anatomical differences place the entire facial complex closer to the cervical spine and thus contribute to the reduction of space available for the airway in both sleep disordered breathing groups.

In snorers the positions of both the hyoid and C3 resembled that of the control group rather than the OSA subjects, in whom hyoid was more inferiorly and posteriorly placed. Again, this agrees with previous investigations (Andersson and Brattström, 1991; Maltais *et al.*, 1991; Zucconi *et al.*, 1992; Pracharktam *et al.*, 1994, 1996; Frohberg *et al.*, 1995). This distance is of interest because of its relationship to tongue position. A low hyoid concentrates more of the tongue mass in the hypopharyngeal region and may therefore be a poor prognostic indicator for the successful use of mandibular advancement splints (Lyberg *et al.*, 1989; Mayer and Meier-Ewert, 1995). With increasing interest in these devices (Bennett *et al.*, 1998; Bernhold and Bondemark, 1998; Smith *et al.*, 1998), the more normal hyoid position in snorers may be relevant. This, coupled with their shorter mandibles, brings the snorer's hyoid closer to point B. Whether this has any influence on the ability of the tongue to move forwards easily during mandibular protrusion is a further point which requires elucidation.

The airways

Both snoring and OSA subjects showed similar reductions in minimum airway dimensions behind the soft palate and tongue, and this is in agreement with most other investigations (Andersson and Brattström, 1991; Frohberg *et al.*, 1995; Pracharktam *et al.*, 1996). Only Pracharktam *et al.* (1994) suggested a narrower post-palatal airway in OSA individuals, but only 20 subjects were examined. In the present study, the airways tended to be smaller in the snoring subjects, although this difference was not significant. Interestingly, the acoustic reflectance studies by Bradley *et al.* (1986) would support this discrepancy. However, as the three-dimensional shape of the airway may also differ between the three groups (Rodenstein *et al.*, 1990), this observation should be treated with care.

The soft palate

Soft palate lengths were very similar in both snoring and OSA subjects, being significantly shorter than in the controls. Both these findings seem at variance with those of most other authors (Maltais *et al.*, 1991; Zucconi *et al.*, 1992; Tangugsorn *et al.*, 1995; Pracharktam *et al.*, 1996). Only Frohberg *et al.* (1995) support the present observation.

Both soft palate thickness and area showed significant differences between snoring and OSA subjects. These seemed to show a gradation in size from the normal subjects through the snorers to the OSA individuals, with the latter exhibiting the largest dimensions. Whether this is related to their slightly larger BMI is unclear. Although OSA individuals have been reported to have accumulations of adipose tissue around the neck (Horner *et al.*, 1989; Mortimore *et al.*, 1998), it is not certain whether these extend to the soft palate as well (Stauffer *et al.*, 1989). Some increase in area could be a result of inflammation caused by noise generation. However, if this were so, it might be expected to apply equally to the snoring subjects. These differences in palatal size do not appear to have been identified previously in snoring populations, either due to smaller sample sizes (Pracharktam *et al.*, 1994; Frohberg *et al.*, 1995) or because they have not been investigated.

The tongue and oropharynx

Tongue size in snorers seemed to mirror that of the soft palate. Both absolute and relative dimensions were mid-way between those of the OSA and normal subjects, and these findings support earlier work in this area (de Berry-Borowiecki, 1988; Pracharktam *et al.*, 1994, 1996).

The oropharyngeal area has received little attention in cephalometric studies (Pae *et al.*, 1994). Because the tongue and soft palate were larger, but the minimum airway dimensions similar, it might have been expected that the oropharyngeal area would also be smaller in the OSA group. Instead, the smallest area was found in the snoring subjects. Further investigation showed that the oropharynx (measured from the ANS–PNS plane to the tip of the epiglottis) was significantly shorter in snorers than in either OSA or control individuals. Mean values were 64.9 mm for snorers, 70.4 mm in controls, and 73.0 mm in OSA subjects. This finding, with its relationship to hyoid position and tongue depth, warrants further investigation.

The discriminant model (Table 4)

The discriminant model failed to distinguish clearly between the control, snoring, and OSA subjects. Approximately one-third of OSA subjects were categorized as snorers and 26 per cent of snorers identified as OSA subjects, indicating the difficulty in isolating distinguishing cephalometric features between the two groups. A robust and accurate three-way discriminant model is much harder to achieve than where only two groups are involved, especially when, as here, one group is thought to lie somewhere between the other two. Furthermore, the difference in BMI between the treatment groups was small, and previous authors have indicated that this variable is important in the distinction between OSA and control subjects (Bacon *et al.*, 1988; Battagel and L'Estrange, 1996; Pracharktam *et al.*, 1996).

Pracharktam *et al.* (1996) suggested that it was feasible to distinguish between OSA and snoring individuals on the basis of selected cephalometric and anthropometric measurements. Their discriminant analysis provided a better than 80 per cent correct identification.

Because this analysis contained 17 variables and 58 subjects, this model was very weak and the authors suggested that to validate it, the paradigm should be applied to a further subset of patients. Unfortunately, because the model was derived from snorers and OSA patients only, and included variables not recorded in the present study, it could not be tested on this data. By contrast, a very similar investigation by Frohberg *et al*. (1995) arrived at the opposite conclusion: that the cephalometry of the two groups was so similar that it was not possible to distinguish between them.

Are snorers part of a continuum?

The scatterplot (Figure 3) derived from the discriminant analysis would tend to support the hypothesis that snorers are part of a continuum between the normal state and OSA. Although there is a large range for all three groups and considerable overlap between them, this shows a recognizable pattern. The control group is on one side of the diagram and the two patient groups on the other. The ellipse for the snorers overlaps two-thirds of that of the OSA individuals, whereas 10 of the 24 control subjects lie outside either treatment group. Snorers therefore, appear to resemble OSA subjects more than they do their control counterparts.

Limitations of the study

In common with all cephalometric investigations, this study suffers from the limitations inherent in examining a three-dimensional object using two-dimensional techniques. The differing transverse dimensions of the airways cannot be seen and therefore the picture obtained is incomplete. Furthermore, the aetiology of sleep disordered breathing is multi-factorial: the differing craniofacial anatomies of these subjects are only part of the equation and the altered patho-physiology of the airway in these conditions must also be recognized. The ability to quantify this information and to include it in the discriminant analysis might add considerably to the power of this investigation.

Conclusions

1. Morphological differences do appear to exist between snoring, control, and OSA subjects, but most of these relate to soft tissue structures.
2. Subjects who snore resemble those with OSA, but differ significantly from normal subjects in the following cephalometric measurements: cranial base angle, mandibular body length and intermaxillary space length, minimum post-palatal and post-lingual airways, and soft palate length.
3. Snorers differ from OSA subjects in that the following dimensions are smaller: hyoid to point B, hyoid to mandibular plane, oropharyngeal area, soft palate area and thickness, tongue area, and tongue proportion.
4. The cephalometric morphology associated with snoring may lend support to the idea that snoring is part of a continuum between normality and OSA.

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