European Journal of Orthodontics 18 (1996) 571–579

Airway dimensions and head posture in obstructive sleep apnoea

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SUMMARY The present cephalometric study aimed to describe the antero–posterior diameters of the pharyngeal airway in a sample of 50 male obstructive sleep apnoea (OSA) patients and a reference sample of 103 male students, and to examine the relationship between these diameters and the posture of the head and the cervical column. Subjects were recorded in the cephalometer standing with the head in its natural position (mirror position). Pharyngeal airway diameters were measured at seven levels ranging from the maxillary tuberosity to the vallecula of the epiglottis. The largest difference was observed at the level behind the soft palate where the diameter was 50 per cent narrower in the OSA sample than in the reference sample. Extension of the cranio-cervical angle and forward inclination of the cervical column were correlated with an increase in the three most caudal airway diameters in the OSA sample: at the uvula, the root of the tongue, and the epiglottis, but only to increase in the lowest diameter in the reference sample. The findings were considered to reflect a compensatory physiological postural mechanism that serves to maintain airway adequacy in OSA patients in the awake erect posture, most efficiently so at the lowest levels of the oropharyngeal airway.

Introduction

In adults, the site of airway occlusion during apnoeic episodes in obstructive sleep apnoea (OSA) is usually located in the oropharyngeal region, involving the soft palate, the dorsum of the tongue and the posterior pharyngeal wall. A number of studies have reported reduced antero-posterior dimensions of the pharyngeal airway in the awake prone posture (Riley *et al.*, 1983; Haponik *et al.*, 1983; Suratt *et al.*, 1983; Rivlin *et al.*, 1984; Guilleminault *et al.*, 1984; Jamieson *et al.*, 1986; Lowe *et al.*, 1986; Rubinstein *et al.*, 1987; Larsson *et al.*, 1988; Bacon *et al.*, 1988, 1990; Lyberg *et al.*, 1989; Horner *et al.*, 1989; Hellsing, 1989; Katz *et al.*, 1990; Ryan *et al.*, 1990; Davies and Stradling, 1990; Andersson and Brattström, 1991; Maltais *et al.*, 1991; Lowe and Fleetham, 1991), as well as an elongated and thicker soft palate (Riley *et al.*, 1983; Jamieson *et al.*, 1986; Partinen *et al.*, 1988; Davies and Stradling, 1990; Bacon *et al.*, 1990; Andersson and Brattström, 1991; Maltais *et al.*, 1991; Lowe and Fleetham, 1991), larger dimensions of the tongue (Lowe *et al.*, 1986; Ryan *et al.*, 1990; Lowe and Fleetham, 1991) and a lower position of the hyoid bone (Riley *et al.*, 1983; Guilleminault *et al.*, 1984; Jamieson *et al.*, 1986; Partinen *et al.*, 1988; Davies and Stradling, 1990; Andersson and Brattström, 1991; Maltais *et al.*, 1991; Lowe and Fleetham, 1991). Most of the studies of the size of the pharyngeal airway have been based on lateral cephalometric radiographs, but some obtained the information by endoscopic examination (Borowiecki *et al.*, 1978; Rojewski *et al.*, 1984), by CT scans (Haponik *et al.*, 1983; Suratt *et al.*, 1983; Lowe *et al.*, 1986; Larsson *et al.*, 1988; Ryan *et al.*, 1991; Lowe and Fleetham, 1991), MR scans (Horner *et al.*, 1989), or by the acoustic reflection technique (Rivlin *et al.*, 1984; Bradley *et al.*, 1986; Brown *et al.*, 1986; D'Urzo *et al.*, 1987; Rubinstein *et al.*, 1987; Katz *et al.*, 1990). The cephalometric and acoustic studies have usually been recorded with the patients in a prone position, whereas studies based on computerized tomography (CT) or magnetic resonance (MR) scans have recorded the patients in the supine position. Pae (1989) reported cephalometric data for both the prone and the supine positions. Each method has its advantages and disadvantages: the cephalometric analysis of the airways permits precise measurements to be taken in the sagittal plane at anatomically well-defined homologous locations, but does not provide information on the transverse dimensions of the airway. CT and MR scans can provide both transversal, sagittal, and area measures of the airway dimensions, but different studies are difficult to compare, due to the lack of standardization of the thickness, direction and precise location of the sections. The acoustic reflection method provides cross-sectional areas of the airway, but the location of the cross-section is only obtained in terms of a distance from the mouth or the nares, so the anatomical location of each measurement can only be crudely inferred from a general knowledge of the anatomy of the region.

Some authors discuss the possibility that flexion or extension of the head could influence the dimensions of the oropharyngeal airway (Rubinstein *et al.*, 1987; Liistro *et al.*, 1988; Hellsing, 1989; Davies and Stradling, 1990; Fitzpatric *et al.*, 1990). To take this factor into account, cephalometric radiographs of the OSA subjects have been recorded with the head in a natural position (Rivlin *et al.*, 1984; Guilleminault *et al.*, 1984; Davies and Stradling, 1990), and Davies and Stradling (1990) further emphasised the importance of ensuring an unstrained position of the cervical column during the exposure of the cephalometric radiograph.

Most studies of airway diameters in OSA report on the dimension termed the posterior airway space (PAS), which is the airway diameter behind the most dorsal part of the root of the tongue along a line through the reference points supramentale (B-point) and gonion (go) on the mandible, as defined by Riley *et al.* (1983). This is not necessarily the site of the most narrow diameter of the pharyngeal airway. The endoscopic studies reported the most narrow site to be located most often in the retropalatal region, but no metrical studies have been made to assess the precise anatomical location of the most narrow sagittal pharyngeal airway diameter in the awake OSA patient.

The obstruction of the upper airway probably triggers a physiological response in the form of an extension of the head relative to the cervical column. Thus Solow *et al.* (1993) in a study of the natural head posture of OSA patients in the standing position found the average cranio-cervical angulation to be extremely large, more than two SD above the mean for reference samples, mainly mediated by a forward inclination of the cervical column. This was confirmed by Petri *et al.* (1994), and similar but smaller changes in head posture have been observed in patient groups with other types of obstruction of the upper airway.

It was the aim of the present cephalometric study to describe the antero-posterior airway diameters at a series of anatomically-defined locations of the pharyngeal airway, to identify the most narrow of these diameters in erect awake OSA patients and a reference sample, and to examine whether a relationship could be found in these patients and in the reference sample between the cranio-cervical angulation and the antero-posterior diameters at the various locations of the pharyngeal airway.

Subjects and methods

Subjects

The OSA sample comprised 50 male patients referred from the Sleep Clinic of the Glostrup County Hospital, Denmark, for cephalometric examination. The mean age was 50.0 years, and mean apnoeic index (AI) was 47.0. Body mass index (BMI) was available for 31 subjects, and showed a mean of 31.1 (Table 1). The diagnosis of OSA had been obtained by polysomnography. The reference sample was obtained from a previous study of natural head posture (Solow and Tallgren, 1971). Lateral cephalometric radiographs had been recorded with the subjects standing with the head in the cephalo-

Table 1 Descriptive statistics for the obstructive sleep apnoea (OSA) sample.

	N	Min	Max	Mean	SD
Age	50	28.7	70.0	50.0	9.4
AI	50	9.0	98.0	47.0	24.8
Kg	33	73.0	158.0	98.5	21.0
BMI	31	21.1	48.0	31.1	6.7

AI = apnoeic index; BMI = body mass index.

meter in a natural position, the mirror position, as described by Solow and Tallgren (1971) and Siersbæk-Nielsen and Solow (1982). From the original sample of 120 male adults aged 20–30, with a mean age of 24 years, 16 subjects were excluded because examination of the oropharyngeal structures on the radiographs revealed that the subjects had been recorded during the swallowing phase. One subject was excluded due to the presence of spina bifida of the first cervical vertebra. The reference sample thus comprised 103 subjects.

Method

The cephalometric radiographs of the OSA sample were recorded in the natural head position (mirror position) by the same method as the reference sample. The focus-to-film distance was 180 cm. In the OSA sample the 15 cm median plane-to-film distance of the cephalometer was used in order to accommodate the frequently obese patients. In the reference sample, the 'normal' distance of 10 cm was used. The corresponding radiographic enlargement of the linear dimensions was 8.3 and 5.6 per cent respectively. In the present study, all linear dimensions were corrected for the radiographic enlargement in both samples.

On each film 20 reference points were marked and digitized (Figs. 1 and 2). Head posture, cervical posture, and antero-posterior diameters of the upper airway were described by 15 variables calculated from digitized reference points. The most caudal reference points were not visible on all films, so the sample size was reduced for some dimensions.

Three categories of postural variables were studied: (i) cranio-vertical angles (NSL/VER, NL/VER); (ii) cranio-cervical angles (NSL/OPT, NL/OPT, NSL/CVT, NL/CVT); and (iii) cervico-horizontal angles (OPT/HOR, CVT/HOR). Several variables were defined in each category in order to provide a certain amount of redundancy in the description (Fig. 1). Airway diameters were determined at seven levels ranging from the maxillary tuberosity to the level of the vallecula of the epiglottis (Fig. 2).

Method errors

Method errors for head posture and cervical posture have previously been reported to range from 1.5–2.5 degrees for the various variables (Solow and Tallgren, 1971). Method errors for the airway dimensions were assessed from re-recorded films of 16 subjects in the reference sample. No significant mean differences between the two series of records were found. The method errors, s(i), determined by the Dahlberg statistic ranged from 0.7–1.1 mm, corresponding to coefficients of reliability (Houston, 1983) from 0.75–0.95 (Table 2).

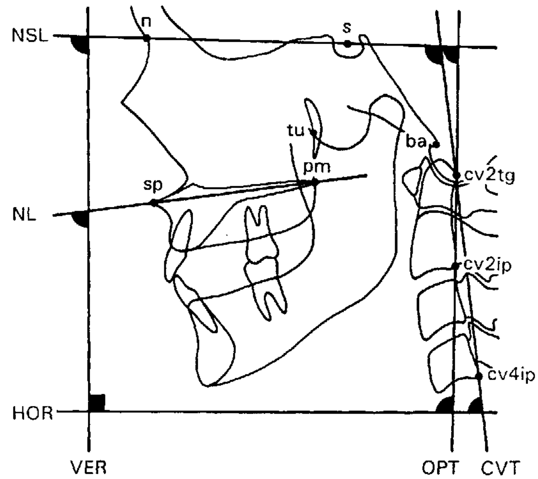

Figure 1 Skeletal reference points and lines. ba = basion, the most postero-inferior point on the basilar part of the occipital bone. cv2ip = the most postero-inferior point on the corpus of the cv2. cv2tg = the tangent point, on the dorsal contour of the odontoid process of cv2, to a line from cv2ip. cv4ip = the most postero-inferior point on the corpus of the cv4. n = nasion, the most anterior point of the frontonasal suture. pm = pterygomaxillare, the intersection between the nasal floor and the dorsal contour of the maxilla. s = sella, the centre of the sella turcica. sp = the apex of the anterior nasal spine. tu = tuber maxillae, the most dorsal point of the maxillary tuberosity. Reference lines: NL = nasal line, through sp and pm. NSL = nasion–sella line. CVT = cervical vertebra tangent, through cv4ip and cv2tg. OPT = odontoid process tangent, through cv2ip and cv2tg. HOR = a line perpendicular to VER. VER = the gravity-determined vertical. Some postural angles are indicated.

Statistical procedures

Differences in means within samples were tested by paired *t*-tests and between samples by unpaired *t*-tests after F-tests for equal or unequal variances. Associations between variables were assessed with Pearson product-moment correlation coefficients.

Results

Mean differences in airway diameters

The average airway diameters in the OSA sample (Table 3) were significantly smaller than

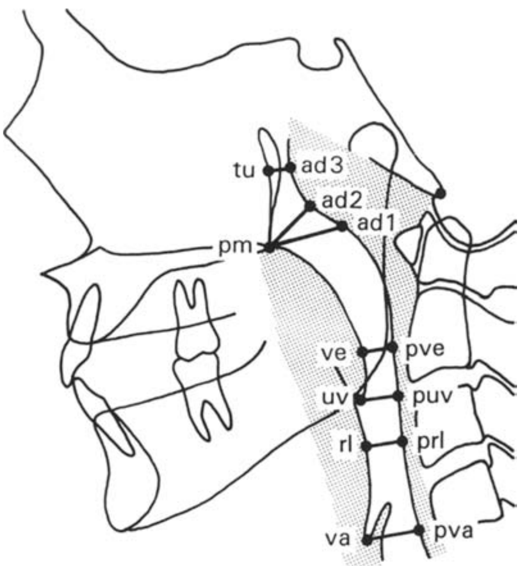

Figure 2 Pharyngeal reference points. ad1 = the intersection of a line from pm to ba with the adenoid tissue/dorsal pharyngeal wall. ad2 = the point on the adenoid tissue/dorsal pharyngeal wall closest to pm. ad3 = the point on the adenoid tissue/dorsal pharyngeal wall closest to tu. pve, puv, prl, pva = the points on the dorsal pharyngeal wall closest to ve, uv, rl and va respectively. rl = radix linguae, the point on the root of the tongue closest to the dorsal pharyngeal wall. uv = uvula, the tip of the uvula of the soft palate. va = the vallecula epiglottis. ve = velum palati, the point on the soft palate closest to the dorsal pharyngeal wall.

Table 2 Method errors for airway diameters: distributions of differences between duplicate measurements.

Variable	Min	Max	Mean	*P*	SE	s(i)	cr
tu–ad3	−3.09	2.03	−0.07	NS	0.36	0.98	0.75
pm–ad2	−3.96	2.84	−0.19	NS	0.40	1.11	0.90
pm–ad1	−2.37	2.02	−0.07	NS	0.33	0.91	0.91
ve–pve	−1.37	1.97	0.03	NS	0.25	0.67	0.95
uv–puv	−2.80	2.10	−0.12	NS	0.30	0.82	0.92
rl–prl	−2.55	1.89	0.15	NS	0.32	0.87	0.93
va–pva	−1.69	2.90	−0.29	NS	0.27	0.77	0.90

Sample size for method error: N = 16. Method error: $s(i) = \sqrt{\Sigma d^2/2N}$, where d is the difference between duplicate measurements. cr: coefficient of reliability $= 1 - s(i)^2/s^2$, where s^2 is the variance of the total sample (N = 103).
NS = not significant.

in the reference sample at several levels of the pharyngeal airway, most pronounced at the level of the narrowest diameter behind the soft palate, ve–pve, which was only approximately half the diameter in the reference sample ($P < 0.001$). The differences decreased in magnitude cranially as well as caudally. The most narrow airway diameter behind the root of the tongue, rl–prl, which corresponds to the commonly used PAS diameter did not differ between the samples.

Airway dimensions and head posture

The relation between head posture and airway dimensions was studied by correlation analysis in the two samples. In the OSA sample, the correlations between airway diameters and head posture showed a systematic pattern of significant associations indicating that on average, a narrow airway diameter at the three most caudal sites studied, uv–puv, rl–prl and va–pva, was seen in connection with a large cranio-cervical angle and a forward inclination of the cervical column (Table 4). No significant associations were found between airway diameters and the cranio-vertical angles.

In the reference sample, no associations were found between the postural angles and the diameters behind the soft palate or the root of the tongue. Only the most caudal diameter, at the epiglottis, va–pva, showed a set of low correlations with the cranio-cervical angles and moderate correlations with cervical inclination. No significant associations were found between airway diameters and the cranio-vertical angles (Table 5).

Discussion

In the present study of head posture and airway dimensions in OSA, a reference sample matched with regard to age could not be obtained for ethical reasons. The OSA sample was therefore compared with radiographs from a previous study of young adults in which cephalometric recordings had been made in the natural head posture (Solow and Tallgren, 1971). In a previous study of OSA patients (Solow *et al.*, 1993) a comparison had been made of the average cranio-cervical angle reported in earlier studies in which cephalometric radiographs had been recorded in the natural head posture. In addition to the reference sample used in the present investigation, these studies comprised Finnish male students, Finnish young, middle-aged and old women recorded in the sitting position, and a sample of congenitally blind. The average cranio-cervical angle varied by only a few

Table 3 Airway diameters in the obstructive sleep apnoea (OSA) sample and the reference sample.

	OSA			Reference sample				
	N	Mean	SD	N	Mean	SD	Mean diff.	F-ratio
tu–ad3	50	11.10	3.20	99	9.10	1.85	2.00***	3.00**
pm–ad2	50	21.44	3.97	103	23.15	3.23	−1.71**	1.51*
pm–ad1	50	22.82	3.50	103	25.69	2.90	−2.87***	1.46
ve–pve	50	5.16	2.34	101	10.09	2.80	−4.93***	1.43
uv–puv	50	9.51	3.09	100	11.79	2.77	−2.28***	1.25
rl–prl	48	10.17	3.54	103	9.30	3.06	0.86	1.34
va–pva	34	17.55	5.23	88	18.59	2.27	−1.04	5.29**

The dimensions have been corrected for linear radiographic enlargement.
* $P<0.05$; ** $P<0.01$, *** $P<0.001$.

Table 4 Head posture and airway diameters: correlation coefficients of obstructive sleep apnoea (OSA) sample.

	NSL/VER	NL/VER	NSL/OPT	NL/OPT	NSL/CVT	NL/CVT	OPT/HOR	CVT/HOR
tu–ad3	−0.23	−0.16	0.09	0.15	0.12	0.21	−0.23	−0.30
pm–ad2	−0.01	0.00	0.04	0.05	0.06	0.08	−0.05	−0.09
pm–ad1	0.14	−0.01	0.12	0.03	0.08	0.01	−0.03	−0.01
ve–pve	0.09	−0.02	0.05	0.09	0.04	0.17	−0.10	−0.17
uv–puv	0.01	0.19	0.40**	0.51***	0.40*	0.55***	−0.40**	−0.44**
rl–prl	0.01	0.23	0.43**	0.55***	0.44**	0.60***	−0.43*	−0.48**
va–pva	0.12	0.02	0.39*	0.33	0.51	0.45*	−0.33	−0.45*

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

Table 5 Head posture and airway diameters: correlation coefficients of reference sample.

	NSL/VER	NL/VER	NSL/OPT	NL/OPT	NSL/CVT	NL/CVT	OPT/HOR	CVT/HOR
tu–ad3	−0.09	0.02	−0.04	0.05	0.00	0.09	−0.03	−0.07
pm–ad2	−0.07	0.10	−0.17	−0.04	−0.13	0.02	0.12	0.07
pm–ad1	0.01	0.06	−0.17	−0.14	−0.19	−0.16	0.18	0.22*
ve–pve	0.06	0.04	−0.11	−0.14	−0.11	−0.13	0.16	0.17
uv–puv	0.07	0.07	0.02	0.01	0.01	0.01	0.04	0.05
rl–prl	−0.01	0.09	0.05	0.14	0.09	0.18	−0.06	−0.10
va–pva	−0.20	−0.16	0.25*	0.31**	0.23*	0.28**	−0.43***	−0.43***

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

degrees among these samples. The broad range of samples and methods provides a certain degree of control for the possible effects of age, sex, recording procedure and the influence of normal vision on head posture.

The assessment of pharyngeal airway diameters from cephalometric radiographs raises some technical problems. The projection geometry must be precisely defined and preferably constant, so that the enlargement of linear dimensions can be compensated for in order to permit the calculation of sample statistics, and the comparison of samples from different studies. In the present study a fixed focus-to-median plane distance of 180 cm was used in both samples studied. The film-to-median plane distance was constant in each sample but differed between the samples. Therefore linear dimensions were reduced to actual size in both samples before statistical comparison.

During the recording of the cephalometric radiograph, the sagittal posture of the head as well as the cervical column must be well defined since it is possible that differences in craniocervical posture will influence the diameters of the pharyngeal airway. The ear-rods of a cephalometer ensure that the median sagittal plane of the patient is coincident with the midplane of the cephalometer, thus establishing one of the fixed planes in the projection geometry. The sagittal tilt of the head and of the cervical column, on the other hand, are determined by the positioning procedures employed by the radiographic operator. Traditionally, many operators place the Frankfort plane, determined by the transmeatal axis and the left infraorbital point, in a horizontal position, because this plane, on average, is parallel to the true horizontal in a normal sample. This procedure is not suitable for studies of natural head posture because the individual variability in posture, which is of particular relevance in OSA patients and other patient groups with obstruction of the upper airways, is thereby eliminated. In the positioning procedure it is important, moreover, that the head is not moved forwards or backwards by the operator to fit the ear-rods of the cephalometer, because this will influence cervical posture. In the present study, the positioning in both samples was based on the procedure described in detail by Siersbæk-Nielsen and Solow (1982), aimed at producing an unstrained reproducible position of the head as well as of the cervical column (the mirror position).

The definition of reference points on the soft tissue contours of the pharyngeal airway raises special problems. Most cephalometric studies of airway diameters in OSA have used conventional skeletal reference points to define lines along which airway diameters were measured (e.g. B–Go line, ANS–PNS line, Frankfort plane, mandibular plane, occlusal plane, etc.). From a physiological point of view, it would seem more relevant to determine airway diameters perpendicularly to the direction of the pharyngeal airway, and at homologous positions defined by the anatomy of the airway itself. Reference lines determined by the facial skeletal morphology are usually not perpendicular to the direction of the airway, and thus do not represent minimum cross-sections at the levels of intersection with the airway. Moreover, the intersections of such lines with the anterior pharyngeal wall do not represent homologous points in different subjects. To overcome these disadvantages, the definitions of airway diameters developed in the present study differ somewhat from those used in most previous studies: (i) instead of measuring soft-tissue diameters along or parallel to reference lines extended dorsally from the facial skeleton, soft-tissue diameters nos. 1–2 and 4–7 were measured perpendicularly to the direction of the airway at each level; (ii) the levels chosen were based on anatomical features of the anterior limitation of the pharyngeal airway: the most dorsal point of the maxillary tuberosity (tu), the posterior nasal spine (pm), the most dorsal point of the soft palate (ve), the tip of the uvula (uv), the most dorsal point of the base of the tongue below the soft palate (rl), and the vallecula of the epiglottis (va). Although some authors have used some of these reference points before in studies of OSA patients, the principle does not seem to have been applied systematically in previous studies.

The screening of the pharyngeal airway diameters showed that whereas in the reference sample the most narrow diameter in the oropharynx was found at the base of the tongue, the most narrow, and dramatically reduced, diameter in the OSA sample was found behind the soft palate. This dimension also showed the largest difference between the OSA and the reference samples, almost a 50 per cent reduction from 10.1 to 5.2 mm. This finding, that the most narrow oropharyngeal airway diameter in the upright awake OSA patient is situated at the level determined by the most dorsal point of the soft palate, confirms endoscopic observations reported by Borowiecki *et al.* (1978) and Rojewski *et al.* (1984).

The PAS dimension measured along the B-Go line represents a more or less oblique diameter of the pharyngeal airway, usually located at the base of the tongue. Jamieson *et al.* (1986) reported a mean PAS of 5.1 mm in their sample of OSA patients, and 10.8 mm in a reference sample. However, some recent studies comparing this dimension in OSA and reference samples found only small differences in this dimension: Lowe and Fleetham (1991), 13.3 versus 14.3 mm; Andersson and Brattström (1991), 11.1 versus 13.3 mm; Petri *et al.* (1994), 10.6 versus 10.6 mm. The reason for the different results in the early studies of the PAS dimension in OSA subjects is not entirely clear, but could perhaps be related to some of the technical problems mentioned above. Our finding, that there was no significant difference between the cephalometrically determined posterior airway space rl-prl in the OSA patients and in the reference sample, is in agreement with those of the more recent studies.

The correlation analysis in the OSA sample showed a clear pattern of associations: a large cranio-cervical angle was, on average, seen in connection with larger than average airway diameters from the level of the uvula down to the level of epiglottis. This can be interpreted as an indication of a compensatory physiological mechanism in these patients, in which the extended cranio-cervical relation serves to lift away the base of the tongue and the soft palate from the posterior pharyngeal wall in order to alleviate the obstructive condition.

A previous study of head posture in OSA patients (Solow *et al.*, 1993) showed that the average cranio-cervical angulation was much larger in the OSA sample than in six reference samples. When the present findings from the analysis of the mean differences in airway dimensions are combined with those from the correlation analysis, it appears that the mechanism described above operates most efficiently on the most caudal diameters: At the epiglottis level and at the base of the tongue there are no significant mean differences in diameter between the samples, probably due to the extended cranio-cervical angle in the OSA sample. At the more coronal level of the soft palate, there are still reduced diameters in the OSA sample. Probably the extended head posture in the OSA subjects has restored the most caudal airway diameters to within normal range, whereas this has not been possible for the more coronal diameters behind the soft palate.

The correlations between posture and airway diameters in the reference sample showed a more sparse set of associations, which occurred essentially at the lowest level studied, the airway diameter at epiglottis. This confirms the findings from the OSA sample, that the mechanism, by which cranio-cervical extension opens the pharyngeal diameters, operates most efficiently at the lowest of the levels studied. This observation is also in agreement with simple geometric considerations: the longest arc is described by the point farthest away from the fulcrum of the tilting of the head on the cervical column, the atlanto-occipital joint (Fig. 3). Similar associations between cranio-cervical angulation and the lowest pharyngeal diameters in normal subjects have previously been demonstrated in experimental studies in which the subjects were recorded with their head positioned at different degrees of extension and flexion (Davies and Stradling, 1990; Hellsing, 1991).

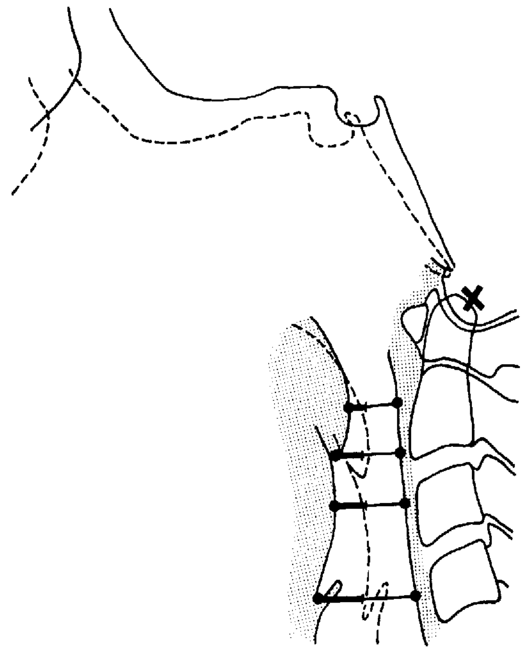

Figure 3 Graphical simulation of the effect of extension of the head on the oropharyngeal airway diameters. The tracing of the head and the anterior pharyngeal structures was rotated in the atlanto-occipital joint in relation to the cervical column. Due to geometrical factors, the effect (heavy line segments) is largest at the sites most remote from the fulcrum (X) at the joint. The extension can be obtained by lifting the head, as illustrated, by proclination of the cervical column, or by a combination.

The scarcity of correlations in the reference sample in comparison with the OSA sample is probably also related to the fact that the cranio-cervical postural angles in the reference sample were located at a much lower range (NSL/OPT: 73–105 degrees, (Solow and Tallgren, 1971), than those in the OSA sample (89–131 degrees, (Solow *et al.*, 1993)). Obviously a large increase in cranio-cervical angulation is required in order to produce an increase in the airway diameters at the levels of the soft palate and the base of the tongue, the sites where OSA obstructions most often occur.

The insight into the postural mechanisms that apparently serve to maintain airway adequacy in the awake prone OSA patient raises several questions: when do these postural changes start, why do they start, and can they be detected early, so that preventive measures could be initiated? Probably long-term longitudinal studies of subjects recorded in the natural head posture would be required to answer such questions.

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