European Journal of Orthodontics 27 (2005) 91–97
doi: 10.1093/ejo/cjh077
European Journal of Orthodontics vol. 27 no. 1

Craniofacial morphology, head posture, and nasal respiratory resistance in obstructive sleep apnoea: an inter-ethnic comparison

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SUMMARY The aim of this study was to measure craniofacial morphology and nasal respiratory resistance (NRR) in Malay, Indian and Chinese subjects with obstructive sleep apnoea (OSA).

The sample consisted of 34 male subjects, 27–52 years of age (Malay n = 11, which included five mild and six moderate–severe OSA; Indian n = 11, which included six mild and five moderate–severe OSA; and Chinese n = 12, which included six mild and six moderate–severe OSA) diagnosed using overnight polysomnography. After use of a decongestant, NRR was recorded using anterior and posterior rhinomanometry. Standardized lateral cephalometric radiographs were used to record linear and angular dimensions.

Malay subjects with moderate–severe OSA had a shorter maxillary (sp–pm) and mandibular (gn–go) length when compared with a mild OSA reference sample ($P < 0.05$). The hyoid bone was located more caudally in the Chinese moderate–severe subjects (hy–NL, hy–ML)($P < 0.05$), and may be a useful diagnostic indicator for severity in this racial group.

No pattern of differences for NRR was seen between the moderate–severe and mild OSA subjects. The consistently lower values for nasopharyngeal resistance in all the moderate–severe subjects when compared with the mild group may indicate that some compensation at this level of the airway had taken place. Strong positive correlations between craniocervical angulation (NL/OPT) and total airway resistance and the turbulent component of flow (k_2) suggest that head posture is sensitive to fluctuations in airway resistance ($P < 0.01$).

Introduction

A family history of obstructive sleep apnoea (OSA) increases the risk of developing this condition (Mathur and Douglas, 1995; Redline *et al.*, 1995; Guilleminault *et al.*, 1995). Genetically determined craniofacial features may predispose the airway to narrowing or closure during sleep (Jamieson *et al.*, 1986; Partinen *et al.*, 1988). When matched for similar risk factors for age, gender, and body mass index (BMI), the severity of OSA based on polysomnographic data has generally been found to be greater in Asians compared with Caucasians (Ong and Clerk, 1998).

Previous cephalometric investigations in Caucasians have revealed significant differences in head posture and craniofacial and upper airway morphology in awake OSA patients (deBerry-Borowiecki *et al.*, 1988; Bacon *et al.*, 1988; Zucconi *et al.*, 1992; Solow *et al.*, 1993; Tangugsorn *et al.*, 1995; Sforza *et al.*, 2000).

The volume of air passing through the nose and nasopharynx is limited by its shape and diameter. Previous investigators have found that patients with sleep apnoea have elevated nasal respiratory resistance (NRR) (Blakely and Mahowald, 1987; Metes *et al.*, 1991; Atkins *et al.*, 1994). Ohki *et al.* (1991), using both anterior and posterior rhinomanometry, found significant differences in nasal resistance that corresponded to variations in the dimensions of the external nose in healthy young Caucasian, Oriental, and Black adults.

Currently, there is limited information available for craniofacial morphology, craniocervical posture (NSL/OPT) and NRR variations in Asian subjects with OSA.

The aim of the present study was, therefore, to measure NRR, craniocervical posture (NSL/CVT) and craniofacial morphology in Chinese, Indian, and Malay subjects with OSA.

Subjects and methods

Thirty-four male subjects (Malay n = 11, mean age 35.2 years; Indian n = 11, mean age 49.2 years; Chinese n = 12, mean age 43.3 years), were recruited consecutively from a group of male patients referred for investigation of OSA (Table 1). Obstruction of the upper airway was diagnosed clinically by a respiratory physician (WCT) and confirmed using recordings obtained in a sleep laboratory using overnight polysomnography at the Department of Respiratory Medicine, National University of Singapore. No subjects with craniofacial anomalies or previous internasal or pharyngeal surgical procedures were included in the study. The diagnosis of OSA was based on interrelated breathing variables, such as the apnoea–hypopnoea index (AHI), respiratory distress index (RDI), arousal index, lowest oxygen saturation, and desaturation index. The definitions of these events or variables, and the criteria for the assessment of the diagnostic category of OSA, have previously been described (Tan and Koh, 1991; Wong, 2000) (Table 2).

The subjects in the mild OSA sample experienced less than 20 apnoeas/hypoapnoeas per hour during sleep, while the moderate–severe OSA subjects had more than 20 apnoeas/hypoapnoeas per hour (Table 2).

The BMI was also available for each subject (Table 1).

Rhinomanometric measurements

Rhinomanometric measurements were undertaken with a NR 6 rhinomanometer (GM Instruments, Kilwinning, Ayrshire, UK), calibrated at the beginning of each recording session with an integrated calibration unit. Anterior and posterior recordings were taken from the mean derived from four respiratory cycles, at a single point on the pressure flow curve of 75 Pascals (Pa). Recordings were made before and 30 minutes after the use of a nasal decongestant spray (oxymetazoline hydrochloride 0.05 per cent).

The measurements were made unilaterally for the right and left nasal compartments using the anterior method described by Solow and Greve (1980), and bilaterally to measure total upper respiratory resistance using the posterior method (Sandham and Solow, 1987). NRR was calculated by measuring the pressure drop across the length of the nasal compartment (Pa) and the rate of airflow (ml/second).

$$\text{NRR (Pa/ml/second)} = \text{transnasal pressure drop } (\Delta P) \text{ (Pa)/rate of airflow } (V) \text{ (ml/second)}$$

The methodology was based on guidelines of the International Committee on Standardization of Rhinomanometry (Clement, 1984).

A more complete description of airflow characteristics was proposed by Rohrer (1915), who demonstrated that the relationship between pressure drop and flow could be best described by the second-degree equation

$$\Delta P = k_1 V + k_2 V^2$$

in which k_1 represents laminar flow and k_2 turbulent flow.

Table 1 Sample size, age, and body mass index (BMI) of Asian subjects with obstructive sleep apnoea (OSA).

	Malay $n = 11$				Indian $n = 11$				Chinese $n = 12$			
	Mild OSA ($n = 5$)		Moderate–severe OSA ($n = 6$)		Mild OSA ($n = 6$)		Moderate–severe OSA ($n = 5$)		Mild OSA ($n = 6$)		Moderate–severe OSA ($n = 6$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	30.6	4.8	39.8	7.9	46.0	10.1	52.4	12.1	40.6	10.7	45.9	8.9
BMI (kg/m^2)	39.6	8.2	31.8	5.8	28.7	7.0	27.1	1.9	28.1	7.7	29.4	5.7

SD, standard deviation.

Table 2 The criteria used for the diagnosis of obstructive sleep apnoea (Tan and Koh, 1991).

	AHI	Arousals per hour	O_2 percentage saturation	Desaturation/hour
Normal	<6	<5	>85	<7
Mild	6–20	5–20	80–85	7–15
Moderate–severe	21–40	21–35	60–80	16–30
Severe	>40	>35	<60	>30

AHI, apnoea–hypopnoea index.

Few studies have reported Rohrer coefficients for nasal airflow, but the rhinomanometer used enabled real-time calculation of these parameters.

The bilateral resistance ($R_{bilateral}$) of the right and left nasal compartments was calculated using the principle of Ohm's law for parallel resistors

$$1/R_{bilateral} = 1/R_{left} + 1/R_{right}$$

where R_{left} and R_{right} are the values obtained from anterior rhinomanometry for unilateral right and left nasal compartments.

Nasopharyngeal resistance was calculated using the assumption that posterior rhinomanometry measures total upper airway resistance (R_{total}). This includes the nasopharyngeal area as well as the right and left nasal compartments, so a calculated value can be derived for the nasopharyngeal resistance R_{np}

$$R_{total} = R_{np} + R_{bilateral}$$

Craniofacial measurements

Lateral skull cephalometric radiographs taken in a standardized head posture at the initial consultation were used to identify craniofacial anthropometric points that formed the basis of the postural and craniofacial analysis (Solow and Sandham, 2002) (Figure 1) and airway dimension measurements (Solow *et al.*, 1996) (Figure 2) for each subject. Seven linear and angular variables were measured, which defined maxillary length (sp–pm), mandibular length (gn–go), lower face height (sp–gn) and NL/ML, craniocervical posture (NSL/OPT), and pharyngeal (ve–pve) and laryngeal (va–pva) airway dimensions, and two that defined the craniocaudal position of the hyoid bone (hy–ML, hy–NL).

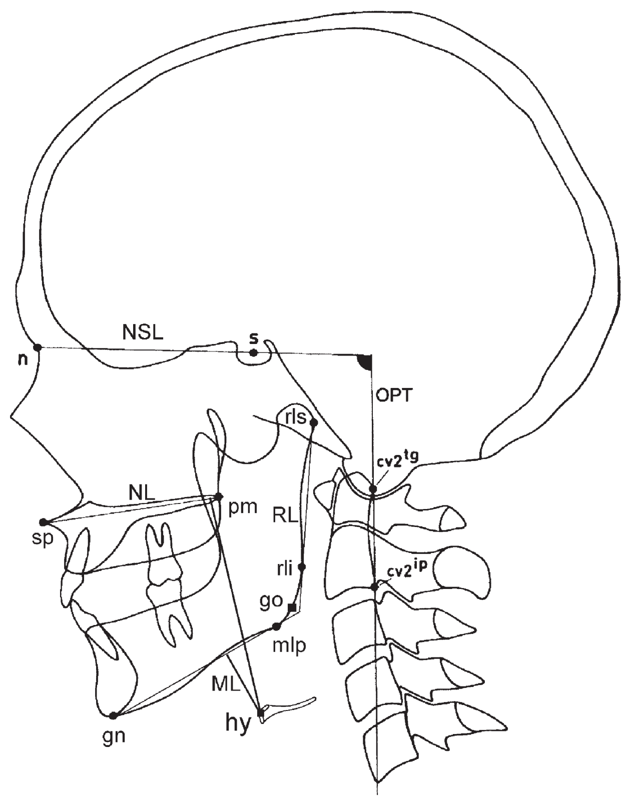

Figure 1 Cephalometric points that define linear and angular variables for maxillary length (sp–pm), mandibular length (gn–go), vertical relationship (NL/ML), lower face height (sp–gn), head posture (NSL/OPT), and hyoid bone position (hy–ML, hy–NL). Ramus line (RL) is a tangent to the posterior border of the mandible drawn though upper (rls) and lower (rli) tangent points. Distances to the hyoid bone (hy) were measured perpendicular from the mandibular (ML) and nasal (NL) planes. Angular values for head posture were measured at the intersection of an extended line from nasion (n) to sella (s) (NSL), with a tangent to the odontoid process of the second cervical vertebra (OPT), defined by an upper ($cv2^{tg}$) and a lower ($tg2^{ip}$) tangent point of the odontoid process.

Method errors

To ensure consistent magnification and to minimize head posture recording errors, the same operator using the same X-ray machine exposed all the standardized lateral cephalometric radiographs.

The technique for recording standardized head posture has been previously reported and showed that the method errors for head posture (NSL/OPT) ranged from 1.5 to 2.6 degrees (Siersbæk-Neilsen and Solow, 1982; Sandham, 1988). The present investigation followed the same guidelines, and duplicate determinations showed no systematic error and no significant differences between the mean values recorded for head posture (NSL/OPT).

Duplicate determinations were also carried out for all the linear and angular variables measured on the lateral cephalometric radiographs. The measurements were undertaken 2 weeks apart and no significant differences were found for any of the craniofacial and airway variables in the two data sets (paired *t*-test).

The reproducibility of NRR recordings has been tested for both anterior and posterior measurements in the present and previous studies (Sandham, 1987; Wong, 2000). This showed a method error between 0.014 and 0.028 Pa/ml/second, which constituted 1.6–7.6 per cent of the total variances in the sample.

Statistics

Due to the distribution form, non-parametric statistics were used, and the recorded data processed using SPSS 11.0 for Windows® (Chicago, Illinois, USA). The Mann–Whitney *U*-test was used to determine if significant craniofacial morphological differences existed between the mild and moderate–severe OSA subjects of the same racial background, the Kruskal–Wallis test to

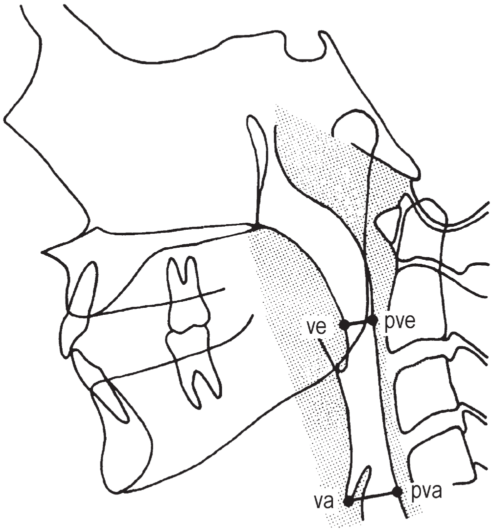

Figure 2 Pharyngeal airway dimension (ve–pve) measured as the distance between the most posterior point on the contour of the soft palate (ve) to a point on the posterior pharyngeal wall (pve), the shortest distance from ve. Laryngeal airway dimension (va–pva) measured as the distance between the deepest point of the vallecula of the larynx (va) to the point on the posterior laryngeal wall (pva), the shortest distance to va.

determine significant differences in OSA values between the three ethnic groups, and Spearman's correlation coefficient (r_s) to detect associations between OSA and craniofacial variables.

Results

Cephalometric measurements

Statistical comparison of cephalometric and airway dimension variables between the mild and moderate–severe OSA subjects showed that the mean values for maxillary length (sp–pm) in moderate–severe OSA subjects were somewhat shorter for all racial groups, but only the values for maxillary length in the moderate–severe OSA Malays were significantly different ($P < 0.05$) for this intra-sample comparison (Table 3, Figure 1).

The mean values for mandibular length (gn–go) in the moderate–severe OSA subjects were only significantly different for Malays ($P < 0.05$) when compared with the mild OSA group (Table 3, Figure 1).

There were no significant differences within each racial group for pharyngeal and laryngeal airway dimensions when subjects with moderate–severe OSA were compared with subjects with mild OSA in the same racial group (Table 3, Figure 2).

The mean values for the hyoid bone position (hy–ML, hy–NL) showed it to be somewhat more caudally positioned in the moderate–severe OSA subjects when compared with the mild OSA subjects for all racial groups. However, the difference was only significant in the Chinese group ($P < 0.05$) (Table 4, Figure 1).

The values for craniocervical angulation (NSL/CVT) were greater in all the moderate–severe OSA subjects

Table 3 Statistical comparison of mean values for cephalometric variables between Malay, Indian, and Chinese subjects diagnosed with mild or moderate–severe obstructive sleep apnoea (OSA).

	Cephalometric variables	Mild OSA		Moderate–severe OSA		*P*-value
		Mean	SD	Mean	SD	
Malay	sp–pm (mm) maxillary length	60.4	2.0	56.3	2.9	0.04*
	gn–go (mm) mandibular length	82.5	3.6	77.3	3.1	0.04*
	NL/ML (°) vertical relationship	18.2	7.8	28.2	5.0	0.04*
	sp–gn (mm) lower face height	70.8	7.6	78.9	3.4	0.17
	Pharyngeal airway ve–pve (mm)	4.6	2.1	4.9	2.7	0.61
	Laryngeal airway va–pva (mm)	15.7	2.9	13.6	3.2	0.17
	NSL/OPT (°) head posture	99.5	5.3	101.8	6.7	0.76
Indian	sp–pm (mm) maxillary length	58.1	4.3	55.5	1.1	0.25
	gn–go (mm) mandibular length	74.5	5.7	78.8	1.1	0.11
	NL/ML (°) vertical relationship	22.0	5.7	23.4	1.1	0.35
	sp–gn (mm) lower face height	71.4	3.4	73.8	1.5	0.25
	Pharyngeal airway ve–pve (mm)	6.7	1.5	7.7	0.9	1.00
	Laryngeal airway va–pva (mm)	16.5	3.3	19.1	1.7	0.47
	NSL/OPT (°) head posture	99.8	4.7	107.7	3.4	0.91
Chinese	sp–pm (mm) maxillary length	56.2	3.4	55.1	3.2	0.86
	gn–go (mm) mandibular length	75.8	5.9	74.6	6.1	0.75
	NL/ML (°) vertical relationship	25.4	6.8	26.7	5.7	0.64
	sp–gn (mm) lower face height	75.6	5.6	74.8	4.1	0.90
	Pharyngeal airway ve–pve (mm)	5.1	3.9	4.6	3.9	0.30
	Laryngeal airway va–pva (mm)	19.2	5.7	17.3	4.3	0.13
	NSL/OPT (°) head posture	98.4	6.3	99.8	6.7	0.84

*$P < 0.05$.
SD, standard deviation.

Table 4 Statistical comparison of craniocaudal location of the hyoid bone between Malay, Indian, and Chinese subjects diagnosed with mild or moderate–severe obstructive sleep apnoea (OSA).

	Hyoid location	Mild OSA		Moderate–severe OSA		*P*-value
		Mean	SD	Mean	SD	
Malay	hy – ML (mm)	21.4	1.5	21.5	5.7	0.61
	hy – NL (mm)	76.8	4.4	80.0	4.8	0.35
Indian	hy – ML (mm)	21.7	6.7	24.1	3.2	0.35
	hy – NL (mm)	75.1	8.5	78.0	4.7	0.35
Chinese	hy – ML (mm)	20.9	6.5	24.7	5.9	0.04*
	hy – NL (mm)	78.2	7.0	82.7	6.7	0.03*

*$P < 0.05$.
SD, standard deviation.

Table 5 Correlations between craniocervical relationships and rhinomanometric variables for total nasal respiratory resistance (NRR).

Craniocervical relationship (°)	Rhinomanometric decongested values	Malay (n = 11)	Indian (n = 11)	Chinese (n = 12)
NL/OPT	Turbulent flow coefficient (k_2) during inspiration	0.72**	ns	0.75**
	Turbulent flow coefficient (k_2) during expiration	0.80**	ns	0.82**
	NRR during inspiration (Pa/ml/second x 10^3)	0.80**	ns	0.79**
	NRR during expiration (Pa/ml/second x 10^3)	0.68*	ns	0.70**

*$P < 0.05$; **$P < 0.01$.
ns, not significant.

when compared with the mild OSA group, but did not reach significance.

The age and BMI of Malay, Indian, and Chinese OSA groups are shown in Table 1. A weak positive correlation between OSA severity and BMI, for all ethnic groups, was found.

Rhinomanometric recordings

This investigation is part of a larger inter-ethnic study, for which NRR values for both inspiration and expiration were recorded. In general, no significant differences were found between values obtained in the decongested subjects for inspiration and expiration. Therefore, these values were pooled (Table 5). The Malay and Chinese groups showed higher NRR for all values recorded in the moderate–severe OSA subjects compared with the mild OSA group, whereas in the Indian sample the values for moderate–severe OSA subjects were all lower than in the mild OSA group (Table 5).

For all three racial groups, the calculated values for nasopharyngeal resistance in the mild OSA group ranged from 67 to 219 Pa/ml/second, while for the moderate–severe OSA subjects these values were all lower, and ranged from 49 to 162 Pa/ml/second (Table 5).

The differences between the values recorded for NRR between the mild and moderate–severe OSA subjects were not significant for all ethnic groups, apart from that between bilateral nasal values for the Malay sample, where the moderate–severe sample was higher ($P < 0.05$) (Table 5).

No significant differences were found between laminar (k_1) and turbulent (k_2) coefficients between the mild and moderate–severe decongested OSA groups in the three ethnic samples.

Correlations between head posture and rhinomanometric variables

Correlations between small samples should be interpreted with care, but strong positive correlations were found using Spearman's rank correlation test (r) when craniocervical angle (NSL/OPT) (Figure 1) and turbulent flow coefficients (NRR) were compared in decongested subjects. An increased craniocervical angulation (NSL/OPT) was seen with an increased turbulent flow coefficient (k_2) for both the Malay (r = 0.72) and Chinese (r = 0.75) samples, for both inspiration and expiration (Table 5). A similar positive correlation existed between craniocervical angulation (NSL/OPT) and increased NRR, i.e. an increased craniocervical angulation (NSL/OPT) being seen with an increased NRR for both inspiration (r = 0.80) and expiration (r = 0.68).

Discussion

The present cohort study was carried out on subjects with mild and moderate–severe OSA. Comparisons were made in three ethnic groups (Malay, Indian, and Chinese) between craniofacial morphology, head posture, and NRR. No reference sample of subjects without OSA was available due to ethical concerns, but each ethnic sample was divided into those with mild OSA and those with moderate–severe clinical problems, so comparisons were possible.

There are real difficulties in obtaining a large sample of diverse ethnic groups in one centre of respiratory medicine, diagnosed by the same clinician and having radiographs taken on the same equipment by the same radiographer. The present sample was obtained over a 9 month period by one author (MLW), and represents a consecutive selection of patients seen at a diagnostic clinic who gave permission to be included in the study. As a consequence of the sample size, these data were subjected to method error testing, and the statistics were interpreted with care.

Airway resistance is subject to posture, diurnal variation, muscle tone, atmospheric and pressure changes (Miljeteig *et al*., 1993). The present rhinomanometric values were obtained in awake subjects sitting upright. Recent studies have shown that NRR is higher in the supine compared with the upright position (Amis *et al*., 1999; Stroud *et al*., 1999). This may account for the few differences which were found in the present study when comparisons were made between the mild and moderate–severe subjects for recordings of NRR and for coefficients of laminar and turbulent flow.

The standardized cephalometric radiographs were also taken in an upright position in a cephalostat and this may also have an effect on pharyngeal measurements, which may be influenced by posture and sleep, although in a study of obese and non-obese subjects pharyngeal dimensions were similar for each category when standing or supine. (Brander *et al*., 1999).

It is interesting to observe that the mean values for both maxillary (sp–pm) and mandibular (gn–go) length in moderate–severe OSA subjects were shorter for Malays when compared with those with mild OSA ($P < 0.05$) and these values may be more diagnostically relevant in Malays than other racial groups. This is somewhat surprising as Chinese facial morphology is generally less prognathic than that of Malays.

The hyoid bone position (hy–ML, hy–NL) was more caudally positioned for moderate–severe OSA subjects when compared with those with mild OSA in all ethnic groups, but reaching a level of significance only for the Chinese cohort ($P < 0.05$). This may be a more diagnostically relevant measurement for severity of OSA in Chinese, and although, in general, previous studies have established the same finding, none has been racially specific for Malays and Chinese and Indian races (Riley *et al*., 1983; Jamieson *et al*., 1986; deBerry-Borowiecki *et al*., 1988; Partinen *et al*., 1988; Tsuchiya *et al*., 1992; Zucconi *et al*., 1992; Tangugsorn *et al*., 1995).

The rhinomanometric results recorded for Malays showed higher values for bilateral measurements of airway resistance in the moderate–severe OSA group when compared with the mild OSA group ($P < 0.05$), and this was to be expected. The values recorded for the moderate–severe Indian sample were, however, lower than those for subjects with mild OSA, but did not reach significance. This is difficult to explain, but may be due to the sample size or rhinomanometric error, or may represent some true racial difference.

The present investigation does, however, show an association between craniocervical angulation (NSL/OPT) and NRR, which has been demonstrated by other investigators (Solow *et al*., 1993, 1996; Huggare and Laine-Alava, 1997). The strong positive correlations (Table 5) not only support these previous studies, but may offer an answer as to why the moderate–severe OSA subjects were found to have a reduced NRR when compared with the mild group, this being due to the compensatory response of head posture change, which results in lowered NRR, of which pharyngeal resistance is a component. The findings of this correlation matrix using small numbers should, however, be interpreted with care (Table 5).

Conclusion

Malay subjects with moderate–severe OSA had a shorter maxillary (sp–pm) and mandibular (gn–go) length when compared with a mild OSA reference sample ($P < 0.05$). This may be a useful diagnostic measurement for Malays with OSA.

However, in the Chinese moderate–severe group, the hyoid bone was located more caudally (hy–NL, hy–ML)($P < 0.05$), and this measurement may be more diagnostically relevant for Chinese with OSA.

No pattern of differences for NRR was seen between the moderate–severe and mild OSA samples. The consistently lower values for nasopharyngeal resistance in all the moderate–severe sample groups may suggest that some compensation has taken place at this level of the airway.

Strong positive correlations between craniocervical angulation (NL/OPT) and total airway resistance and the turbulent component of flow (k_2) suggest that head posture is sensitive to fluctuations in airway resistance ($P < 0.01$), and seem to confirm that a head postural response occurs as airway resistance increases.

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Acknowledgement

The study was supported by grant no. NUS R-172-000-083-213 from the National University of Singapore.

References

Amis T C, O'Neill N, Wheatley J R 1999 Oral airway resistance during wakefulness in patients with obstructive sleep apnea. Thorax 4: 423–426

Atkins M, Taskar V, Clayton N 1994 Nasal resistance in obstructive sleep apnoea. Chest 105: 1133–1135

Bacon W H, Krieger J, Turlot J C, Stierle J L 1988 Craniofacial characteristics in patients with obstructive sleep apnoea syndrome. Cleft Palate Journal 25: 374–378

Blakely B W, Mahowald M W 1987 Nasal resistance and sleep apnoea. Laryngoscope 97: 752–754

Brander P E, Mortimore I L, Douglas N J 1999 Effect of obesity and erect/supine posture on lateral cephalometry: relationship to sleep disordered breathing. European Respiratory Journal 13: 398–402

Clement P A R 1984 Committee report on standardization of rhinomanometry. Rhinology 22: 151–155

deBerry-Borowiecki B, Kukura A, Blanks R H 1988 Cephalometric analysis for diagnosis and treatment of obstructive sleep apnoea. Laryngoscope 98: 226–234

Guilleminault C, Partinen M, Hollman K, Powell N, Stoohs R 1995 Familial aggregates in obstructive sleep apnoea syndrome. Chest 107: 1545–1551

Huggare J Å V, Laine-Alava T 1997 Nasorespiratory function and head posture. American Journal of Orthodontics and Dentofacial Orthopedics 112: 507–511

Jamieson A, Guilleminault C, Partinen M, Quera-Salva M A 1986 Obstructive apneic patients have cranio-mandibular abnormalities. Sleep 9: 469–477

Mathur R, Douglas N J 1995 Family studies in patients with sleep apnoea–hypoapnoea syndrome. Annals of Internal Medicine 151: 688–691

Metes A, Ohki M, Cole P 1991 Snoring, apnea and nasal resistance in men and women. Journal of Otolarygology 20: 57–61

Miljeteig H, Savard D, Mateiki S 1993 Snoring and nasal resistance during sleep. Laryngoscope 103: 918–923

Ohki M, Naito K, Cole P 1991 Dimensions and resistance of the human nose: racial differences. Laryngoscope 101: 276–278

Ong K C, Clerk A A 1998 Comparison of the severity of sleep-disordered breathing in Asian and Caucasian patients seen at a sleep disorders centre. Respiratory Medicine 92: 843–848

Partinen M, Guilleminault C, Quera-Salva M, Jamieson A 1988 Obstructive sleep apnoea and cephalometric roentgenograms. The role of anatomic upper airway abnormalities in the definition of abnormal breathing during sleep. Chest 93: 1199–1205

Redline S, Tishler P V, Williamson J, Kump K, Browner I, Ferrette V, Krejci P 1995 The familial aggregation of sleep apnea. American Journal of Respiratory and Critical Care Medicine 151: 682–687

Riley R W, Guilleminault C, Herrna J, Powell N 1983 Cephalometric analyses and flow volume loops in obstructive sleep apnea. Sleep 6: 303–311

Rohrer F 1915 Der Strömungswiderstandin den menschlichen Atemwegen und der Einfluss der unregelmassigen Verzweigung den Bronchialsystems auf den Atmungsverlauf in verschiedenen Lungenbezirken. Pflugers Archiv für die gesamte Physiologie des Menschen und der Tiere 162: 225–299

Sandham A 1987 Rhinomanometric method error in the assessment of nasal respiratory resistance. Rhinology 26: 191–201

Sandham A 1988 Repeatability of head posture recordings from lateral cephalometric radiographs. British Journal of Orthodontics 15: 57–162

Sandham A, Solow B 1987 Nasal respiratory resistance in cleft lip and palate. Cleft Palate Journal 24: 278–285

Sforza E, Bacon W, Weiss T, Thibault A, Petiau C, Krieger J 2000 Upper airway collapsibility and cephalometric variables in patients with obstructive sleep apnea. American Journal of Respiratory and Critical Care Medicine 161: 347–352

Siersbæk-Neilsen S, Solow B 1982 Intra- and inter-examiner variability in head posture recorded by dental auxiliaries. American Journal of Orthodontics 82: 50–57

Solow B, Greve E 1980 Rhinomanometric recording in children. Rhinology 18: 31–42

Solow B, Sandham A 2002 Cranio-cervical posture: a factor in the development and function of the dentofacial structures. European Journal of Orthodontics 24: 447–456

Solow B, Ovensen J, Würtzen Nielsen P, Wildschiødtz G, Tallgren A 1993 Head posture in obstructive sleep apnoea. European Journal of Orthodontics 15: 107–114

Solow B, Skov S, Ovensen J, Norup P W, Wildschiødtz G 1996 Airway dimensions and head posture in obstructive sleep apnoea. European Journal of Orthodontics 18: 571–579

Stroud R H, Wright S T, Calhoun K H 1999 Nocturnal nasal congestion and nasal resistance. Laryngoscope 109: 1450–1453

Tan W C, Koh T H 1991 Evaluation of obstructive sleep apnoea in Singapore using computerised polygraphic monitoring. Annals of the Academy of Medicine Singapore 20: 196–200

Tangugsorn V, Skatvedt O, Krogstad O, Lyberg T 1995 Obstructive sleep apnoea (OSA): a cephalometric study. Part I: cervical–craniofacial skeletal morphology. European Journal of Orthodontics 17: 45–56

Tsuchiya M, Lowe A A, Pae E K, Fleetham J A 1992 Obstructive sleep apnea subtypes by cluster analysis. American Journal of Orthodontics and Dentofacial Orthopedics 101: 533–542

Wong D C 2000 Nasal airway resistance and airflow characteristics in subjects with obstructive sleep apnoea. Thesis, National University of Singapore

Zucconi C W, Ferini-Strambi L, Palazzi S, Orena C, Zonta S, Smirne S 1992 Habitual snoring with and without obstructive sleep apnoea: the importance of cephalometric variables. Thorax 47: 157–161