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Cephalometric evaluation of children with nocturnal sleep-disordered breathing

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SUMMARY The present study aimed to assess the cephalometric features in children with sleep-disordered breathing (SDB). The subjects were 70 children (34 boys and 36 girls, mean age 7.3, SD 1.72, range 4.2–11.9 years) with habitual snoring and symptoms of obstructive sleep disorder for more than 6 months. On the basis of overnight polygraphic findings, the subjects were further divided into subgroups of 26 children with diagnosed obstructive sleep apnoea (OSA), 17 with signs of upper airway resistance syndrome (UARS), and 27 with snoring. A control group of 70 non-obstructed children matched for age and gender was selected. Lateral skull radiographs were taken and cephalograms were traced and measured. The differences between the matched groups were studied using *t*-test for paired samples. Differences between the subgroups were studied using analysis of variance followed by Duncan's multiple comparison method.

Children with SDB were characterized by an increased antero-posterior jaw relationship ($P = 0.001$), increased mandibular inclination in relation to the palatal line ($P = 0.01$), increased total ($P = 0.019$) and lower ($P = 0.005$) anterior face heights, a longer ($P = 0.018$) and thicker ($P = 0.002$) soft palate, smaller airway diameters at multiple levels of the naso- and oropharynx, larger oropharyngeal airway diameter at the level of the base of the tongue ($P = 0.011$), lower hyoid bone position ($P = 0.000$), and larger craniocervical angles (NSL–CVT, $P = 0.014$; NSL–OPT, $P = 0.023$) when compared with the non-obstructed controls.

When divided into subgroups according to the severity of the disorder, OSA children deviated significantly from the control children especially in the oropharyngeal variables. Children with UARS and snoring also deviated from the controls, but the obstructed subgroups were not confidently distinguishable from each other by cephalometric measurements. Logistic regression analysis indicated that UARS and OSA were associated with decreased pharyngeal diameters at the levels of the adenoids (PNS–ad1) and tip of the uvula (u1–u2), an increased diameter at the level of the base of the tongue (rl1–rl2), a thicker soft palate, and anteriorly positioned maxilla in relation to the cranial base.

Lateral cephalogram may thus reveal important predictors for SDB in children. Attention should be paid to pharyngeal measurements. Systematic orthodontic evaluation of SDB children is needed because of the effects of obstructed sleep on the developing craniofacial skeleton.

Introduction

Snoring, upper airway resistance syndrome (UARS), and obstructive sleep apnoea (OSA) are gaining more attention in the field of paediatrics, since they lie behind a spectrum of sleep-related breathing disorders, which may have deleterious health implications if untreated (Guilleminault *et al.*, 1996; Guilleminault, 2001; Carroll, 2003; Baldassari *et al.*, 2008).

Snoring has been reported in about 10 per cent of preschool children (Carbo *et al.*, 1989; Teculescu *et al.*, 1992; Ali *et al.*, 1993, 1994). Habitual snoring may progress into OSA, which is characterized by recurrent cessation of airflow during sleep due to upper airway collapse (Guilleminault and Stoohs, 1990). OSA has been estimated to occur in about 0.7–2.9 per cent of preschool children (Ali *et al.*, 1993, 1994; Gislason and Benediktsdottir, 1995; Löfstrand-Tideström *et al.*, 1999). UARS refers to increased nocturnal upper airway collapsibility that is not severe enough to meet the diagnostic criteria of OSA (Bao and Guilleminault, 2004). It has been stated that UARS is more common in children than OSA (Guilleminault and Khramtsov, 2001). The prevalence of sleep-disordered breathing (SDB) is probably higher than previously believed since there has been a lack of widely accepted standards for diagnosing UARS and OSA in the paediatric age group (Carroll, 2003; Lumeng and Chervin, 2008).

Children with UARS or mild OSA are not always detected since the symptoms of the disorder can be insidious (Guilleminault, 2001). Children with suspected SDB are commonly seen in dental practices, and orthodontists have an important role in recognizing these subjects. Cephalometric analysis on lateral radiographs is widely used in the field of orthodontics to record craniofacial form. A lateral cephalogram is generally used in adults with obstructive symptoms as a screening tool for assessing craniofacial pattern and upper airway morphology in order to identify the subjects at risk for OSA and to study the efficacy of treatment options (deBerry-Borowiecki *et al.*, 1988; Rintala *et al.*, 1991; Hochban and Brandenburg, 1994; Battagel and L'Estrange, 1996).

Several cephalometric studies in children with OSA have shown specific craniofacial characteristics (e.g. a vertical growth pattern of the mandible, retrognathia of both maxilla and mandible, smaller cranial base angle, and reduced antero-posterior (AP) linear dimensions of the bony nasopharynx) that may influence upper airway patency and contribute to the disorder (Shintani *et al.*, 1996; Ågren *et al.*, 1998; Löfstrand-Tideström *et al.*, 1999; Zucconi *et al.*, 1999; Finkelstein *et al.*, 2000; Kawashima *et al.*, 2000, 2002; Zettergren-Wijk *et al.*, 2006). The craniofacial structure may predispose to the pharyngeal occlusion, but soft tissue changes including adenotonsillar enlargement, structural narrowing of the upper airway, and abnormal neuromuscular tone during sleep are considered essential factors for the development of OSA in children (Shintani *et al.*, 1996; Isono *et al.*, 1998; Fregosi *et al.*, 2003; Katz and D'Ambrosio, 2008).

Little attention has been paid to craniofacial and pharyngeal morphology in children with mild nocturnal breathing disorders even though there is still a lack of information as to why snoring and sleep disruption may, in some children, develop into OSA. The purpose of the present study was to identify the distinct craniofacial features that characterize children with SDB. A further aim was to assess the effects of obstructed sleep on craniofacial variables when divided into subgroups according to the severity of the disorder and also to test the validity of cephalometric predictors to identify the children at risk for UARS and OSA. The hypothesis was that children with severe obstruction would have larger deviations from normal than less obstructed children.

Subjects and methods

The study protocol was approved by the Ethical Committee of Oulu University Hospital, Finland. An informed consent was obtained from the parents or guardians and a verbal assent from the children before they entered the study.

Subjects

The sample was selected from children who were referred by general practitioners to the Department of Otorhinolaryngology of Oulu University Hospital because of snoring problems or suspicion of sleep apnoea during 2000–2002. Parents responded to a questionnaire about their perception of the children's nocturnal sleeping and snoring habits and possible difficulties in breathing during sleep before the clinical examination. The final sample selection was made by one otorhinolaryngologist (HL) on the basis of anamnestic records and clinical examination. Good general health, normal weight, prepubertal age, and no previous orthodontic treatment were presumed for inclusion. Children with known upper airway anomalies, abnormal development, chronic or recurrent infections (for example tonsillitis or sinusitis), asthma, or perennial allergy were excluded. All 70 selected children (34 boys and 36 girls) who had a history of habitual snoring for more than 6 months were evaluated by overnight polygraphy (PG). The mean age of the study group was 7.3 (SD 1.72) years and the age range 4.17–11.96 years. The weight and height were measured at the time of the medical examination in order to calculate the body mass index (weight in kilograms divided by height in square metres) for each child.

For ethical reasons, cephalometric radiographs could not be obtained from non-symptomatic control children. Instead, the study data were compared with previously obtained cephalograms of 70 randomly selected age- and gender-matched children at the Oulu health centre before they entered orthodontic treatment during 2002. Before undergoing the orthodontic examination, the parents filled out a detailed questionnaire regarding their child's nocturnal and daytime obstructive symptoms and medical history. Children with a history of snoring, respiratory, or health-related problems were excluded. Skeletal type was defined in the AP plane of space, but inclusion criteria were not based on skeletal jaw relationship. In the control group, 72.9 per cent of the children had a Class I skeletal type (balanced skeletal jaw relationship) and 27.1 per cent a Class II (the mandible was positioned distally relative to the maxilla) malocclusion, which is about the average prevalence in the Finnish population in this age group (Myllärniemi, 1970; Keski-Nisula *et al.*, 2003). None of the examined children had a Class III skeletal type. The prevalence of Class III malocclusion in Finnish prepupertal population is relatively low (Myllärniemi, 1970). The control children did not undergo PG assessment since they had no history of snoring or respiratory problems. Obstructive apnoeas are rare in asymptomatic non-snoring children (Marcus *et al.*, 1992; Nieminen *et al.*, 2000). The mean age in the control group was 7.3 (SD 1.81) years, range 4.67–11.81 years.

On the basis of the PG findings, children in the SDB group were further divided into three subgroups according

to the severity of the disorder. The first group consisted of children with diagnosed OSA (n = 26), the second group children with UARS (n = 17), and the third group snoring children (n = 27). Demographic data for the examined groups are presented in Table 1.

Methods

Overnight PG. Children with suspected SDB were evaluated by overnight PG in order to determine the incidence of breathing abnormalities and oxygen saturation. Polygraphic monitoring was carried out in hospital under the surveillance of a trained nurse. The children were accompanied by a parent through the night.

A six-channel computerized PG device developed by the Department of Clinical Neurophysiology of Oulu University Hospital with leads for an oronasal thermistor (qualitative measurement of oronasal airflow), a pulseoximeter (oxygen saturation and pulse waveform), a thoracoabdominal strain gauge (measurement of thoracoabdominal movement), leg electromyography, a body-position sensor, and a static charge-sensitive bed was used.

PG analysis was undertaken by one neurophysiologist (UT). Despite the possibility for automatic analysis of nocturnal events, all recordings were checked manually. An obstructive apnoeic episode was defined as total cessation of oronasal airflow with continued respiratory effort for 10 seconds or more. An obstructive hypopnoea period was determined as at least a 50 per cent decrease in oronasal airflow signal with continued chest wall motion lasting 10 seconds or more. Mixed apnoea was defined as a cessation in oronasal airflow signal lasting 10 seconds or more at the beginning of the apnoea with absence of chest wall motion but with respiratory effort in the latter part of the apnoea.

The severity of possible OSA was expressed using the obstructive apnoea–hypopnoea index (AHI), which was calculated as the sum of obstructive and mixed apnoeas and hypopnoeas per hour of sleep during PG registration. Based on previous findings in younger children, AHI was considered abnormal when the value was greater than 1, which was used as the criterion for OSA (Carroll and Loughlin, 1992; Marcus *et al.*, 1992; Rosen *et al.*, 1992; Nieminen *et al.*, 2000; Carroll, 2003).

To detect periods of increased upper airway respiratory resistance outside of clinically significant apnoeas and hypopnoeas, an indirect method was used. The PG recordings were manually checked for both periodic ventilation restrictions and single long-lasting ventilation restrictions with a less than a 50 per cent amplitude decrease and flattening in the oronasal signal. Episodes linked with a pulse increase and amplitude increase as well as sharpening of the oronasal signal at the termination of the events were interpreted as UAR episodes. These respiratory-induced pulse increases indicate arousals and may be linked to UARS.

Cephalometric methods. The lateral radiographs in both the study and control groups were taken in the same Cephalix cephalostat (Tagarno A. S., Horsens, Denmark) at the Department of Oral Radiology at the University of Oulu. The distance from the focus to the median plane was 200 cm and the median plane–film distance was 10 cm, giving an enlargement of the midline structures of 5.0 per cent. Since the magnification was the same for all radiographs, the enlargement factor was disregarded. Lateral cephalometric radiographs were taken with the subjects standing, the head fixed in the cephalostat with ear rods and a support on the forehead, the teeth in the maximum intercuspal position, the lips in a relaxed position, and the head in the natural position. The true vertical was indicated on the films with a 1.5 mm weighted metal band mounted in front of the cassette during radiographic exposure.

Definitions of cephalometric landmarks, reference lines, and cephalometric measurements are presented in Figure 1. Conventional cephalometric landmarks, reference lines, and measurements were used for skeletal structures. The nasopharyngeal airway was measured according to the analysis of Linder-Aronson (1970). Oropharyngeal airway, soft palate, and hyoid bone variables were measured as previously described by Solow *et al.* (1996). Craniocervical

Table 1 Descriptive data for the subgroups of children with sleep-disordered breathing (SDB) [obstructive sleep apnoea (OSA); upper airway resistance syndrome (UARS)] and control children.

	Children with SDB (n = 70)			Control group (n = 70)
	OSA group (n = 26)	UARS group (n = 17)	Snoring group (n = 27)	
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Age (years)	7.7 (1.91)	6.9 (1.64)	7.3 (1.61)	7.3 (1.78)
Male:female ratio	14:12	11:6	9:18	34:36
Body mass index (kg/m^2)	16.6 (3.46)	16.0 (3.00)	16.8 (2.52)	16.6 (2.23)
Apnoea–hypopnoea Index	2.5 (1.18)	0.3 (0.25)	0.2 (0.10)	—
Skeletal type (Class I:Class II)	8:18	9:8	12:15	51:19

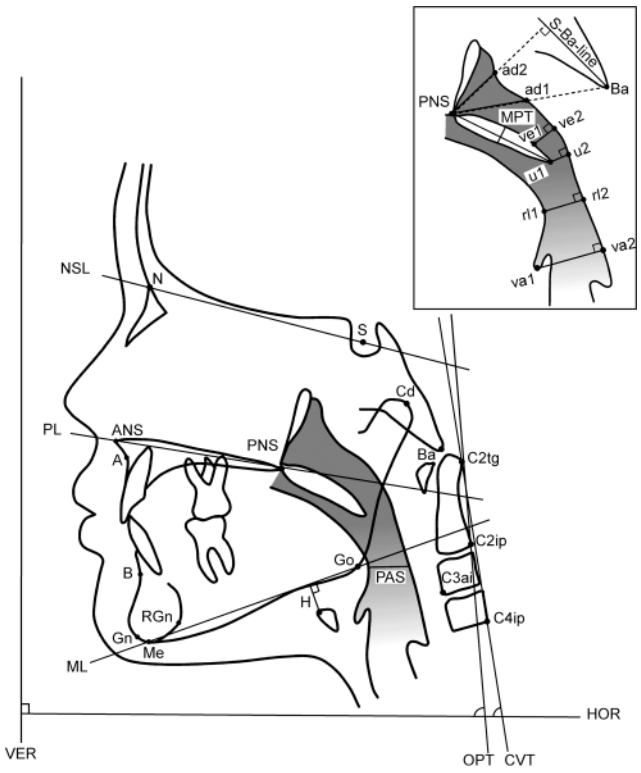

Figure 1 Reference points and lines on the cephalograms. *Skeletal landmarks*—ANS: anterior nasal spine, the most anterior point of the bony nasal floor; Ba: basion, the most inferior posterior point in the midsagittal plane on the anterior rim of the foramen magnum; Cd: condylion, the most postero-superior point of the mandibular condyle; C4ip: fourth cervical vertebrae, the most postero-inferior point on the fourth cervical vertebrae; Gn: gnathion, the most antero-inferior point in the contour of the bony chin; Go: gonion, a midplane point at the gonial angle located by bisecting the posterior and inferior borders of the mandible; H: hyoid bone, the most antero-superior point on the body of the hyoid bone; Me: menton, the most inferior point of the symphysis; N: nasion, the most anterior point of the frontonasal suture; C2tg: odontoid process tangent, the tangent point, on the dorsal contour of the odontoid process of C2, to a line from C2ip; PNS: posterior nasal spine, the most posterior point of the bony hard palate; RGn: retrognathion, the most postero-inferior point on the mandibular symphysis; C2ip: second cervical vertebrae, the most postero-inferior point on the second cervical vertebrae; S: sella, the central point of sella turcica; B: supramentale, the most inferior point on the anterior mandibular contour; A: subspinale, the most posterior point on the concave outline of the upper labial alveolar process; C3ai: third cervical vertebrae, the most antero-inferior point on the third cervical vertebrae. Reference lines—NSL: nasion–sella line, the line through nasion and sella; ML: mandibular line, the line through menton and gonion; PL: palatal line, the line through ANS and PNS; CVT: cervical vertebra tangent, the line through C4ip and C2tg; OPT: odontoid process tangent, the line through C2ip and C2tg; HOR: horizontal line, the line perpendicular to the gravity-determined vertical; *Craniofacial measurements*—SNA: antero-posterior position of the maxilla in relation to the anterior cranial base (the angle between the lines S–N and N–A); SNB: antero-posterior position of the mandible in relation to anterior cranial base (the angle between the lines S–N and N–B); ANB: antero-posterior position of the mandible in relation to the maxilla (the angle between the lines A–N and N–B); NSL–ML: inclination of the mandible in relation to the anterior cranial base (the angle between the N–S line and the mandibular line); PL–ML: intermaxillary inclination of the jaws (the angle between the palatal line and the mandibular line); ANS–PNS: palatal length (the distance from ANS to PNS); Cd–Gn: mandibular length (the distance from Cd to Gn); N–Me: total anterior face height (the distance from N to Me); ANS–Me: lower anterior face height (the distance from ANS to Me); S–Go: posterior face height (the distance from S to Go); N–S–Ba: anterior cranial base angle (the angle between the lines N–S and S–Ba); *Pharyngeal measurements*—PNS–ad1: distance from PNS to the nearest adenoid tissue measured along the line PNS–Ba; PNS–ad2: distance from PNS to the nearest adenoid tissue measured along the line through PNS perpendicular to S–Ba; ve 1–ve2: minimal distance from the velum palatine to the posterior pharyngeal wall measured perpendicular to the direction of the airway; u1–u2: airway space on a line from the tip of uvula to the posterior pharyngeal wall measured perpendicular to the direction of the airway; rl 1–rl2: minimal distance from the radix linguae (base of the tongue) to the posterior pharyngeal wall measured perpendicular to the direction of the airway; va 1–va2: Distance from the vallecula epiglottis to the posterior pharyngeal wall measured perpendicular to the direction of the airway; PNS–Ba: linear distance from PNS to Ba; PAS: posterior airway space measured between the posterior pharyngeal wall and the dorsum of the tongue on a line joining the gonion (Go) to the supramentale (B); PNS–u1: soft palate length [the linear distance between PNS and u1, the tip of the soft palate (uvula)]; MPT: maximum palatal thickness (the maximal thickness of the soft palate measured on a line perpendicular to the PNS–U–line); Hyoid bone position—H–ML: vertical position of the hyoid bone (perpendicular distance of the hyoid point from the mandibular line); H-C3ai: antero-posterior position of the hyoid bone [linear distance from the hyoid point to the third cervical vertebra (antero-inferior)]; H–RGn: antero-posterior position of the hyoid bone (linear distance from the hyoid point to the retrognathion); *Craniocervical measurements*—NSL–CVT: craniocervical angulation (the angle between the nasion–sella line and the CVT–line); NSL–OPT: craniocervical angulation (the angle between the nasion–sella line and the OPT–line); CVT–HOR: cervical inclination (the angle between the CVT–line and the true horizontal line); OP T–HOR: cervical inclination (the angle between the OPT line and the true horizontal line); OP T–CVT: the curvature of the cervical column (the angle between the lines OPT and CVT).

posture was assessed using the method of Solow and Tallgren (1976).

Cephalometric measurements included 11 morphologic, 10 airway, three hyoid bone position, and five postural variables. In total, there were 11 angular and 18 linear measurements. The measurements were calculated to the nearest 0.5 mm or 0.5 degrees. Cephalograms were traced and measured manually by an orthodontist (KP-P), who was blinded to the results of the clinical and PG data.

Assessing the method errors. Twenty-five radiographs chosen at random were traced and measured on two separate occasions by the same author (KP-P) at least 4 weeks apart in order to calculate the error of the method, which was determined by intraclass correlation coefficients (ICC) using an absolute agreement definition. ICC varied from 0.937 to 0.995 for angular measurements and from 0.932 to 0.997 for linear measurements, indicating a satisfactory level of intra-investigator reliability.

Statistical analysis

The differences between the matched pairs (cases and controls) were tested for statistical significance with a *t*-test for paired samples. The SDB group was then divided into three subgroups (OSA, UARS, and snoring children) on the basis of PG findings. Because of the significant disparity in the ages and genders of the subgroups and the control group, age- and gender-adjusted differences between the groups were examined using analysis of variance. There was no

significant age or gender difference in craniofacial angular, pharyngeal, or craniocervical measurements between the subgroups and the controls. These differences were further tested using analysis of variance followed by Duncan's multiple comparison method. For craniofacial linear and hyoid bone measurements, paired differences between the cases and the controls were used in order to reduce the effects of age and gender when comparing SDB subgroups. Logistic regression analysis was used in order to identify the subjects at risk for OSA and UARS on the basis of cephalometric variables.

Results

Cephalometric comparison between children with SDB and control children

The AP jaw relationship (ANB, $P = 0.001$), mandibular inclination in relation to the palatal line (PL–ML, $P = 0.01$), total (N–Me, $P = 0.019$), and lower (PNS–Me, $P = 0.005$) anterior face heights were increased in children with SDB when compared with the control children. Naso- and oropharyngeal AP airway diameter was significantly smaller at the levels of PNS–ad1 ($P = 0.001$), PNS–ad2 ($P = 0.012$), ve1–ve2 ($P = 0.000$), and u1–u2 ($P = 0.000$) and larger at the level of rl1–rl2 ($P = 0.011$) in children with SDB than in the controls. The soft palate was longer (PNS–u1, $P = 0.018$) and thicker (MPT, $P = 0.002$) in children with SDB than in the control children. Hyoid bone position was lower in the SDB group when compared with the controls (H–ML, $P = 0.000$). Craniocervical angles were larger in the obstructed children than in the controls (NSL–CVT, $P = 0.014$; NSL–OPT, $P = 0.023$; Figure 2).

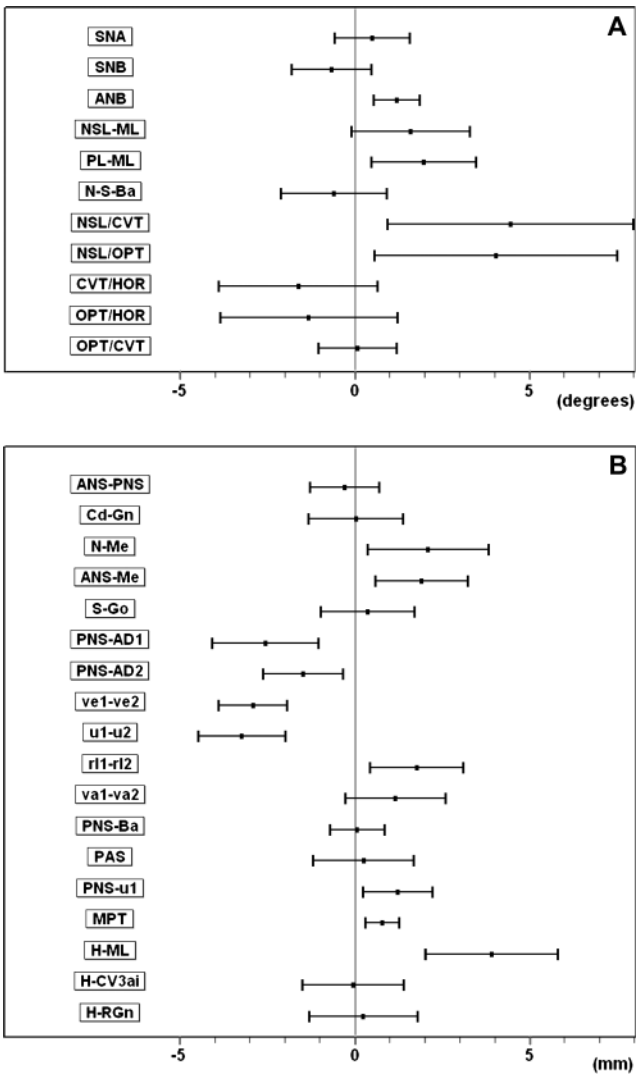

Figure 2 Paired differences (mean and 95 per cent confidence interval) in (A) angular (degrees) and (B) linear (millimetre) measurements between the children with sleep-disordered breathing (SDB; $n = 70$) and the control children ($n = 70$). Positive difference refers to the larger value of the measurement in the SDB group when compared with the controls and *vice versa*.

Cephalometric comparison between obstructed subgroups and control children

The position of the maxilla in relation to the anterior skull base (SNA) was more anterior in OSA children than in the snorers ($P < 0.05$). The position of the mandible in relation to the maxilla (ANB) was more posterior in OSA children than in the controls ($P < 0.01$). Mandibular inclination in relation to the anterior cranial base (NSL–ML) was increased in snoring children compared with UARS children ($P < 0.05$) and the controls ($P < 0.05$). Mandibular inclination in relation to the palatal plane (PL–ML) was also increased in snoring children when compared with the controls ($P < 0.05$; Table 2).

Nasopharyngeal AP airway at the line of PNS–ad1 was significantly smaller ($P < 0.05$) in OSA children when compared with the controls. The oropharyngeal AP airway at the levels of the velum palatine (ve1–ve2) and the tip of uvula (u1–u2) was significantly smaller in all groups of obstructive sleep disordered subjects when compared with the control children ($P < 0.01$), but there were no significant differences between the obstructed subgroups. The AP airway at the level of the base of the tongue (rl1–rl2) was significantly increased in children with diagnosed OSA compared with the UARS children ($P < 0.01$) and the controls ($P < 0.01$). The soft palate (MPT) was significantly thicker in UARS children when compared with OSA ($P < 0.01$), snoring ($P < 0.01$), and control ($P < 0.01$) children. There were no significant intergroup differences in craniocervical measurements between the subgroups with SDB and control children (Table 2).

There were no significant differences in craniofacial linear and hyoid bone measurements between the obstructed subgroups.

Table 2 Mean values, standard deviations (SDs), and significances of the difference for craniofacial angular, pharyngeal, and craniocervical measurements in children with diagnosed obstructive sleep apnoea (OSA), upper airway resistance syndrome (UARS), snoring children, and controls.

Variable	OSA group[A] (n = 26)	UARS group[B] (n = 17)	Snoring group[C] (n = 27)	Control group[D] (n = 70)	Statistical significance					
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	A–B	A–C	A–D	B–C	B–D	C–D
Craniofacial measurements										
SNA	82.9 (3.61)	81.9 (3.55)	80.7 (3.57)	81.3 (2.93)	—	*	—	—	—	—
SNB	77.3 (3.32)	77.1 (3.84)	75.6 (2.80)	77.2 (2.93)	—	—	—	—	—	—
ANB	5.7 (2.40)	4.8 (2.43)	5.1 (1.58)	4.0 (2.11)	—	—	**	—	—	—
NSL–ML	35.5 (4.62)	34.8 (4.15)	37.4 (3.69)	34.5 (4.68)	—	—	—	*	—	*
PL–ML	30.1 (4.63)	28.6 (3.25)	30.4 (3.55)	27.9 (4.20)	—	—	—	—	—	*
N–S–Ba	129.4 (4.25)	129.4 (4.04)	130.5 (5.06)	130.5 (4.48)	—	—	—	—	—	—
Pharyngeal measurements										
PNS–ad1	17.3 (6.20)	18.7 (4.01)	18.9 (5.62)	20.9 (3.92)	—	—	*	—	—	—
PNS–ad2	13.7 (4.70)	15.0 (3.93)	14.3 (4.23)	15.8 (3.30)	—	—	—	—	—	—
ve1–ve2	4.0 (3.01)	4.6 (2.09)	4.9 (2.81)	7.4 (2.89)	—	—	**	—	**	**
u1–u2	5.6 (3.34)	5.4 (3.20)	7.4 (3.63)	9.6 (3.39)	—	—	**	—	**	*
rl1–rl2	12.7 (3.76)	9.4 (3.32)	11.4 (3.85)	10.1 (3.05)	**	—	**	—	—	—
va1–va2	13.2 (3.75)	11.0 (2.61)	12.3 (3.42)	11.9 (3.44)	—	—	—	—	—	—
PAS	12.0 (5.30)	10.9 (3.58)	12.6 (4.61)	11.9 (3.98)	—	—	—	—	—	—
PNS–u1	28.4 (4.06)	28.9 (2.82)	28.9 (3.37)	27.7 (2.97)	—	—	—	—	—	—
MPT	8.2 (1.27)	9.4 (1.50)	8.1 (1.34)	7.6 (1.10)	**	—	—	**	**	—
Craniocervical measurements										
NSL–CVT	104.5 (13.02)	100.2 (9.57)	104.8 (7.83)	99.5 (9.26)	—	—	—	—	—	—
NSL–OPT	99.3 (12.7)	94.4 (8.72)	99.9 (8.02)	94.7 (9.70)	—	—	—	—	—	—
CVT–HOR	85.3 (8.72)	88.6 (8.29)	87.2 (7.25)	88.1 (6.33)	—	—	—	—	—	—
OPT–HOR	90.5 (8.75)	94.0 (7.65)	91.9 (7.24)	92.9 (7.27)	—	—	—	—	—	—
OPT–CVT	5.2 (2.80)	5.5 (2.98)	4.6 (3.22)	5.0 (2.99)	—	—	—	—	—	—

Statistically significant difference between the groups as determined by analysis of variance with Duncan's multiple comparison method, *$P < 0.05$, **$P < 0.01$. The superscripts (A–D) refer to the table of comparison.

Table 3 Parameter estimates of the logistic regression for upper airway resistance syndrome and obstructive sleep apnoea.

Variable	Coefficients	T	Significance
Constant	−94.03	13.79	0.000
SNA	0.96	13.23	0.000
PNS–ad1	−0.18	4.15	0.042
u1–u2	−0.54	12.01	0.001
rl1–rl2	0.64	11.44	0.001
MPT	1.81	11.75	0.001

Logistic regression analysis indicated that UARS and OSA in children were associated with decreased pharyngeal diameters at the levels of PNS–ad1, u1–u2, larger pharyngeal diameters at the level of rl1–rl2, thicker soft palates, and anteriorly positioned maxillae in relation to the cranial base (Table 3).

Discussion

The results of the present study indicate several differences in craniofacial and pharyngeal morphology between children with SDB and non-obstructed controls. The most significant differences were seen in pharyngeal measurements. When divided into subgroups according to the severity of the disorder, children with diagnosed OSA deviated most from the control children in cephalometric findings. Children with UARS and snoring symptoms also differed from the control children, but a gradation in relation to the severity of the disorder was only seen in a few pharyngeal measurements (PNS–ad1, ve1–ve2, and u1–u2), even though the differences between the subgroups were not statistically significant. This may be explained by some degree of overlap between the obstructed subgroups. Also the duration of SDB in the examined subjects may have varied and thus have some influence on the results.

Craniofacial assessment

The purpose of this study was to assess morphological and postural differences between children with SDB and non-obstructed controls. Since a Class II skeletal type is relatively common in the Finnish population (Myllärniemi, 1970; Keski-Nisula *et al.*, 2003), mandibular retrognathia would have been a very obvious finding if children with nocturnal breathing disorders had been compared with control children with an ideal occlusion and Class I skeletal type. This is the reason why skeletal or occlusal criteria were not used when

forming the control group. Despite this, OSA children were found to have an increased AP jaw discrepancy when compared with non-obstructed controls, which probably indicates some degree of genetic predisposition to the disorder.

Children with SDB had a significantly larger palatomandibular angle (PL–ML). In addition, total and lower anterior face heights were increased. These findings refer to the vertical growth pattern of the mandible, which has earlier been reported in OSA children (Ågren *et al.*, 1998; Löfstrand-Tideström *et al.*, 1999; Zucconi *et al.*, 1999; Kawashima *et al.*, 2000, 2002; Zettergren-Wijk *et al.*, 2006). When divided into subgroups, especially, snoring children were found to have more posteriorly inclined mandibles. A vertical growth direction of the mandible is a common finding in children with adenotonsillar hypertrophy (Linder-Aronson, 1970; Adamidis and Spyropoulos, 1983; Behlfelt *et al.*, 1990). Adenotonsillectomy has been shown to change the mode of breathing and improve mandibular growth direction in young children (Linder-Aronson *et al.*, 1986; Hultcrantz *et al.*, 1991; Ågren *et al.*, 1998; Zettergren-Wijk *et al.*, 2006), which supports the assumption that mandibular growth direction is secondary to chronic airway obstruction. It has also been hypothesized that decreased mandibular growth is caused by abnormal nocturnal secretion of growth hormone and its mediators in children with SDB (Peltomäki, 2007).

Previous studies in children with OSA have also found significant differences in cranial base measurements (Löfstrand-Tideström *et al.*, 1999; Finkelstein *et al.*, 2000; Özdemir *et al.*, 2004; Zettergren-Wijk *et al.*, 2006); however, this was not indicated by the present results.

Pharyngeal and hyoid bone assessment

There was no significant age or gender difference in the pharyngeal soft tissue variables measured. The size of the pharyngeal space, the diameter of the posterior nasopharyngeal wall, and the nasopharyngeal airway are reported to have high genetic contributions (Billing *et al.*, 1988). The sizes of the nasopharyngeal airway and adenoid tissue in particular are shown to follow an atypical growth pattern, reflecting more a reaction to infection than to tissue growth (Linder-Aronson and Leighton, 1983). Upper airway adequacy is shown to be maintained by a complex combination of morphological, postural, and physiological factors (Solow *et al.*, 1984, 1993, 1996).

Statistically, the most significant differences in the present study were found in pharyngeal measurements. Upper airway measurements revealed narrowing in the naso- and oropharynx at multiple levels in children with diagnosed OSA when compared with the non-obstructed controls. The narrowest AP airway diameter was seen at the level behind the soft palate. Children with UARS and snoring also had a significant decrease in airway size at the retropalatal area. Measurements at the caudal levels of the oropharynx showed a tendency for an increase in airway space in children with OSA. A significant increase in AP airway dimension was seen at the level of the base of the tongue in children with OSA when compared with UARS and control children. This can be explained by compensatory change in tongue position to maintain airway adequacy in OSA children in the upright posture due to enlarged tonsils. Lingual musculature is largely attached to the hyoid bone, the position of which was found to be lower in relation to the mandibular plane in children with OSA, supporting previous reports (Shintani *et al.*, 1996; Finkelstein *et al.*, 2000). Pharyngeal measurements (PNS–ad1, u1–u2, rl1–rl2, and MPT) also revealed important predictors when evaluating children with suspected treatment-requiring SDB as shown by logistic regression analysis.

Many cephalometric studies of children with OSA have focused on craniofacial deformities, while less attention has been paid to airway evaluation. Reduced nasopharyngeal airway space has previously been reported (Zucconi *et al.*, 1999; Kawashima *et al.*, 2000, 2002; Zettergren-Wijk *et al.*, 2006). According to current opinion, orovelopharyngeal factors, including palatal tonsils and decreased airway volume, are considered dominant in the development of nocturnal obstructive symptoms in children (Fernbach *et al.*, 1983; Suto *et al.*, 1996; Arens *et al.*, 2001; Fregosi *et al.*, 2003). Due to the lateral position of the palatal tonsils in the oropharynx, their size cannot be confidently computed on the lateral cephalogram. When visible on a cephalogram, large tonsils are usually seen at the level of the soft palate, where the most significant reduction in airway diameter (ve1–ve2 and u1–u2) was found in all subgroups with SDB. The present results are in accordance with the findings of Li *et al.* (2002), who reported that the tonsillar-pharyngeal ratio as assessed on lateral cephalograms correlates positively with the severity of OSA.

Posterior airway space (PAS) measurement, as defined by Riley *et al.* (1983), is widely used in adults with OSA to assess upper airway morphology on cephalometric radiographs. This measurement, which is the airway diameter behind the base of the tongue, is reported to be decreased in OSA adults (Jamieson *et al.*, 1986; Partinen *et al.*, 1988). The current findings showed no statistically significant difference in PAS dimension between the groups, indicating that PAS measurement has no diagnostic value in children with suspected SDB. Instead, there was a tendency for an increase in PAS values in OSA and snoring children when compared with the UARS subjects and control children. The PAS dimension is dependent on external reference points B and Go, and it is prone to several sources of error, such as mandibular inclination (Solow *et al.*, 1996). The pharyngeal measurements in the present study were mainly chosen on the basis of anatomical pharyngeal landmarks, and diameters were determined perpendicular to the direction of the upper airway as described by Solow *et al.* (1996).

In general, SDB was associated with a longer soft palate. Similar soft palate changes have previously been reported in OSA children (Kawashima *et al.*, 2002). Lower tongue position in SDB children may be a contributing factor to the longer soft palate since a close relationship between the tongue base and the soft palate is probably needed in the airway regulatory mechanisms. The tongue and the soft palate are shown to move in unison, with close contact being maintained between these structures as a result of lower jaw movement (L'Estrange *et al.*, 1996).

Children with UARS had a significantly thicker soft palate than the other obstructed subgroups and the controls. A hyperplastic appearance of the uvula may be secondary effect from vibration of snoring and respiration against increased resistance in the upper airways (Hamans *et al.*, 2000). Soft palate enlargement in SDB adults has been shown to be attributable to inflammation, interstitial oedema, and epithelial thickening in the uvula mucosa (Sekosan *et al.*, 1996; Hamans *et al.*, 2000). Children with UARS symptoms may differ from OSA and snoring children in terms of anatomical soft tissue changes that predispose them to increased upper airway resistance but which were not sufficiently severe to meet the diagnostic criteria of OSA.

Craniocervical assessment

It has been suggested that upper airway obstruction leads to increase in craniocervical angulation in order to maintain airway adequacy (Solow *et al.*, 1984, 1993, 1996). The results of the present study showed that children with SDB had significantly larger craniocervical angles (NSL–CVT and NSL–OPT) than the controls. This is in accordance with previous findings in OSA adults (Solow *et al.*, 1993, 1996). An extended posture of the head has been also reported in children with enlarged tonsils (Behlfelt, 1990).

Limitations of the methodology

A full-scale polysomnography was not performed since eye movements, electromyographic, and electroencephalographic activity were not recorded. Polysomnography is quite invasive, may disturb the child's natural sleep, and is not always easy to perform on young children. The PG device used in this research meets the minimum requirements of the consensus statement of the American Thoracic Society (1996). The method has been validated in relation to full-scale polysomnography and has been used in instances where the effect of sleep apnoeas on sleep structure has not been studied (de Miguel-Diez *et al.*, 2003).

Oronasal airflow was measured using an oronasal thermistor sensor. For definition of partial upper airway obstruction, the measurement of nasal pressure is more exact than the thermistor detection, although both are semi-quantitative. A reproducibility study of the measurement technique was not been performed. The method has previously produced relevant results (Nieminen *et al.*, 2002). However, without overnight polysomnography or oesophageal pressure measurement, the evaluation of partial upper airway obstruction remains, to some degree, inaccurate.

The control group in this study was not a concurrent group since, for ethical reasons, the controls were orthodontic patients. The craniofacial characteristics of the control group, however, corresponded with the distribution of average prevalences in the Finnish population in this age group.

Practical implications of the results

Lateral cephalometry has the merit of being simple, easily available, and inexpensive for routine use regardless of its limitations when assessing an upright two-dimensional radiographic view of a three-dimensional structure. Cephalometric analysis of orthodontic patients should include lymphoid tissue and pharyngeal assessment. Lateral radiographs may reveal important risk factors for SDB even though cephalometric measurements are not useful for distinguishing OSA from UARS. Dental personnel may have an important role in referring children with occult UARS or OSA for consultation. Dental examinations have revealed that children with nocturnal breathing obstruction have an increased overjet, a reduced overbite, a narrower maxilla, and a shorter lower dental arch when compared with controls (Löfstrand-Tideström *et al.*, 1999; Pirilä-Parkkinen *et al.*, 2009). A prevalence of lateral crossbites has been noted to be greater in SDB children (Löfstrand-Tideström *et al.*, 1999). Early recognition of children with suspected SDB is also important since certain orthodontic procedures, such as cervical headgear, may even aggravate the underlying untreated disorder (Pirilä-Parkkinen *et al.*, 1999).

Surgical removal of adenoids and tonsils is the first choice of treatment for most children with OSA or UARS (Suen *et al.*, 1995; Nieminen *et al.*, 2000; Carroll, 2003). Systematic orthodontic evaluation of children is recommended because of the known effects of increased upper airway resistance during sleep on craniofacial morphology and occlusion (Guilleminault and Stoohs, 1990; Guilleminault, 2001; Guilleminault and Khramtsov, 2001).

Conclusions

The results showed significant craniofacial and pharyngeal predictors for SDB in children. The craniofacial findings of the present study support previous reports on OSA and snoring children. However, the most significant differences were found in pharyngeal measurements, suggesting that more attention should be paid to airway assessment in children. Cephalometric measurements were not fully able to distinguish obstructed subgroups, even though the children with diagnosed OSA deviated most from the

control children when compared with the less obstructed groups.

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