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Postural variation in oropharyngeal dimensions in subjects with sleep disordered breathing: a cephalometric study

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SUMMARY This radiographic study analysed the changes that occurred in the airway and surrounding structures when subjects with sleep disordered breathing moved from the upright to the supine position. Radiographs of 100 dentate, Caucasian males were examined. Fifty individuals were non-apnoeic snorers and in 50 a diagnosis of obstructive sleep apnoea (OSA) had been confirmed by polysomnography. Radiographs were traced and digitized and comparisons were made of the behaviour of the oropharynx, soft palate, tongue, and hyoid between the two groups.

When moving from the upright to the supine position, both OSA and snoring subjects showed a similar pattern of change. The antero-posterior dimensions of the oropharyngeal airway decreased highly significantly ($P < 0.001$) at all levels, with a concomitant reduction in cross-sectional area ($P < 0.001$). The narrowing was most severe behind the soft palate, where the minimum airway reduced by approximately 40 per cent. Behind the tongue, a 20 per cent decrease was seen. The soft palate showed small but significant increases in area, whilst the tongue altered in shape but not in its overall cross-sectional area. In non-apnoeic snorers only, tongue proportion increased ($P < 0.05$). At the same time, the hyoid dropped and moved anteriorly, maintaining a constant relationship with the lower border of the mandible.

There were no differences between the non-apnoeic snorers and the OSA subjects in any of the postural changes recorded.

Introduction

Sleep-related breathing disorders may occur in 40 per cent of the UK adult population (Ohayon *et al.*, 1997). In the USA 20 per cent of middle-aged males and 10 per cent of females snore, with 4 per cent of males and 2 per cent of females exhibiting obstructive sleep apnoea (OSA) (Young *et al.*, 1993). A review by Gibson *et al.* (1998) suggested that OSA affected 1–2 per cent of males in the UK and approximately half this number of females. OSA can be detrimental to health (Carlson *et al.*, 1994; Pankow *et al.*, 1997), whilst snoring alone is socially disruptive and can lead to marital breakdown. After allowing for confounding factors such as age, sex, obesity, smoking, alcohol consumption, stress, and other cardiac disease, it is likely that OSA is associated with a greater risk of both hypertension and coronary artery disease (Peker *et al.*, 1999; Ohayon *et al.*, 2000). Exact data indicating an increased mortality rate in OSA patients are lacking (Fleetham, 1998), but this group of patients has an increased rate of road traffic accidents and performs significantly less well under simulated driving conditions (Juniper *et al.*, 2000; George, 2001).

Craniofacial measurements in both simple snorers and subjects with OSA have been shown to differ from those of control individuals (Schafer *et al.*, 1989; Andersson and Brattström, 1991; Battagel *et al.*, 2000). Although the sleep disordered breathing groups do not show identical morphologies, they bear more resemblance to each other than to normal subjects (Battagel *et al.*, 2000), with cephalometry demonstrating skeletal as well as oral and pharyngeal abnormalities (Lowe *et al.*, 1986; Andersson and Brattström, 1991; Maltais *et al.*, 1991; Frohberg *et al.*, 1995; Battagel and L'Estrange, 1996; Pracharktam *et al.*, 1996). Despite the limitations of recording a three-dimensional (3D) airway on a two-dimensional (2D) radiograph, the upright lateral cephalogram has been thought to provide a useful diagnostic tool in the analysis of snoring and OSA subjects (Lyberg *et al.*, 1989; Yildirim *et al.*, 1991; Pae *et al.*, 1994; Brander *et al.*, 1999). However, cephalometric measurements correlate poorly with disease severity (Eveloff *et al.*, 1994; Brander *et al.*, 1999; Battagel *et al.*, 2000) and any predictor variables isolated by multivariate analyses have yet to be validated outside the study in which they were generated. Neck circumference was found to be a better indicator of disease severity than any measurements of radiographic pharyngeal anatomy (Davies and Stradling, 1990).

With few exceptions, cephalometric examinations have been carried out in the upright position, yet during sleep the subject is lying down. It would therefore seem more clinically relevant to examine the airways and surrounding structures in this position. Studies to examine the supine airway and any differences exhibited between the upright and supine positions are limited (Yildirim *et al.*, 1991; Pae *et al.*, 1994; Pracharktam *et al.*, 1994; Brander *et al.*, 1999; Johal and Battagel, 1999), and apart from the pilot investigation by Pracharktam *et al.* (1994) have been restricted to OSA subjects. There is also little agreement between authors as to the behaviour of the pharynx and associated structures when the subject becomes supine. The data are further complicated because, apart from the studies by Yildirim *et al.* (1991) and Pracharktam *et al.* (1994), it is not clear whether the subjects used as controls were simple snorers or normal individuals. Changes have been reported in normal subjects, snorers, and OSA subjects (Yildirim *et al.*, 1991; Pae *et al.*, 1994; Pracharktam *et al.*, 1994; Lowe *et al.*, 1996).

Reductions in the airway behind the bulk of the soft palate of between 1.4 and 3.6 mm have been reported in OSA subjects as the soft palate alters in shape when the subjects lie down (Yildirim *et al.*, 1991; Pae *et al.*, 1994; Pracharktam *et al.*, 1994; Lowe *et al.*, 1996; Johal and Battagel, 1999). Behind the tongue, expectations are contradictory. The airway is variously described as being reduced (Pae *et al.*, 1994; Pracharktam *et al.*, 1994; Johal and Battagel, 1999) or increased (Yildirim *et al.*, 1991). These apparent contradictions may be due to differences in study design. Furthermore, the 2D radiographic assessment cannot detect any compensatory changes that may occur in the lateral walls of the pharynx. Pae *et al.* (1994) and Lowe *et al.* (1996) reported reductions in the airway post-lingually, but in non-snorers, no significant changes occurred (Yildirim *et al.*, 1991). However, acoustic reflectance data (Jan *et al.*, 1994) demonstrated significant reductions in pharyngeal cross-sectional area when normal adults moved from a sitting to a supine position.

Soft tissue measurements may also differ from those made when the subject is upright. An increase in soft palate area has been reported (Pae *et al.*, 1994; Lowe *et al.*, 1996) and this may be accompanied by increments in length and/or thickness (Yildirim *et al.*, 1991; Brander *et al.*, 1999). Small increases in tongue size were found by Pae *et al.* (1994) and in tongue proportion (Johal and Battagel, 1999) in OSA subjects. Although Pracharktam *et al.* (1994) reported no changes, this may have been due to the smaller numbers surveyed.

Hyoid behaviour is also unclear. Whereas Pae *et al.* (1994) found that the hyoid bone moved closer to the mandibular plane, other authors were unable to demonstrate this (Yildirim *et al.*, 1991; Pracharktam *et al.*, 1994; Johal and Battagel, 1999). An anterior movement was normally noted (Yildirim *et al.*, 1991; Pae *et al.*, 1994; Ono *et al.*, 1996; Johal and Battagel, 1999).

Although Pracharktam *et al.* (1994) suggested that supine radiography did not show any additional differences between snoring and OSA subjects when compared with traditional, upright films, those authors only examined 10 subjects in each group. Furthermore, their findings have not been corroborated. Further information on the morphology of the airway and associated structures in the supine position would seem to be helpful. Because airway size is generally reduced in the supine posture, any predictions as to the efficacy or otherwise of mandibular advancement devices might be more usefully determined on radiographs taken in this position.

The aims of the present study therefore, were to investigate: (1) the magnitude of any changes in the airway and associated structures between the upright and the supine position; and (2) whether these alterations were the same in both snoring and OSA subjects.

Subjects

The material for this study comprised pairs of lateral cephalometric and supine lateral skull radiographs of 100 dentate, male Caucasians: 50 snorers and 50 OSA subjects. All subjects had been referred to the Royal National Throat Nose and Ear Hospital, London, with a complaint of snoring and/or excessive daytime tiredness. A definitive diagnosis was made following overnight polysomnography. Referrals were not confined to any particular socio-economic group.

Height and weight were recorded for all individuals and the body mass index (BMI) calculated. (BMI = weight in kilograms divided by height in square metres). The distinction between snorers and OSA subjects was made on the basis of their apnoea/hypopnoea indices (AHI), calculated from the sleep study data. The AHI describes the number of abnormal breathing events per hour of sleep: an arbitrary cut off value of 9.9 was considered as the upper limit for simple snoring, and similarly, a minimum value of 15 was taken as the lower limit for the OSA group. Subjects with AHI values between these points and individuals with upper airway 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) to reduce the size of their soft palates. Their data were excluded from all calculations involving the soft palate and its associated airway.

Methods

Radiography

Standardized lateral cephalograms in the natural head position and with the teeth in maximal intercuspation were taken as part of the normal protocol for evaluation of sleep disordered breathing subjects. Barium sulphate contrast medium was applied to the dorsum of the tongue to enhance its radiographic appearance. In order to fix the 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.

Supine lateral skull films were obtained using an adjustable Orbix machine (Siemens PLC, Bracknell, Berkshire, UK). Subjects lay supine with a foam head support placed in a position that resembled as closely as possible that which they adopted during supine sleep. Contrast medium was applied to the tongue and the subjects were asked to place their teeth in light occlusion. Lateral head position was carefully aligned and checked by the radiographer, and the magnification associated with each film was recorded. Again, all films were taken at end-expiration by staff familiar with the radiographic protocol. This procedure was adopted because it was not possible to obtain supine recordings using the cephalostat.

A validation study of the two sets of radiographic equipment was carried out using a mannequin. Two vertical, metal markers were taped on the lateral aspect of the neck, and both upright and supine films of the doll were exposed. Once the magnification factors had been taken into account, no differences were found in the actual and imaged measurements for either X-ray machine.

Cephalometric analysis

Radiographs were traced by two examiners: snorers by AMS and OSA subjects by AJ.

Films were orientated with the maxillary plane horizontal and 12 conventional hard tissue points identified on the lateral cephalogram (Figure 1). Sixteen additional points relating to the cervical spine, hyoid, oropharynx, epiglottis, soft palate, and tongue were recorded (Figure 2). Definitions of the additional landmarks and of those conventional points not conforming to the British Standards Institution definitions (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 were automatically realigned to the maxillary horizontal, a perpendicular reference line dropped from sella, and all subsequent calculations made with this orientation. Twenty-six linear, angular, and proportional measurements were calculated, together with the areas of the intermaxillary space, soft palate, oropharynx, and tongue. All measurements were converted to life size.

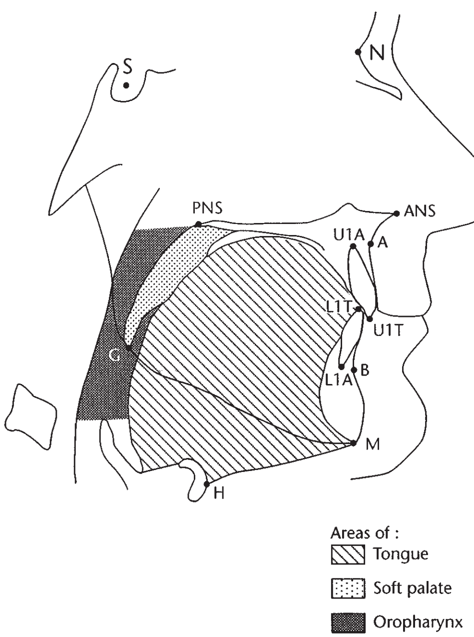

Figure 1 The cephalometric points recorded. Except where listed below, points, lines, and planes conformed to British Standard definitions (British Standard Institution, 1983). Hard tissue: A, point 'A'; ANS, anterior nasal spine; B, point 'B'; G, gonion (the point where the bisector of the angle between the posterior and lower mandibular border tangents meets the mandibular angle); H, hyoid; 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; S, sella; U1A, upper incisor apex; U1T, upper incisor tip.

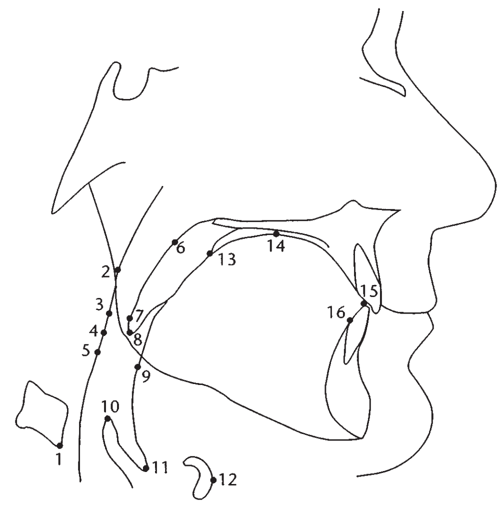

Figure 2 1, most antero-inferior point on the third cervical vertebra; 2, the point of intersection of the occlusal plane with the posterior pharyngeal wall; 3, the point on the posterior pharyngeal wall where the post-palatal airway is at its narrowest; 4, the point on the posterior pharyngeal wall opposite the tip of the soft palate; 5, the point on the posterior pharyngeal wall where the post-lingual airway is at its narrowest; 6, the point on the nasal surface of the soft palate where the soft palate is at its thickest; 7, the point on the posterior surface of the soft palate where the post-palatal airway is at its narrowest; 8, the tip of the soft palate; 9, the point on the posterior surface of the tongue where the post-lingual airway is at its narrowest; 10, the tip of the epiglottis; 11, the vallecula; 12, the most anterior point on the hyoid bone; 13, the point on the oral surface of the soft palate where the soft palate is at its thickest; 14, the highest point on the tongue; 15, the tip of the tongue; 16, the lingual gingival margin of the lower incisor. Minimum airway behind soft palate, point 3 to point 7; airway at tip of soft palate, point 4 to point 8; minimum airway behind tongue, point 5 to point 9; soft palate depth, horizontal distance between point 8 and PNS; soft palate length, PNS to point 8; soft palate thickness, point 6 to point 13; tongue length, vallecula (point 11) to tongue tip (point 15); tongue to maxillary plane, point 14 to maxillary plane; intermaxillary space length, the distance between points 2 and 16; intermaxillary space area, the area enclosed by the trapezium drawn through the maxillary and mandibular planes, the posterior pharyngeal wall (at point 2), and the lingual contour of the lower incisor (point 16). The lines through points 2 and 16 were drawn at right angles to the maxillary plane.

Method error (Tables 1a,b)

Duplicate tracings of 20 upright and 20 supine films were made by both examiners, and random method error was assessed for each individual, 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. Inter-examiner reliability was assessed using Fleiss's intraclass correlation coefficient (ICC) (Fleiss, 1986). Dahlberg errors were expressed as percentages of the actual measurement and were slightly greater for the supine films. Mean method errors for all measurements are shown in Tables 1a and b. Dahlberg errors varied

Table 1a Mean method errors associated with digitizing upright cephalometric radiographs.

Variable	Dahlberg values given in percentages	Houston's coefficient of reliability (percentage)	Systematic error
S–N (mm)	0.6	98.8	none
SNA (°)	0.6	98.6	none
SNB (°)	0.5	98.2	none
Mandibular body length (mm)	1.8	96.8	none
Maxillo-mandibular planes angle (°)	2.8	98.7	none
Lower anterior face height (%)	1.1	96.4	none
Upper incisor inclination (°)	0.7	99.0	none
Lower incisor inclination (°)	1.4	98.8	none

Table 1b Mean method errors associated with digitizing upright and supine radiographs: measurements related to airway and surrounding structures.

Variable	Dahlberg values given in percentages		Houston's coefficient of reliability (percentage)		Systematic error	
	Upright	Supine	Upright	Supine	Upright	Supine
Airway						
Minimum airway behind soft palate (mm)	5.8	6.6	98.3	98.8	none	none
Airway at tip of soft palate (mm)	3.0	4.3	98.5	98.3	yes	none
Minimum airway behind tongue (mm)	4.0	3.6	99.0	99.7	none	none
Length of oropharynx (mm)	1.1	0.7	99.2	99.7	none	none
Area of oropharynx (cm^2)	2.3	3.9	98.9	99.7	none	none
Soft palate and tongue						
Soft palate depth (mm)	2.7	3.5	97.4	97.1	yes	yes
Soft palate length (mm)	1.9	1.8	97.5	96.3	yes	yes
Soft palate thickness (mm)	4.1	2.4	93.4	97.8	none	none
Soft palate area (cm^2)	2.2	2.8	99.0	97.8	none	none
Tongue length (mm)	1.1	0.9	98.1	98.6	none	none
Tongue to maxillary plane (mm)	4.2	6.7	98.5	90.3	none	none
Tongue area (cm^2)	0.6	0.7	99.8	99.9	yes	none
Tongue proportion (%)	1.6	1.7	98.6	99.2	none	none
Hyoid and cervical spine						
Hyoid to maxillary plane (mm)	0.7	0.7	99.6	98.8	none	none
Hyoid to mandibular plane (mm)	2.8	2.7	99.1	99.5	none	none
Hyoid to gonion (vert) (mm)	3.9	3.8	96.1	98.4	none	yes
Hyoid to menton (mm)	1.5	1.7	98.8	99.1	none	yes
Hyoid to C3 (mm)	1.4	1.6	99.2	98.9	none	none
C3 to sella vertical (mm)	2.1	2.3	97.6	98.2	none	none
Intermaxillary space						
Intermaxillary space length (mm)	0.6	0.9	99.4	99.5	yes	none
Intermaxillary space area (cm^2)	1.2	1.1	99.5	99.8	none	none

between 0.5 and 6.7 per cent, with 19 variables showing errors of less than 2 per cent for both examiners. The largest errors were associated with the minimum airway behind the soft palate as this dimension was itself small: less than 6 mm. Houston's coefficient of reliability ranged from 90.3 to 99.9 per cent. Some systematic errors were seen involving both individuals but these were not in any consistent direction; sometimes values for the repeat measurements were larger than for the original digitization and sometimes they were smaller. The hyoid and soft palate tip seemed susceptible to systematic error, especially in the supine position. Inter-examiner reliability was satisfactory with an ICC of 0.77.

Statistical evaluation

Data were analysed using SPSS for Windows, version 6.1 (SPSS Inc., Chicago, Illinois, USA). Means, standard deviations, and ranges were calculated for each variable. Paired *t*-tests compared the differences between upright and supine measurements within each group and unpaired *t*-tests were used to examine any differences in the changes due to posture between the groups. Values of P equal to or less than 0.05 were considered to be statistically significant.

Results

Demographic data (Table 2)

The ages of the snoring and OSA groups were very similar: 51.7 and 49.1 years, respectively (Table 2).

Both groups were overweight and had similar BMI ranges: snorers showed a mean BMI of 26.8 (range 20.7 to 33.1) whilst in OSA subjects the value was 27.6 (range 19.9 to 34.1).

The mean AHI for snorers was 5.9 (range 1–9.8), and that for OSA subjects was 37.5 with a range of 15.2–78.0.

Cephalometric findings (Table 3)

Few differences were seen in the basic cephalometric measurements between the two groups. Cranial base length was slightly longer in snorers (2.0 mm, $P < 0.05$) and the maxillo-mandibular planes angle was 3.4 degrees lower ($P < 0.05$).

Changes from the upright to the supine position in OSA subjects (Tables 4a,b, Figure 3)

The airway. The minimum airway dimensions behind both the soft palate and tongue showed highly significant reductions ($P < 0.001$) in the supine position. The minimum post-palatal airway decreased from 5.4 to 3.1 mm and the retrolingual dimension from 9.6 to 7.4 mm. A 2 mm decrease was seen at the tip of the soft palate and the cross-sectional area of the pharynx reduced from 5.2 to 4.2 cm^2 ($P < 0.001$). Pharyngeal length remained unchanged. These findings are shown graphically in Figure 3.

The soft palate and tongue (Table 4a). The soft palate area increased by 0.2 cm^2 in the supine position and this was just significant ($P < 0.05$). No changes were seen in either the depth, length, or thickness of the palate.

Measurements related to the tongue indicated a change in shape but not of overall size. Tongue length reduced by 3.3 mm ($P < 0.001$), and also moved 1.9 mm closer to the maxillary plane ($P < 0.05$). Neither tongue area nor tongue proportion showed significant postural alterations.

The hyoid. The hyoid bone moved anteriorly and inferiorly when subjects became supine. Its

Table 2 Demographic data.

	OSA mean (SD) (n = 50)	Snorers mean (SD) (n = 50)	Difference (OSA–snorer) and its significance
Age years	51.7 (10.3)	49.1 (9.8)	2.6 ns
Body mass index (BMI) (wt/ht^2)	27.6 (3.4)	26.8 (2.7)	0.8 ns
Apnoea/hypopnoea index (AHI)	37.5 (17.5)	5.9 (2.8)	31.6 $P < 0.001$

Table 3 Upright cephalometric facial dimensions in snoring and OSA patients.

Variable	OSA mean (SD) (n = 50)	Snorers mean (SD) (n = 50)	Difference (OSA minus snoring subjects) and its significance
Cranial base			
S–N (mm)	68.2 (3.8)	70.2 (3.6)	–2.0*
Maxilla			
SNA (°)	80.3 (4.6)	81.0 (4.1)	–0.7 ns
Mandible			
SNB (°)	76.8 (4.5)	76.9 (4.2)	–0.1 ns
Mandibular body length (G–M) (mm)	68.6 (5.4)	67.7 (4.3)	–0.9 ns
Intermaxillary			
Maxillo-mandibular planes angle (°)	30.6 (8.4)	26.8 (7.1)	3.4*
Lower anterior face height (%)	56.2 (2.3)	56.1 (2.5)	0.2 ns
Dental			
Upper incisor inclination (°)	106.1 (10.2)	106.7 (10.1)	–0.6 ns
Lower incisor inclination (°)	89.8 (9.3)	90.8 (8.3)	–1.0 ns

*$P < 0.05$.

Table 4a Comparison between upright and supine dimensions in OSA patients.

Variable	Upright mean (SD) (n = 50)	Supine mean (SD) (n = 50)	Difference (upright–supine position) and its significance
Airway			
Minimum airway behind soft palate (mm)	5.4 (3.2)	3.1 (2.4)	2.3***
Airway at tip of soft palate (mm)	10.1 (4.0)	7.6 (3.2)	2.5***
Minimum airway behind tongue (mm)	9.6 (4.6)	7.4 (3.1)	2.1***
Length of oropharynx (mm)	54.3 (7.1)	54.7 (8.5)	–0.5 ns
Area of oropharynx (cm^2)	5.2 (1.8)	4.2 (1.3)	1.0***
Soft palate and tongue			
Soft palate depth (mm)	25.5 (5.1)	25.3 (4.9)	0.2 ns
Soft palate length (mm)	39.1 (5.2)	38.8 (5.8)	0.4 ns
Soft palate thickness (mm)	12.1 (1.6)	12.1 (2.1)	–0.0 ns
Soft palate area (cm^2)	3.8 (0.6)	4.0 (0.8)	–0.2*
Tongue length (mm)	82.4 (7.9)	79.1 (7.4)	3.2***
Tongue to maxillary plane (mm)	8.1 (5.4)	6.2 (3.7)	1.9*
Tongue area (cm^2)	34.5 (3.9)	35.4 (4.3)	–0.9 ns
Tongue proportion (%)	90.9 (13.2)	93.6 (10.4)	–2.8 ns
Hyoid and cervical spine			
Hyoid to maxillary plane (mm)	72.7 (6.5)	76.9 (8.9)	–4.2***
Hyoid to mandibular plane (mm)	25.4 (5.8)	26.6 (7.9)	–1.2 ns
Hyoid to gonion (vert) (mm)	38.0 (8.0)	42.3 (10.1)	–4.3***
Hyoid to menton (mm)	46.5 (5.7)	41.7 (6.0)	4.8***
Hyoid to C3 (mm)	37.8 (5.8)	36.2 (5.5)	1.8*
C3 to sella vertical (mm)	29.7 (6.8)	29.4 (6.9)	0.3 ns
Intermaxillary space			
Intermaxillary space length (mm)	74.2 (6.7)	72.7 (6.8)	1.5**
Intermaxillary space area (cm^2)	38.3 (4.6)	37.9 (5.1)	0.4 ns

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 4b Comparison between upright and supine dimensions in non-apnoeic snorers.

Variable	Upright mean (SD) (n = 50)	Supine mean (SD) (n = 50)	Difference (upright–supine position) and its significance	Positional differences between snoring and OSA groups and their significance
Airway				
Minimum airway behind soft palate (mm)	5.8 (2.7)	3.6 (2.0)	2.1***	0.2 ns
Airway at tip of soft palate (mm)	9.6 (3.5)	6.9 (2.7)	2.7***	–0.2 ns
Minimum airway behind tongue (mm)	9.5 (4.0)	7.5 (3.3)	2.0***	0.1 ns
Length of oropharynx (mm)	54.1 (6.7)	54.4 (7.2)	–0.4 ns	–0.1 ns
Area of oropharynx (cm^2)	5.5 (1.7)	4.4 (1.0)	1.1***	–0.1 ns
Soft palate and tongue				
Soft palate depth (mm)	24.0 (5.4)	24.8 (5.0)	–0.9 ns	–1.1 ns
Soft palate length (mm)	42.1 (5.2)	41.3 (4.9)	0.8 ns	–0.5 ns
Soft palate thickness (mm)	11.1 (1.7)	11.3 (1.7)	–0.1 ns	0.1 ns
Soft palate area (cm^2)	3.7 (0.7)	3.9 (0.8)	–0.2*	0.0 ns
Tongue length (mm)	80.5 (6.1)	76.9 (5.8)	3.6***	–0.3 ns
Tongue to maxillary plane (mm)	8.3 (5.5)	5.9 (3.9)	2.4**	–0.5 ns
Tongue area (cm^2)	33.4 (3.8)	33.7 (4.2)	–0.3 ns	0.6 ns
Tongue proportion (%)	83.1 (7.3)	86.6 (9.0)	–3.5***	1.3 ns
Hyoid and cervical spine				
Hyoid to maxillary plane (mm)	71.2 (6.2)	73.5 (8.3)	–2.3**	–1.8 ns
Hyoid to mandibular plane (mm)	20.9 (5.3)	21.1 (6.7)	–0.3 ns	–0.9 ns
Hyoid to gonion (vert) (mm)	32.2 (6.4)	35.7 (8.9)	–3.5**	0.8 ns
Hyoid to menton (mm)	45.0 (6.9)	39.0 (6.3)	6.0***	–1.1 ns
Hyoid to C3 (mm)	38.7 (5.2)	37.1 (5.4)	1.6*	0.2 ns
C3 to sella vertical (mm)	28.2 (5.6)	28.6 (9.0)	0.2 ns	0.1 ns
Intermaxillary space				
Intermaxillary space length (mm)	76.2 (5.7)	74.1 (5.1)	2.1***	–0.6 ns
Intermaxillary space area (cm^2)	40.4 (4.6)	39.2 (4.5)	1.2***	–0.8 ns

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

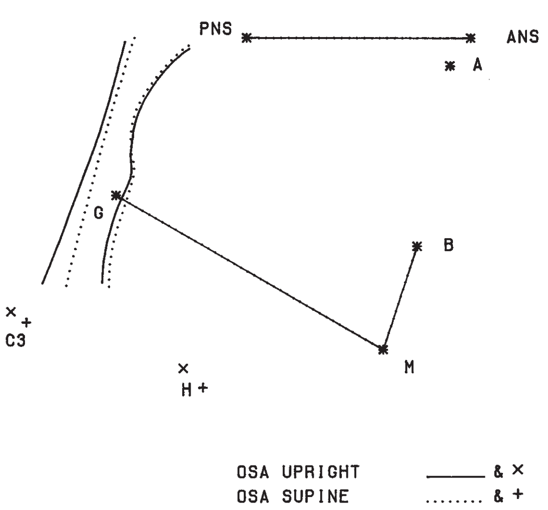

Figure 3 Average postural changes in the pharynx, hyoid, and cervical spine between the upright and supine positions in OSA subjects, superimposed on the maxillary plane, registered at PNS. Solid line, upright; dotted line, supine.

distance from the mandibular plane was unaltered but this was a reflection of the inclination of the plane itself. In the vertical plane, hyoid dropped in relation to both the maxilla (4.2 mm, $P < 0.01$) and the gonial angle (4.2 mm, $P < 0.001$). Antero-posteriorly, hyoid became significantly closer to menton (4.8 mm, $P < 0.001$). The inter-relationship of the changes in oropharynx, hyoid, and C3 can be seen in Figure 3.

The intermaxillary space. Intermaxillary space length decreased by 1.5 mm ($P < 0.01$) between the upright and supine positions but its area was unchanged.

Changes from the upright to the supine position in snoring subjects (Table 4b, Figure 4)

The airway. The airway in snorers exhibited the same postural changes as in subjects with OSA. Percentage reductions in minimum antero-posterior airway dimensions varied from 38 per cent (5.8–3.6 mm) for the minimum post-palatal airway to 21 per cent (9.5–7.5 mm) for the minimum retroglossal measurement. The oropharyngeal area reduced by a similar amount, from 5.5 to 4.4 cm^2. Numerically, these reductions were very similar to those recorded in OSA subjects and were statistically significant at the 1 per cent level. As in OSA individuals, no postural changes in oropharyngeal length were seen. The comparison between upright and supine dimensions is shown graphically in Figure 4.

The soft palate and tongue. These tissues also showed a similar response to lying down as was seen in the OSA subjects. Soft palate area increased by 0.2 cm^2 ($P < 0.05$) but its length, depth, and thickness were unchanged. Tongue area was unchanged but a 3.5 per cent increase in tongue proportion was noted ($P < 0.05$).

The hyoid. The pattern of hyoid behaviour when non-apnoeic snorers moved from the upright to the supine position was similar to that of their OSA counterparts. The hyoid dropped in relation to gonion (3.5 mm) and the maxillary plane (2.3 mm, $P < 0.01$), and moved anteriorly (6.0 mm)

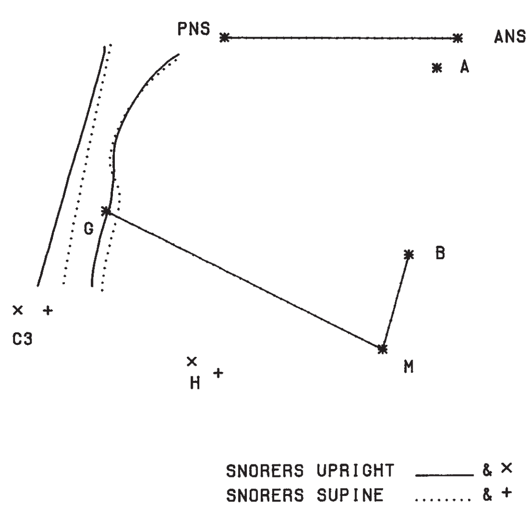

Figure 4 Average postural changes in the pharynx, hyoid, and cervical spine between the upright and supine positions in non-apnoeic snorers, superimposed on the maxillary plane, registered at PNS. Solid line, upright; dotted line, supine.

when its relationship with menton was examined ($P < 0.001$).

The intermaxillary space. Both intermaxillary length and area showed significant reductions between the upright and supine positions.

Comparison between snoring and OSA subjects

When the differences between the upright and supine measurements were compared for snorers and OSA subjects, no statistically significant differences were seen.

Discussion

Postural changes

In the present study, clear reductions in the antero-posterior dimensions of the oropharynx due to posture were seen in both non-apnoeic snorers and subjects with OSA. However, there were differences in airway compliance between OSA individuals (in whom the pharynx is more yielding) and simple snorers (Brown *et al.*, 1985). Thus, even if the anatomical changes appear the same, the effects on the airway may differ when the subject is asleep. Studies of the airways of OSA subjects during both wakefulness and sleep reveal that there is no correlation between the sites of narrowing when awake and the sites of obstruction whilst asleep (Horner *et al.*, 1989; Suto *et al.*, 1993). Posterior displacement of the soft palate and tongue with lateral displacement of the pharyngeal walls contribute to airway occlusion (Horner *et al.*, 1989) and similar, but less marked, changes are seen in normal individuals (Trudo *et al.*, 1998).

It is also of interest that postural alterations in the airway and associated structures have been reported in normal, non-snoring individuals. Jan *et al.* (1994), using acoustic reflectance in this group, demonstrated decreases in pharyngeal cross-sectional area. Cephalometric data do not seem to support this: non-snoring, normal subjects showed an increase in uvular width but no significant reduction in the post-palatal airway, whilst the retroglossal airway increased (Yildirim *et al.*, 1991).

Since the effect of postural changes on the oropharynx and associated structures was the same in both OSAs and simple snorers, both groups will be considered together.

The airway

The dimensions of the oropharynx were markedly narrower at all levels in the supine, compared with the upright position. This would suggest a postural increase in soft palate dimensions and some retraction of the tongue under the influence of gravity. This is in agreement with the marked reductions in the post-palatal airways in normal, snoring, and OSA subjects reported by previous authors (Yildirim *et al.*, 1991; Pae *et al.*, 1994; Pracharktam *et al.*, 1994; Lowe *et al.*, 1996; Brander *et al.*, 1999). In the retroglossal region, the present study showed a similar picture: the minimum airway reduced in both snorers and OSA subjects. Numerically the decrease was similar to that seen behind the soft palate, but proportionately, it was much smaller (approximately 20 per cent rather than the 30–40 per cent reductions in the post-palatal region). This pattern of airway reduction alters from that suggested by Miyamoto *et al.* (1997), where the changes in tongue shape were recorded. In that study, there was very little alteration in OSA subjects, whereas in non-apnoeic snorers, significant changes were found behind the soft palate. The reduction in post-lingual airway is in agreement with OSA subjects examined by Pae *et al.* (1994), Lowe *et al.* (1996) and Johal and Battagel (1999). In contrast, Yildirim *et al.* (1991) found that the retroglossal airway widened, suggesting that this was due to increased genioglossal and geniohyoid muscle activity and was necessary to maintain a patent airway. Unfortunately, there is no unanimity between authors as to the orientation of the films and the exact site at which the airway measurements were taken. If the airway does not behave in a uniform manner then discrepancies in the results might be expected, depending on the site of measurement. Furthermore, airway dimensions vary with the phase of respiration, being at their smallest at the end of expiration (Schwab *et al.*, 1993), and this variable has not been controlled in most investigations.

A further confounder, which may affect both airway dimensions and hyoid position, is the craniocervical angulation. An increased angulation of the cervical spine to the nasion–sella line in OSA subjects was reported by Solow *et al.* (1993), when compared with a range of control individuals. Particularly at more caudal levels, this extended head posture could affect the resultant airway (Solow *et al.*, 1996). In the present study, measurement of the horizontal distance between C3 and sella vertical showed no alteration due to posture, despite the differing methods used to support the head.

The current investigation failed to demonstrate any alterations in either the length or cross-sectional area of the oropharynx. When individual data were examined, some subjects showed a reduction in pharyngeal length and others an increase, with no consistent trend. Using an approximation of pharyngeal length (PNS to vallecula), Pae *et al.* (1994) similarly failed to find any significant changes in the supine position. As expected, if the antero-posterior measurements reduce, with no change in length, the oropharyngeal area also diminishes. Pae *et al.* (1994) noted a 36 per cent reduction in oropharyngeal area whilst the 20 per cent decrease described by Lowe *et al.* (1996) was similar to that seen in the present investigation. The latter authors, however, reported an increase in the hypopharyngeal airway, illustrating the sensitivity of the measurements to the precise areas chosen.

The soft palate and tongue

As expected, in the supine position, both the soft palate and tongue fell back, significantly reducing the minimal airway dimensions, and this is well illustrated in Figures 3 and 4. Although no changes could be seen in the discrete measurements of the soft palate, its area increased by approximately 5 per cent in both groups. Data from other authors are inconclusive with regard to alterations in soft palate length and thickness. Whereas Yildirim *et al.* (1991) found an increase in soft palate width, and

Brander *et al.* (1999) an increase in length, others reported no changes. The increase in palatal area is more universally noted (Pae *et al.*, 1994; Lowe *et al.*, 1996; Johal and Battagel, 1999). Examination of individual films confirmed that the overall shape of the soft palate did alter: the structure became more rounded, but without any real change in maximum thickness. This illustrates the desirability of examining areas as well as linear distances, as the latter do not provide any information about shape.

The tongue also exhibited alterations in shape: its length reduced as it fell back and it became closer to the maxillary plane. Changes in its area were not seen, but in snorers an increase in tongue proportion was noted. Modest increases in tongue area were noted by Pae *et al.* (1994) in OSA subjects but not by Lowe *et al.* (1996); the differing behaviour of OSA and snoring subjects noted by Miyamoto *et al.* (1997) has already been mentioned. Further work is currently under way to attempt to quantify the alterations in both soft palate and tongue shape when the supine position is adopted.

The hyoid

Postural changes cause the hyoid to drop and move anteriorly and this latter movement has been reported previously (Yildirim *et al.*, 1991; Brander *et al.*, 1999; Johal and Battagel, 1999). Such a movement might be a mechanism to maintain airway patency, accompanied by contraction of both supra- and infra-hyoid musculature. Figures 3 and 4 show that the downward and forward movements of hyoid approximate the slope of the mandibular plane, explaining why the hyoid to mandibular plane distances remain constant. This finding concurs with those of other authors for OSA subjects (Pae *et al.*, 1994; Pracharktam *et al.*, 1994; Lowe *et al.*, 1996). Interestingly, in non-snoring controls, hyoid position did alter in relation to the mandibular plane, suggesting that in this group, forward movement did not need to be accompanied by any downward component. It could be rationalized that, in sleep disordered breathing subjects, some compensatory lowering of the hyoid was necessary to maintain some retroglossal airway.

Why the effect of posture change was the same in both groups

Both groups suffer from breathing disturbances during sleep, in which the altered physiology acts on an anatomically vulnerable template. Recent work indicates that anatomically, the facial morphologies of snorers and OSA subjects show more similarities than differences, when compared with normal individuals (Battagel *et al.*, 2000). The differing positions of hyoid and C3 reflect the orientation of the retroglossal section of the pharynx and the tendency towards a shorter anterior cranial base and therefore a more retrusive face in the OSA group. This behaviour of hyoid and C3 is in turn related to the need to keep the airway patent.

Would a supine film be more useful than an upright cephalogram?

Supine films provide a more realistic anatomical picture of the airway and surrounding structures. The soft palate and tongue occupy a larger proportion of the airway in this position and the hyoid moves anteriorly and inferiorly. In individual patients, subtle changes in form were seen at the base of the tongue when the subject became supine. In others, usually OSA subjects, the dimensions of the airway showed very marked reductions in width, giving a very different picture from that on the upright film. The study by Miyamoto *et al.* (1997) suggested that the tongue in OSA subjects showed no dimensional changes in the supine position but that in simple snorers the upper portion, behind the soft palate, did fall back. This pattern could not be confirmed in the present study.

The precise location of the narrowest part of the airway has a bearing on the management options for non-apnoeic snorers and those with mild to moderate OSA. On the basis of nasendoscopic examinations performed during propofol- and midazolam-induced sleep, Pringle and Croft (1993) described five different grades, based on the site or sites of obstruction. Where the base of the tongue is implicated, a mandibular advancement splint would seem a logical treatment option. However, when the soft palate alone is involved, this approach may be less helpful. Further work is in progress to examine these inter-relationships in more detail.

Limitations of the study

The study would have been enhanced by the addition of a control group of age- and BMI-matched subjects. This would have given an opportunity to consider the effects of postural change in normal subjects. In common with all cephalometric investigations, the study also suffers from the limitations inherent in examining a 3D object using 2D techniques. The differing transverse dimensions of the airways cannot be seen and therefore the picture obtained is incomplete. The airway in sleep disordered breathing subjects is circular or elliptical with its long axis in the sagittal plane. This is in contrast with the normal airway, which is also elliptical but with the long axis in the coronal direction (Rodenstein *et al.*, 1990; Schwab *et al.*, 1993). Thus the 2D cephalogram does not provide an ideal view of the actual changes taking place and ignores any contribution of the lateral pharyngeal walls. It overestimates the true airway area in OSA subjects but underestimates the available airspace in normal individuals.

Furthermore, the aetiology of sleep disordered breathing disorders is multifactorial: the differing craniofacial anatomies of these subjects are only part of the equation and the altered pathophysiology of the airway in these conditions must also be recognized. In this context, the poor association between one or more cephalometric variables and the severity of OSA should be emphasized (Eveloff *et al.*, 1994; Brander *et al.*, 1999; Battagel *et al.*, 2000). Neck circumference remains a better indicator of disease severity than obesity or any measurements of radiographic pharyngeal anatomy (Davies and Stradling, 1990).

No power calculations were made to establish a minimum sample size required for the study. Unlike a clinical trial, where the outcome can be anticipated and quantified in advance, in cephalometric studies it may be less helpful to pre-select a single outcome variable. Because there is no clear cut, typical 'sleep disordered breathing' face, attempting to suggest that a specific change in a single variable, e.g. the minimum airway behind the tongue, might have been counterproductive. Furthermore, this would have been at variance with the aims of the study.

Conclusions

1. Both snorers and OSA subjects show similar changes when they move from the upright to the supine position.
2. The oropharyngeal airway becomes narrower in the antero-posterior dimension with the greatest reductions occurring behind the soft palate.
3. The soft palate becomes larger and more rounded in the antero-posterior dimension and the area occupied by the tongue increases.
4. The hyoid moves anteriorly and inferiorly to accommodate the altered bulk of the tongue.

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