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Cephalometric comparison of pharyngeal changes in subjects with upper airway resistance syndrome or obstructive sleep apnoea in upright and supine positions

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SUMMARY The aim of the present study was to cephalometrically compare pharyngeal changes between upright and supine positions in patients with upper airway resistance syndrome (UARS) or obstructive sleep apnoea (OSA). Eighty-two OSA patients, 70 men (mean age 49 ± 11.8 years) and 12 women (45.9 ± 8.3 years), underwent cephalometric sleep apnoea analysis. One upright and one supine radiograph were taken of each patient (a total of 164 cephalometric radiographs).

The results showed no significant changes either in naso- or hypopharyngeal soft tissues between the two positions. In contrast, the shortest distance from the soft palate (ve1–ve2) and the tip of the soft palate (u1–u2) to the posterior oropharyngeal wall was significantly narrower ($P < 0.001$) in the supine position. Furthermore, in the supine position a slight thickening in the soft palate (sp1–sp2, $P < 0.05$) was detected with no change in the length of the soft palate (PNS–u1). The form of the tongue changed significantly: it was shorter (Tt–Tgo, $P < 0.001$; Tt–va, $P < 0.001$) and thicker (Ts/Tt–Tgo, $P < 0.05$) in the supine position.

The present results suggest that OSA patients are prone to significant narrowing of their oropharyngeal, but not of their naso- or hypopharyngeal, airways in the supine position. Thus, treatment of OSA and UARS patients should mainly be aimed at preventing further oropharyngeal airway narrowing as a result of supine-dependent sleep.

Introduction

Obstructive sleep apnoea (OSA), currently recognized as a potentially lethal condition, affects 2–4 per cent of adults (Young *et al.*, 1993). It is defined as repeated cessation of breathing (apnoea), which occurs a minimum of five times per hour of sleep lasting for at least 10 seconds, due to an occlusion in the upper airway. Several symptoms are characteristic of OSA, i.e. daytime sleepiness, morning headache, diminished libido or impotence, depression, mood disorders, impaired memory and concentration and heavy snoring (Erkinjuntti *et al.*, 1990). Due to repeated apnoea, OSA patients have an increased risk of diurnal hypertension, coronary artery atherosclerosis and ischaemic stroke (Strollo and Rogers, 1996; Sullivan and McNamara, 1998; Young and Finn, 1998). Upper airway resistance syndrome (UARS) is indicated by increased pleural pressure swings and a plateau on the inspiratory flow time profile. Both OSA and UARS patients complain of daytime tiredness, fatigue, and variable degrees of sleepiness (Guilleminault *et al.*, 1993, 2001; Ress *et al.*, 2000).

Certain skeletal structures are characteristic of OSA male patients, for example reduced sagittal linear dimensions of the cranial base, maxilla and bony naso- and oropharynx. The hyoid bone between the fourth and sixth cerebra vertebrae is located more inferiorly in OSA male patients than in healthy males. Retrognathia of both maxilla and mandible and increased lower face height have a strong relationship with OSA (Bacon *et al.*, 1989; Tangugsorn *et al.*, 1995; Kollias and Krogstad, 1999). Soft tissue factors can also predispose to OSA, for example tonsillar hyperthropy and obesity, which can cause fatty infiltration into the pharyngeal tissues (Erkinjuntti *et al.*, 1990; Strollo and Rogers, 1996). In addition to anatomical factors that result in a narrowed upper airway space, suppression of pharyngeal muscle activity in sleep is also critical to OSA by producing a narrower airspace that is more vulnerable to collapse on inspiration. OSA is ultimately caused by the impact of brain sleep mechanisms on the processes that control motor outflow to the pharyngeal muscles, the tone of which is necessary and sufficient to keep the airway space open during wakefulness (Horner, 2001).

Although skeletal structures can predispose to the development of OSA, soft tissue changes in the pharynx are probably even more essential in the development of OSA. Tangugsorn *et al.* (1995) showed that in the upright position the soft palate was both thicker and longer, had a more upright position and occupied 15 per cent more of the pharyngeal area in OSA patients than in non-apnoeic controls. The contact length between the soft palate and the tongue increased two-fold. The uvula, which is part of the soft palate, has been shown to be approximately 3 mm longer and 1 mm thicker in OSA patients compared with controls (Hochban and Brandenburg, 1994).

Tangugsorn *et al.* (1995) reported that the tongues of OSA patients were larger, but not longer or thicker, and in a more upright position compared with controls. In contrast, Lowe *et al.* (1996) found that the tongues of skeletal Class I and II OSA patients were significantly longer compared with controls in the upright position. The sagittal dimensions of the oropharynx were also shown to be significantly diminished in the studied groups.

Taken together, significant narrowing of the upper airway has been detected in the upright position in OSA patients. However, in the supine position, during nocturnal sleep, the pharyngeal soft tissues obstruct the pharyngeal airway even more. Thus, the aim of the present study was to compare cephalometrically pharyngeal changes between the upright and the supine position in patients with UARS or OSA.

Subjects and methods

Patients

Eighty-two patients, 70 men, mean age 49 ± 11.8 years (range 18–73 years) and 12 women, mean age 45.9 ± 8.3 years (range 29–60 years) diagnosed by a neurologist as having UARS or OSA were included in the study. All patients underwent an overnight sleep study (Kiuru *et al.*, 1999). The patients were referred to the Department of Pedodontics and Orthodontics, Institute of Dentistry, University of Helsinki, Finland for medical reasons to help target the most optimal treatment for each patient.

Cephalometric procedure

Lateral cephalograms were taken according to a standardized method at the Department of Pedodontics and Orthodontics, University of Helsinki during 1997–1998. The upright radiograph was taken in the natural head position with a Björk cephalostat (distance film focus 154 cm, median sagittal plane focus 140 cm) with a 10 per cent linear enlargement at the median plane, which was corrected. Supine radiography was performed using a cephalostat constructed for sleep apnoea patients, allowing adjustment of the supine subject to the level of the X-ray beam of a conventional X-ray unit, equipped with a rotating anode tube. The soft tissue filter was adjusted on the profile or the pharyngeal region to improve soft tissue imaging. During supine radiography, the subjects were lying in a relaxed and awake state. All radiographs were exposed at the end of expiration. The height of the pillow was a constant 5 cm. For cephalometric analysis, the radiographs were orientated on the light screen to the Frankfort horizontal plane. The cephalometric points on 164 radiographs (Figure 1) were digitized and computer registered, and the cephalometric linear and angular variables calculated (X-metrix, Smartsystem, Finland) (Hurmerinta *et al.*, 1997; Kiuru *et al.*, 1999).

The upper pharyngeal airway was divided into naso-, oro- and hypopharyngeal airways according to the horizontal lines from the PNS or gonion to the posterior pharyngeal wall. The nasopharynx is above the PNS line and the oropharynx is between the PNS and gonion lines. The hypopharynx is under the gonion line (Figure 2).

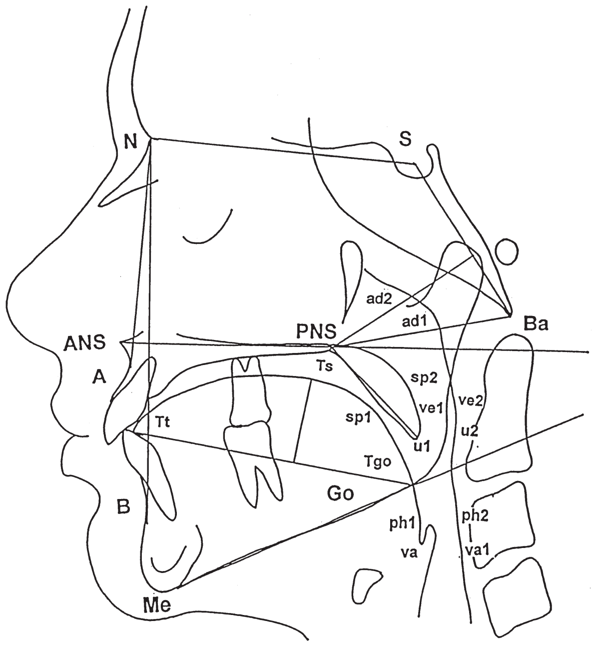

Figure 1 Cephalometric points and lines used in the study. A, most posterior point on the anterior contour of the upper alveolar process; ANS, anterior nasal spine; B, most posterior point on the anterior contour of the lower alveolar process; Ba, basion; Go, gonion; Me, menton; N, nasion; ph1, point on the anterior pharyngeal wall, where the sagittal hypopharyngeal airway distance is shortest; ph2, point on the posterior pharyngeal wall, where the sagittal hypopharyngeal airway distance is shortest; PNS, posterior nasal spine; S, sella; sp1, point on the oral surface of the soft palate, where the thickness of the soft palate is greatest; sp2, point on the pharyngeal surface of the soft palate, where the thickness of the soft palate is greatest; Tgo, intersection of the mandible and the pharyngeal surface of the tongue; Ts, highest vertical point of the tongue; Tt, tip of the tongue; u1, tip of the soft palate; u2, point on the posterior pharyngeal wall opposite the tip of the soft palate; va, vallecula; va1, point on the posterior pharyngeal wall opposite the vallecula; ve1, velum palati; ve2, point on the posterior pharyngeal wall opposite the velum palati; ad1, intersection between PNS–basion line and the posterior nasopharyngeal wall; ad2, intersection between PNS to the midpoint of the sella–basion line and the posterior pharyngeal wall; ANS–PNS, palatal plane; ML, menton–gonion, mandibular plane; Ts/Tt–Tgo, height of the tongue, length from Ts to the line Tt–Tgo; Tt–Tgo, oral length of the tongue; Tt–va, total length of the tongue.

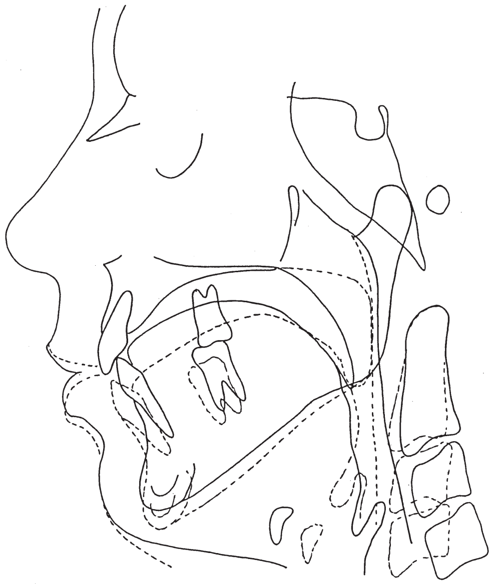

Figure 2 Tracing of a cephalometric radiograph of a 37-year-old male patient in the upright (solid line) and supine (broken line) positions. The upper pharyngeal airway was divided into naso-, oro- and hypopharyngeal airways according to the horizontal lines from PNS or gonion to the posterior pharyngeal wall. The nasopharynx is above the PNS line. The oropharynx is between the PNS and gonion lines. The hypopharynx is under the gonion line.

Statistical procedure

Descriptive statistics, including the mean and standard deviations, were calculated for each cephalometric variable. All radiographs were initially digitized by a single clinician (TI). For the error study, 20 randomly selected cephalograms were redigitized after a 2 month period. This was carried out using the formula: error = $\sqrt{(\sum d^2/2N)}$, where d is the difference between the first and the second tracing measurements and N is the number of cephalograms (Dahlberg, 1948). The range of error between two registrations was 0.9 mm for linear measurements and 1.2 degrees for angular measurements. A Student's paired *t*-test was used to analyse whether the changes in the cephalometric variables between the upright and supine positions were statistically significant (Kirkwood, 1996).

Results

Skeletal description of jaw relationships in male and female patients

The patients were divided into vertical jaw relationship groups according to the angle between the palatal plane and the mandibular plane (ANS–PNS/ML). An angle of more than 27 degrees was classified as open, between 23 and 27 degrees as neutral and less than 23 degrees as a closing jaw relationship. The results showed that most patients (58 per cent of the males and 42 per cent of the females) had a closing jaw relationship. The sagittal description according to the ANB value showed that 58 per cent of the male patients and 59 per cent of the female patients had a Class I jaw relationship. One-third of both groups were diagnosed as skeletal Class II and 9 per cent of the males and 8 per cent of the females were diagnosed as skeletal Class III (Table 1).

Skeletal structures of male patients in the supine position

Significant differences in vertical skeletal measurements were found. Lower face height (ANS–Me, $P < 0.01$) and the percentage of lower face height to anterior face height (ANS–Me/N–Me, $P < 0.001$) were significantly increased in the supine position compared with the upright position. This was due to opening of the lower jaw in the supine position. The measured sagittal skeletal variables were unchanged in both studied positions.

Pharyngeal changes in the upright and supine positions in males

No significant changes were detected in either naso- (ad1, ad2) or hypopharyngeal (ph1–ph2; va–va1) soft tissues. In contrast, the soft palate was closer to the posterior oropharyngeal wall in the supine position compared with the upright position. Both the shortest distance between the soft palate (ve1–ve2, $P < 0.001$) or the tip of the soft palate (u1–u2, $P < 0.001$) and the posterior pharyngeal wall were significantly diminished in the supine position. A slight thickening in the soft palate (sp1–sp2, $P < 0.05$) was noted in the supine position. However, the length of the soft palate (PNS–u1) did not change significantly.

The form of the tongue changed significantly: it was shorter (Tt–Tgo, $P < 0.001$; Tt–va, $P < 0.001$) and thicker (Ts/Tt–Tgo, $P < 0.05$) in the supine position (Figure 2, Table 2).

Table 1 Cephalometric skeletal measurements and comparisons [mean (standard deviation)] in the upright position in males ($n = 70$) and females ($n = 12$).

Variable	Male	Female
SNA °	83.3 (3.6)	82.1 (4.5)
SNB °	80.2 (4.2)	78.0 (4.1)
ANB °	3.1 (2.6)	4.1 (3.2)
ANS–PNS/ML (°)	22.2 (6.3)	25.2 (6.4)
ANS–PNS/ML <23°	58%	42%
ANS–PNS/ML 23–27°	16%	25%
ANS–PNS/ML >27°	26%	33%
ANB <0°	9%	8%
ANB 0–4°	58%	59%
ANB >4°	33%	33%

Table 2 Cephalometric pharyngeal soft tissue changes [mean (standard deviation)] in the upright and supine positions in males (n = 70) and females (n = 12). Owing to the small sample size, no statistical comparison was performed for the female group.

Variable	Male			Female	
	Upright	Supine	t-test	Upright	Supine
Nasopharynx					
ad1 (mm)	26.6 (3.6)	25.6 (3.0)	NS	25.4 (4.2)	25.0 (2.5)
ad2 (mm)	26.1 (3.5)	25.3 (3.8)	NS	23.0 (4.7)	24.0 (3.3)
Oropharynx					
ve1–ve2 (mm)	7.2 (2.4)	4.2 (3.4)	***	5.9 (2.6)	4.9 (5.4)
u1–u2 (mm)	9.3 (2.7)	7.1 (3.4)	***	7.4 (2.8)	6.4 (3.3)
Uvula					
sp1–sp2 (mm)	10.7 (1.8)	11.5 (2.6)	*	8.9 (1.4)	10.2 (2.0)
PNS–u1 (mm)	38.8 (4.3)	39.8 (5.5)	NS	36.2 (4.9)	34.9 (5.8)
Tongue					
Oral length of the tongue (mm)	69.7 (5.7)	65.5 (5.4)	***	64.5 (7.1)	61.0 (7.8)
Height of the tongue (mm)	21.2 (3.8)	22.6 (4.3)	*		
Total length of the tongue (mm)	77.3 (5.6)	72.0 (5.5)	***	72.1 (8.1)	68.2 (7.9)
Hypopharynx					
ph1–ph2	10.7 (4.0)	10.4 (4.9)	NS	8.0 (4.1)	6.3 (3.7)
va–va1	19.1 (4.6)	18.7 (4.3)	NS	16.4 (5.8)	15.3 (3.8)

*P < 0.05; **P < 0.01; ***P < 0.001

Cephalometric changes in the upright and supine positions in females

Owing to the small sample size (12 patients), no statistical comparison was performed for the female group (Table 2).

Discussion

Several cephalometric investigations have previously been undertaken on the pharyngeal airways of OSA patients in the upright position (Tangugsorn *et al.*, 1995; Ono *et al.*, 1996). However, only a few studies have been carried out on upright and supine cephalometric radiographs for comparison between the two positions (Lowe *et al.*, 1996; Pae *et al.*, 1997). In the present investigation, the pharyngeal airway dimensions were studied in both the upright and supine positions in 82 patients. The oropharyngeal airway was found to be significantly narrower in the supine position than in the upright position in male OSA patients. Previous studies have shown significant narrowing of the upper airway in the upright position in OSA patients. However, the primary symptom of OSA, i.e. repeated cessation of breathing (apnoeas), occurs during nocturnal sleep (in the supine position). Thus, the position of pharyngeal tissues in the supine position is essential in determining the severity of OSA.

Although the supine examination does not resemble the true sleeping position, as the patients are awake and the pillow is not individually adjusted, the position of the pharyngeal tissues in the supine position is more essential in determining the severity of OSA. Sleep and supine rest induce alterations in the neuromuscular function of the upper airway. Hiyama *et al.* (2000) compared the supine cephalograms of healthy, non-apnoeic subjects during wakefulness and in stage 1–2 of non-rapid eye movement sleep. The results showed a small but significant increase in the amount of jaw opening and a decrease in the antero-posterior width of the upper airway during sleep. Thus, jaw opening in normal subjects, and even more so in patients with OSA, seems to cause narrowing of the hypopharyngeal airway.

Obesity is known to be a major contributing factor to OSA, causing deposition of fat and an increased mass in pharyngeal tissues (Schwab *et al.*, 1995). However, even in subjects matched for body mass index, more fat deposits are found surrounding the pharynx in patients with sleep apnoea than in their controls (Horner *et al.*, 1989). Pae *et al.* (1997) studied pharyngeal length on 80 pairs of cephalometric radiographs in the upright and supine positions, and showed that the pharynx became considerably longer in the apnoeic group after a body position change from upright to supine. Ono *et al.* (1996) found that the necks in 61 OSA patients were more extended and the hyoid bone moved more antero-superiorly in conjunction with upward and forward rotation of the mandible with a body position change from upright to supine. Tangugsorn *et al.* (1995) showed cephalometrically smaller sagittal dimensions of the pharyngeal airway of OSA patients compared with a healthy control group in the upright position: the horizontal dimension was reduced 16.5 per cent at the nasopharynx, 24.5 per cent at the oropharynx and 33 per cent at the hypopharynx. Thus, the pharyngeal airway dimension in OSA patients is diminished. However, the present results do not show a significant worsening in airway dimensions in either the naso- or hypopharyngeal soft tissues when moving from the upright to the supine position. Instead, there was a significant narrowing of the oropharyngeal sagittal dimensions in the supine position compared with the upright position: the sagittal dimension was even more narrow between the soft palate and the distal pharyngeal wall. The detected thickening of the soft palate in the supine position might cause this. However, the length of the soft palate did not change significantly. Thus, treatment to widen the pharyngeal airway space should be targeted mainly at the oropharyngeal area.

The findings of the present investigation also demonstrated significant change in the form of the tongue between the two studied positions. The tongue was shown to become shorter and thicker in the supine position. This is most likely due to the positional change from the upright to the supine position, when the tongue falls back, resulting in the oral airway becoming even narrower. These results are in agreement with those of Pae *et al.* (1999) who also observed a significant deformation of the tongue following a change in body position from upright to supine in the non-apnoeic control group and in the mild, moderate and severe OSA groups. However, only insignificant differences were detected in tongue shape between the studied groups in either the supine or the upright position. Thus, the change in tongue shape when moving from upright to supine might not be related to the severity of OSA, but could be due to the physiological change in tongue position. Pae *et al.* (1994) found the tongue to be longer in OSA patients compared with controls in the upright position, but tongue length was observed to be similar in both groups in the two studied positions. Thus, OSA patients might have longer tongues, but no differences in positional changes.

Conclusions

The present results suggest that OSA patients are prone to significant narrowing of their oropharyngeal, but not of their naso- or hypopharyngeal airways, in the supine position compared with the upright position. The main problem seems to be the narrowing of the airway space between the soft palate and the distal pharyngeal wall of the oropharynx as well as changes in the form of the tongue. These tongue changes are most likely responsible for the narrowing of the oropharyngeal airway. Thus, treatment of OSA patients should be mainly targeted at preventing oropharyngeal airway narrowing during nocturnal sleep.

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