Sleep, Breathing, and Cephalometrics in Older Children and Young Adults*

Part I—Normative Values

Christine Acebo, PhD; Richard P. Millman, MD, FCCP; Cynthia Rosenberg, DDS; Anita Cavallo, MD; and Mary A. Carskadon, PhD

Study objectives: **Aims were (1) to provide normative values for sleep and sleep-related breathing variables and physical features (cephalometrics, body mass index [BMI], and tonsillar size) in older children/adolescents and young adults, (2) to describe sex and age group differences, and (3) to evaluate relationships between physical features and sleep-related breathing variables.**

Design: **Standard polysomnographic variables describing sleep and breathing were measured during a single night. Cephalometric measures were obtained from a standing lateral skull radiograph.**

Subjects: **Normal, healthy boys (n=23; mean age=13.3±2.1 years), girls (n=22; mean age=13.8±1.8 years), men (n=23; mean age=22.2±1.5 years), and women (n=24; mean age=22.4±1.8 years) with BMI less than 27 were evaluated.**

Results: **Sleep variables showed age group and sex differences consistent with published norms. Slow-wave sleep and rapid eye movement (REM) latency declined with age; transient arousals increased with age. Sleep-related breathing variables showed few changes related to age group or sex: small but statistically significant sex differences were found for arterial oxygen saturation nadir (lower in male subjects) and respiration disturbance index in non-REM sleep (greater in male subjects). Differences in cephalometric measures largely reflected normal growth and expected sex differences. No significant relationships between sleep-related breathing variables and physical findings were observed.**

Conclusions: **These data provide well-controlled normative values for sleep, breathing, and cephalometrics in a group of normal older children, adolescents, and young adults. The data provide useful reference points for patients of these ages in whom sleep apnea is suspected, particularly since such clinical studies are normally based on first-night polysomnography. Furthermore, these values represent developmentally appropriate grouping of the data.**

(CHEST 1996; 109:664-72)

A=A point; ANB=A point to nasion to B point angle, anteroposterior discrepancy between the mandible and maxilla in degrees; ANS=anterior nasal spine; ANS-Gn=anterior nasal spine to Gn, lower partial height; BMI=body mass index; H=hyoid bone; MP-H=vertical position of the hyoid, hyoid to mandibular plane distance; N=nasion; N-ANS=nasion to ANS, upper facial height in mm; NREM=nonrapid eye movement sleep; OSA=obstructive sleep apnea; OSAS=obstructive sleep apnea syndrome; PAS=posterior airway space; linear distance between a point on the base of the tongue and another point on the posterior pharyngeal wall both determined by an extension of a line from point B through Go); PNS=posterior nasal spine; PNS-P=soft palate length; RDI=respiratory disturbance index=apneas+hypopneas per hour of sleep; REM=rapid eye movement sleep; S=sella; SaO_2=arterial oxygen saturation from finger oximetry; SNA=sella to nasion to A point angle, anteroposterior position of maxilla in degrees; SNB=sella to nasion to B point angle, anteroposterior position of mandible in degrees; SN-MP=sella to nasion to Go-Gn angle, mandibular plane angle in degrees; SPT=sleep period time (sleep onset to sleep offset); TIB=time in bed; TST=total sleep time; TWT=total wake time (includes sleep latency, WASO, and wake after sleep offset); WASO=wake time after sleep onset

Key words: adolescent; apnea; body mass index; cephalometrics; development; normative; sleep; young adult

A major area of emphasis for current research on sleep apnea syndromes includes epidemiologic assessment.[1-7] Most such efforts focus on working adult or elderly populations. Older children, adolescents, and young adults are thought to be at reduced risk for sleep apnea syndromes and, therefore, have not received such assessment. Furthermore, childhood obstructive sleep apnea (OSA) is thought to be related to a fairly circumscribed number of causes, including se-

*From the Sleep and Chronobiology Research Laboratory (Drs. Acebo and Carskadon), Department of Psychiatry and Human Behavior, E.P. Bradley Hospital/Brown University, East Providence, RI; the Sleep Disorders Center (Dr. Millman), Department of Medicine, and Department of Plastic Surgery (Dr. Rosenberg), Rhode Island Hospital/Brown University, Providence; and the Department of Pediatrics (Dr. Cavallo), Children's Hospital Medical Center, University of Cincinnati College of Medicine.

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Reprint requests: Dr. Carskadon, Sleep Lab, E.P. Bradley Hospital, 1011 Veterans Memorial Parkway, East Providence, RI 02915

Table 1—*Demographic Measures for Each Group: Mean (SD) and Range*

Measure	Boys	Girls	Men	Women
Age, yr	13.3 (2.1)	13.8 (1.8)	22.2 (1.5)	22.4 (1.8)
	9.7-16.7	10.2-16.8	19.9-25.3	20.1-25.2
BMI,* kg/m^2	19.3 (2.8)	20.3 (3.0)	22.3 (2.8)	21.8 (2.2)
	15.1-25.0	15.3-26.6	17.2-26.8	17.9-25.5

*Significant effect for age group.

rious craniofacial abnormalities, obesity, and adenotonsillar hypertrophy.[8-10] Other evidence suggests that subsyndromal respiratory disturbances during sleep, upper airway resistance, may be of significance in producing significant and treatable symptoms.[11,12] Nocturnal symptoms associated with sleep-related respiratory disturbance include heavy snoring, labored breathing, respiratory pauses, fragmented sleep, and abnormal movements;[8,13] however, very few quantitative data exist to describe breathing during sleep in normal older children, adolescents, and young adults. Numerous reports have described data for infants,[14] and limited data are available for children.[8,14-17] One recent report described measures of sleep-related respiration for infants and children;[18] however, values pooled across subjects aged 1 to 17 years reduce the usefulness of these data as developmentally relevant normative values.

Another active research area has been the description of cephalometric features in adult patients, and several have been implicated as indicators of anatomic upper airway narrowing that may favor collapse during sleep.[19-23] Again, few studies have investigated such indicators in younger, nonclinical subjects. The purpose of this report is to present normative data on sleep, breathing, oximetry, and cephalometrics from 92 normal, healthy subjects, including 45 boys and girls and 47 young adult men and women with no known risk factors for sleep apnea, including family history and obesity. In addition, we explored relationships among respiration, cephalometric, and other subject characteristics.

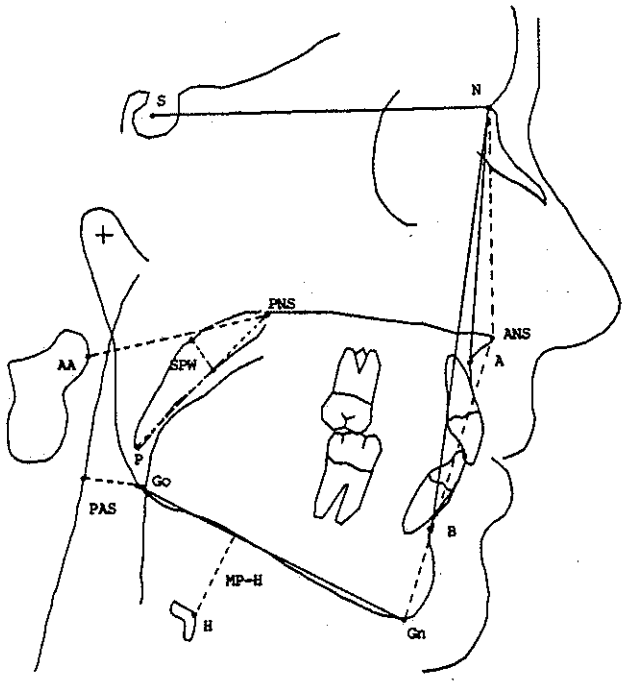

FIGURE 1. Graphic description, definitions, and measures of cephalometric parameters as listed in text and Table 6, where S=sella; N=nasion; H=hyoid bone; A=A point; PNS=posterior nasal spine; ANS=anterior nasal spine; PNS-P=soft palate length; MP-H=hyoid to mandibular plane distance; PAS=posterior airway space (linear distance [mm] between a point on the base of the tongue and another point on the posterior pharyngeal wall both determined by an extension of a line from point B through Go); ANB=A point to nasion to B point angle; SNA=sella to nasion to A point angle; SNB=sella to nasion to B point angle; SN-MP=sella to nasion to Go-Gn angle; N-ANS=nasion to ANS (mm); ANS-GN=anterior nasal spine to Gn (mm); maxillary incisor inclination=an acute angle formed by measuring the midline of the upper incisor to the line NA to determine the relative angulation of the incisor to the maxilla; mandibular incisor inclination=an acute angle formed by measuring the midline of the upper incisor to the line NB to determine the relative angulation of the incisor to the mandible; anterior overbite=distance between the incisor tips of the upper and lower incisors measured perpendicular to the occlusal plane; anterior overjet=distance between the tips of the upper and lower incisors measured along the occlusal plane; superior airway space=most anterior point on atlas vertebrae and PNS (mm); soft palate width=soft palate thickness (mm) in midsagittal plane.

MATERIALS AND METHODS

Subjects

Volunteers were 23 boys, 22 girls, 23 young men, and 24 young women from 84 families recruited through flyers and advertisements in local collegiate and city newspapers. The study was approved by the E. P. Bradley Hospital and Rhode Island Hospital Institutional Review Boards, and informed written consent was obtained from each subject (and parents of boys and girls) in accordance with review board procedures. Table 1 presents age values for each group. Seventy-nine subjects were white, 3 were Hispanic (2 boys, 1 girl), 3 were African-American (1 girl, 1 man, 1 woman), and 7 were Asian-American (1 boy, 4 men, 2 women). The following exclusion criteria were applied during screening: chronic illness, current use of decongestant or antihistamine preparations (medication free for >48 h), upper respiratory tract infection, acute otitis media, ongoing orthodontic treatment, dysmorphic features or syndromes (*eg*, Turner, Noonan, Pierre-Robin, or fetal alcohol syndromes), substance abuse, family history of narcolepsy, and mental retardation. By self or parental report, volunteers were in good health (free of chronic or recurrent illness), had regular sleep habits, and were not habitual nappers. The volunteers were free of sleep disorders in themselves and in first-degree relatives, except for two girls whose father was diagnosed as having sleep apnea requiring no intervention. (Except for parents of the children, we did not interview or examine the first-degree relatives.) Subject selection was constrained to exclude volunteers with body mass index (BMI) greater than 27 (BMI=kilograms/meter^2). A second night of study for the larger project included a nasal occlusion procedure. Five additional subjects (one boy, one man, and three women) were not included in the analysis because they were unable to sleep through the night with the occlusion and asked to have it removed; hence, they did not complete the study.

Table 2—*Frequency Distribution of Tanner Stages for Boys (n=23) and Girls (n=22)*

Tanner Stage	1	2	3	4	5	Missing
Boys	9	1	4	4	1	4
Girls	3	2	2	8	2	5

Physical Assessment

Physical examination confirmed subjects' self-reported health status. Independent visual inspection of the airway was obtained by an expert in sleep disorders and pulmonary medicine (R.P.M.) and an orthodontist (C.R.) who rated tonsillar size using the Brodsky[24] scale. For the younger subjects, Tanner[25] staging was performed by a pediatrician (A.C.). Height and weight were obtained and BMI was calculated as kilogram per meter^2.

Sleep and Breathing Evaluation

Sleep data were collected on a single first laboratory night. Volunteers came to the sleep laboratory approximately 2.5 h before bedtime, which was set according to the subject's usual schedule, providing for at least 8 h of sleep in young adults and 9 to 11 hours (depending on usual sleep requirement) in children before the subject needed to arise the following morning.

Nocturnal sleep monitoring included the following parameters: EEG from referential central (C3 or C4) and occipital (O1 or O2) electrodes applied to the scalp; referential electro-oculogram from surface electrodes taped at the left and right outer canthi; chin electromyogram from electrodes taped over the mentalis/submentalis muscles; respiratory airflow from thermistors or thermocouples positioned to pick up nasal and oral air flow; respiratory effort from mercury-filled capillary strain gauges taped to chest and abdomen or from piezo-crystal belts on chest and abdomen; arterial oxygen saturation (SaO_2) from finger oximetry; heart rate from electrodes taped on right shoulder and left side (modified lead II). Recordings were made at a paper speed of 10 mm/s on polygraphs (Grass Instruments). For EEG channels, the low-frequency cutoff was 1.0 cps for children and 0.3 cycles per second (cps) for young adults, high frequency of 35 cps, and the calibration level was 50 μV/cm.

Sleep was visually scored in 30-s epochs using Rechtschaffen/Kales[26] standard criteria. Sleep onset latency was calculated as elapsed time from lights out to the first of three contiguous epochs of sleep. Latency to rapid eye movement (REM) sleep was calculated as elapsed time from sleep onset to the first epoch of REM sleep, including intervening wakefulness. Transient (≤15 s) arousals were evaluated according to the criteria of the American Sleep Disorders Association.[27] The transient arousal index was calculated as the number of such arousals per hour of sleep.

Apneas were scored during sleep when airflow stopped for at least 10 s. For the young adults, sleep-related hypopneas were scored when airflow and effort dropped to less than 50% of basal for at least 10 s *and* when the return to basal excursion was accompanied by any signs of arousal in the recording *or* a fall of 4% in oxygen saturation. A fall of 4% in SaO_2 was not required to score hypopnea in older children/adolescents, since they were expected to be on the flat portion of the oxyhemoglobin dissociation curve and might have significant "hypopnea" without a large decline in SaO_2. Breathing variables included frequency and mean length of apneas and hypopneas in REM and non-REM (NREM) sleep; an apnea index (apneas per hour) and a respiratory disturbance index (RDI=apneas+hypopneas per hour) were derived separately for REM and NREM sleep. SaO_2 nadir was the lowest measured value of SaO_2 that occurred during the night.

Cephalometric Measurements

Clinical evaluation of the upper airway and lateral skull radiography were performed within 1 week of the sleep recordings by an expert in such assessments (C.R.). A lateral projection of the skull was taken (using an Oralix Ceph unit; Philips Dental Systems; Shelton, Conn) with a technique of 71 kVp and 10 mA at 0.8 s exposure time. Film (Kodak T-mat G) was used in combination with rare earth screens (Lanex). The lateral cephalograms were taken using a film focus distance of 5 feet with the subject's head secured in a cephalostat. All cephalograms were recorded in natural head posture with the subject standing and using a mirror eye reference position. This method is highly reproducible,[28] allowing superimposition of serial radiographs. Soft tissue and bony structure points from the radiographs were digitized using the cephalometric software (Quick-Ceph; Orthodontic Processing; Chula Vista, Calif), and tracings were constructed. As illustrated in Figure 1, measures obtained from these procedures included soft palate length (PNS-P, mm), vertical position of the hyoid (MP-H, mm), posterior airway space (PAS, mm) measured along the B-Go line, anteroposterior discrepancy between the mandible and maxilla (ANB, degrees), anteroposterior position of maxilla (SNA, degrees), anteroposterior position of mandible (SNB, degrees), mandibular plane angle (SN-MP, degrees), upper facial height (N-ANS, mm), lower facial height (ANS-Gn, mm), maxillary incisor inclination (degrees), mandibular incisor inclination (degrees), anterior overbite (mm), anterior overjet (mm), superior airway space (mm), and soft palate width (mm).

Table 3—*Frequency Distribution of Brodsky Scores (Tonsillar Size) for Each Group*

Brodsky Score	0	1	2	3	4	Missing
Boys	2	6	5	1	3	6
Girls	1	4	8	0	1	8
Men	6	5	2	0	0	10
Women	7	2	0	0	0	15

Data Analysis

Each variable was assessed for age group and sex differences using analysis of variance. A probability value less than 0.05 was required for significance of main and interaction effects. *Post hoc* tests of individual means were Bonferroni adjusted. Relationships among sleep, breathing, cephalometric, and demographic variables were assessed using Pearson product moment or Spearman correlations, as appropriate. Analyses were performed using software (Systat version 5.2; Systat Inc) for the computer (Macintosh).

Results

Physical Findings

BMI (kg/m^2) ranged from 15.1 to 26.8 and a significant age effect was found with older subjects having higher BMIs: ($F[1,89]=12.1$; $p<0.001$) (Table 1). Boys and girls spanned the Tanner stages (Table 2); young adults were all postpubescent. Tonsillar sizes included the full range of the Brodsky[24] scale, though few subjects showed evidence of tonsillar hypertrophy (Table 3).

Sleep Parameters

Mean values, SDs, and minimum and maximum values for each group are presented in Table 4 for sleep measures, in Table 5 for respiration measures, and in Table 6 for cephalometric measures. The presence of

Table 4—*Baseline Sleep Measures for Each Group: Mean (SD) and Range*

Measure	Boys	Girls	Men	Women
TIB,*† min	576 (38)	557 (27)	484 (17)	478 (5)
	536-656	530-601	466-540	468-494
SPT,* min	553 (37)	531 (41)	463 (29)	460 (20)
	493-628	420-598	384-524	406-490
TST,* min	515 (55)	510 (36)	437 (40)	430 (42)
	413-627	443-597	341-506	305-478
Sleep efficiency, TST % of SPT	89.4 (7.5)	91.6 (5.2)	90.3 (7.4)	89.9 (8.4)
	70.6-97.3	73.8-99.3	70.7-98.1	64.1-99.6
Sleep onset latency, min	20 (12)	21 (12)	20 (25)	19 (18)
	7-57	2-43	2-96	0-72
Latency to REM,* min	159 (50)	161 (77)	117 (42)	132 (65)
	68-279	20-386	54-203	61-324
Stage 1, min	43 (19)	34 (16)	35 (15)	34 (16)
	22-99	13-77	13-79	9-62
Stage 1, % of TST	8.4 (3.7)	6.9 (3.4)	8.0 (3.6)	8.2 (4.6)
	4.7-19.5	2.6-16.7	3.4-16.6	1.9-18.4
Stage 2,† min	224 (57)	253 (32)	235 (43)	218 (48)
	93-321	192-310	154-333	138-308
Stage 2,*† % of TST	43.7 (10.9)	50.0 (7.8)	53.8 (8.8)	50.4 (8.9)
	17.8-62.2	33.3-64.2	35.2-74.0	37.6-73.0
Stage 3,* min	46 (23)	41 (23)	34 (11)	33 (14)
	14-102	14-87	10-59	15-70
Stage 3, % of TST	8.8 (4.2)	7.9 (4.0)	7.8 (2.3)	7.6 (3.3)
	2.7-18.6	2.8-14.9	2.7-13.0	4.0-15.1
Stage 4,*† min	108 (47)	92 (29)	51 (24)	68 (28)
	43-213	24-156	9-107	12-118
Stage 4,*† % of TST	20.7 (8.5)	17.9 (5.0)	11.7 (5.3)	15.7 (6.2)
	8.3-41.5	5.0-27.0	2.0-24.4	2.8-27.1
REM,* min	92 (25)	86 (22)	76 (25)	75 (24)
	61-147	54-120	36-110	26-111
REM, % of TST	17.7 (3.7)	16.8 (3.7)	17.5 (5.4)	17.3 (5.5)
	11.1-24.8	11.0-23.4	8.0-27.3	6.2-28.0
NREM,* min	420 (44)	421 (25)	356 (40)	352 (40)
	340-501	380-481	273-412	263-409
NREM, % of TST	81.6 (3.7)	82.7 (3.9)	81.4 (5.6)	81.9 (5.5)
	74.3-88.7	76.1-88.6	72.5-91.6	72.0-92.7
Transient arousals, frequency	27 (17)	39 (26)	42 (29)	38 (27)
	1-58	3-89	3-128	1-119
Transient arousal index,*	3.2 (2.0)	4.6 (3.1)	5.8 (3.7)	5.3 (4.1)
(frequency/TST) ×60	0.1-6.5	0.3-10.9	0.5-15.2	0.1-19.4
WASO, min	37 (32)	25 (28)	26 (22)	29 (27)
	1-112	0-125	6-80	0-116
WASO, % of SPT	6.8 (6.0)	4.6 (4.9)	5.8 (4.9)	6.6 (6.3)
	0.2-21.4	0-22.0	1.3-17.6	0-27.6
Total wake time, min	61 (43)	47 (31)	47 (36)	47 (40)
	15-173	3-158	10-141	2-172

*Significant effect for age group.
†Significant effect for sex.
‡Significant effect for age group by sex.

a significant effect for age-group (adolescent or adult), sex, or an age-group-by-sex interaction is also indicated in these tables.

A number of sleep measures showed significant age-group effects. Younger subjects had longer time in bed (TIB), sleep period time (SPT), and total sleep time (TST). In addition, minutes of stage 3 sleep, minutes and percentage of stage 4 sleep, minutes of REM sleep, and minutes of NREM sleep were greater in the boys and girls than in the young adults. Younger subjects also had longer latency to REM and lower transient arousal index than the older group. A significant main effect for sex was found only for TIB, which was greater in male than female subjects. Significant age-group-by-sex interactions were found for several sleep variables. These included minutes and percentages of stage 2 and stage 4 sleep, and percentage of slow-wave sleep. Bonferroni adjusted *post hoc* tests indicated that for stage 4 sleep (minutes and percentage) and for percentage of slow-wave sleep, the mean value for boys was higher than for both men and women, and the mean value for girls was higher than

Table 5—*Baseline Breathing Measures for Each Group: Mean (SD) and Range*

Measure	Boys	Girls	Men	Women
Apnea index, total	1.0 (1.0) 0.1-3.6	0.9 (0.7) 0-2.7	1.1 (1.3) 0-4.5	0.7 (0.4) 0-1.9
Apnea index, NREM	1.0 (1.0) 0.1-3.4	0.9 (0.7) 0-2.4	1.0 (1.2) 0-4.6	0.5 (0.5) 0-2.1
Apnea index, REM	1.3 (1.5) 0-5.4	1.4 (1.2) 0-4.1	1.4 (3.2) 0-15.7	1.5 (1.5) 0-6.2
RDI, total	1.3 (1.3) 0.2-6.2	1.1 (0.7) 0-2.8	1.3 (1.3) 0-5.0	0.7 (0.5) 0-2.2
RDI,* NREM	1.2 (1.3) 0.1-5.8	1.0 (0.7) 0-2.6	1.2 (1.3) 0-5.5	0.5 (0.5) 0-2.4
RDI, REM	1.5 (2.0) 0-8.2	1.6 (1.3) 0-4.1	1.6 (3.2) 0-15.7	1.6 (1.5) 0-6.2
Mean length apnea, total	14.2 (4.3) 10-30	14.1 (2.5) 10.9-21.6	15.3 (3.8) 10-22.3	14.8 (5.9) 10.6-37.7
Hypopnea mean length, total	20.5 (9.6) 10-47	19.6 (9.3) 10-36	20.3 (9.8) 10-39	26.3 (13.4) 12-42
SaO_2 nadir,*	93.5 (2.7) 88-98	94.3 (1.7) 91-97	92.1 (4.8) 79-97	94.5 (1.7) 91-97

*Significant effect for sex.

for men; thus, the maturational decline was steeper for male subjects than female subjects, as illustrated for minutes of stage 4 sleep in Figure 2.

Breathing Variables

No significant sex, age group, or interaction effects were found for any of the respiration measures, except for SaO_2 nadir and NREM sleep RDI, for which small, but statistically significant differences were found. Male subjects showed lower nadir SaO_2 values and higher RDIs in NREM sleep than female subjects regardless of age. Total RDI (NREM and REM sleep combined) exceeded 5 in only one case, a 15-year-old boy with an RDI of 6.2.

Cephalometric Measures

A number of cephalometric measures varied as a function of age and/or sex. A significant effect for age group indicated that anterior overjet was shorter for older subjects. Several variables showed both age group and sex differences: soft palate length, upper facial height, lower facial height, and soft palate width were all shorter in younger subjects vs older, and shorter for female vs male subjects. Vertical position of the hyoid was significantly shorter in younger subjects than older. This cephalometric variable also showed a significant age-group-by-sex interaction, reflecting an increased maturational slope for this measure between boys and young men as compared with girls and young

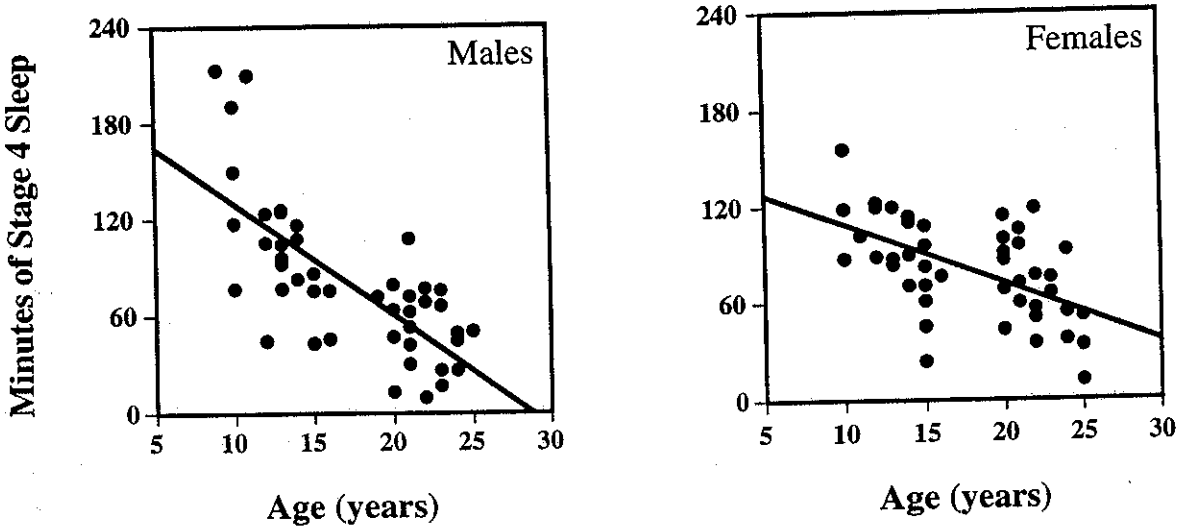

FIGURE 2. Scatterplots for minutes of stage 4 sleep vs age in years for male subjects (n=46) and female subjects (n=46). Standard linear regression lines are shown.

Table 6—*Cephalometric Measures for Each Group: Mean (SD) and Range*

Measure	Boys	Girls	Men	Women
Soft palate length,*† mm (PNS-P)	36.8 (4.8)	35.9 (2.9)	41.0 (3.3)	37.3 (3.8)
	29.9-52.1	31.2-41.9	35.9-48.4	30.9-44.2
Vertical position of*† hyoid, mm (MP-H)	14.8 (5.3)	15.9 (5.5)	19.5 (7.1)	15.8 (4.1)
	3.7-25.4	2.7-26.6	10.7-42.3	8.1-23.5
Posterior airway space, mm (PAS)	15.3 (4.1)	14.7 (3.4)	14.5 (3.5)	13.7 (3.3)
	5.9-20.6	10.0-23.9	8.4-22.6	10.1-19.8
Anteroposterior mx/mn† discrepancy, degrees (ANB)	1.9 (1.9)	2.8 (2.2)	2.5 (2.0)	1.5 (1.9)
	-1.1-7.1	-1.1-6.2	-1.2-6.7	-2.4-4.0
Anteroposterior position of maxilla, degrees (SNA)	80.2 (3.1)	80.8 (3.5)	81.7 (4.6)	80.7 (4.8)
	74.3-85.1	71.3-87.6	74.8-91.3	68.6-88.1
Anteroposterior position of mandible, degrees (SNB)	78.3 (3.2)	77.9 (3.4)	79.1 (4.9)	79.2 (4.4)
	71.8-84.4	69.7-84.9	71.5-86.6	67.2-88.2
Mandibular angulation, degrees (SN-MP)	32.1 (5.0)	31.6 (5.4)	30.8 (7.2)	31.3 (5.9)
	17.9-39.5	22.0-40.9	17.8-44.8	20.6-43.1
Upper facial height,*† mm (N-ANS)	55.2 (4.9)	53.5 (3.9)	60.0 (3.9)	55.5 (3.7)
	48.2-65.4	46.2-61.4	53.3-65.9	46.9-60.8
Lower facial height,*† mm (ANS-Gn)	69.4 (6.1)	67.7 (5.5)	77.3 (5.9)	73.1 (7.7)
	56.9-81.3	57.0-75.0	64.9-87.8	59.9-85.9
Maxillary incisor† inclination, degrees	24.8 (5.7)	22.1 (7.7)	21.5 (6.0)	26.0 (7.5)
	16.1-42.6	6.3-36.9	8.0-34.0	13.1-43.6
Mandibular incisor inclination, degrees	24.9 (6.0)	24.6 (7.2)	26.1 (7.4)	26.2 (6.0)
	14.5-39.3	6.1-39.7	14.4-42.6	15.3-39.6
Anterior overbite, mm	2.7 (1.9)	2.7 (2.6)	2.5 (2.2)	1.7 (1.6)
	-.4-6.0	-4.2-6.6	-1.6-6.1	-1.0-4.8
Anterior overjet,* mm	4.1 (1.9)	5.0 (2.3)	3.4 (1.0)	3.5 (1.1)
	0-8.6	1.5-11.7	0.7-5.1	1.9-6.0
Superior airway space,†† mm	39.8 (3.8)	39.3 (5.2)	42.3 (3.9)	37.2 (3.7)
	30.2-46.3	26.7-49.6	34.5-50.2	29.0-45.7
Soft palate width,*†† mm	9.8 (1.4)	8.9 (1.4)	11.8 (1.9)	9.6 (1.2)
	7.7-12.5	6.6-11.5	8.2-15.5	7.5-12.0

*Significant effect for age group.
†Significant effect for sex.
‡Significant effect for age group by sex.

women. Superior airway space also showed a significant effect for sex and an age-group-by-sex interaction, reflecting a larger value for men than for the other three groups. A significant complex interaction was found for anteroposterior discrepancy: young men had larger values than boys, but young women had smaller values than girls. Maxillary incisor inclination also showed a significant complex interaction: young men had a smaller value than boys, although young women had a larger value than girls.

Correlations

No significant relationships (Pearson product moment correlations or Spearman correlations, as appropriate) were found within groups among cephalometric measures, BMI scores, or Brodsky score values vs respiration measures. In the boys and girls, Tanner stages showed expected significant correlations to age-linked sleep and cephalometric variables.

Discussion

This study provides normative data from a single night of polysomnography, as well as cephalometric values, for older children and young adults with no known risk factors for sleep apnea. The use of a single first night of recording was chosen since this is typical of data obtained in clinical settings. The demonstrated differences as a function of sex and age illustrate the importance of referencing appropriate values for clinical cases. Nevertheless, we also acknowledge the significant contribution of methodologic considerations in certain of these results.

Sleep Variables

Several findings result in part from the procedures imposed by the experimenter. For example, the total time of the recording was shorter for the young adults vs the children; hence, variables affected by length of time in bed show reasonable "age-related" differences reflecting this constraint. These variables include SPT, TST, and minutes of REM sleep. The significant differences for minutes and percentages of NREM stages 3 and 4, in contrast, more likely represent true maturational changes. Maturational trends for the sleep measures are consistent with other reports.[29-31] Thus, minutes and percentages of stage 3, stage 4 (Fig 2), and combined slow-wave sleep show a clear decline with age. The interaction of sex-by-age-group found for

slow wave and stage 4 sleep percentages may speak to different trajectories for the maturational decline in slow-wave sleep as a function of sex. The decline in slow-wave sleep was mirrored by an increase in the percentage of stage 2 sleep as a function of age, with a sharper increase in male subjects. Latency to REM sleep onset, although slightly longer overall than in other reports,[30-32] was longer in adolescents than adults, as has generally been reported. The larger number of transient arousals in the young adult subjects vs children may presage the great increase in this measure in the elderly.[1] The sex difference found in this study for TIB was primarily due to the very long normal bedtime time in bed of three of the youngest boys (>10 h). Total slow wave and wake time after sleep onset (WASO) were somewhat higher than other reports.[31,32] Some of these differences are related to differences in method, *eg*, the longer time in bed as noted above, and the use of a 30-s scoring epoch (vs 1-min epochs in Williams et al[32]). Other differences may be a function of our choice to report first-night data. For example, the high variability of sleep efficiency could be a function of greater sensitivity to the first-night effect by some individuals, much as one might see in a clinical setting. Such first-night data, therefore, are probably most relevant for clinical case comparisons.

Measures of Breathing

We emphasize that our results show minimal respiratory disturbances in these normal healthy volunteers. Three subjects had no respiratory events (one girl, one man, and one woman); and three other subjects had no apneas and fewer than five hypopneas (two men and one woman). As noted previously, RDI across the night exceeded 5 in only one case, a boy with a long uvula and a Brodsky score of +4. Thus, this boy's data suggest some minimal upper airway compromise. Examination of the parent questionnaire about the child indicated that this boy *sometimes* snores loudly and disruptively, breathes through his mouth when awake, sleeps restlessly, and has frequent nasal allergies or runny nose. His father also snores. These minimal indications of occasional problems are not striking until taken in context with the ear, nose, and throat examination and the breathing data.

In general, apneas were more frequently scored than hypopneas, which may be due to difficulties inherent in evaluating hypopneas with the method utilized in this study. In other words, more hypopnic events might have been identified had we used such methods as endoesophageal pressure recording. We found that normal older boys and girls could have up to four apneas per hour of sleep. This contrasts to a recent report by Marcus and colleagues[18] concluding that obstructive apnea greater than one episode per hour should be considered pathologic. The nadir SaO_2 values for these volunteers reflect the minimal amount of respiratory disturbance that was seen. In 28% of subjects, SaO_2 remained above 95% throughout the night. None of the volunteers snored to a significant extent while in the laboratory.

Because the prevalence of clinically significant OSA is higher in adult men and increases with age, we thought we might identify suggestive trends in these younger subjects. No sleep-related respiratory variable showed age-group differences in the predicted direction, and only two showed sex differences in the predicted direction. Thus, the NREM RDI was higher in male than female subjects (though quite low overall), and the SaO_2 nadir was lower in male than female subjects). The small magnitude of these differences, which overlap the likely measurement error, does not support population-wide age by sex changes in sleep-related breathing over the adolescent/young adult age range.

Cephalometrics

The cephalometric data suggest that normative values for adult men as collected in case-controlled studies to date are inadequate for assessing younger, normal weight individuals. For example, posterior airway space in our sample showed a consistently greater value than reported in adult control populations.[19] Several measures—such as SNA, SNB, ANB, and PNS-P—were quite similar in our volunteers to norms reported by Riley and colleagues.[19] Differences in our data for soft palate length (PNS-P) between older children and young adults, however, suggest a significant effect of growth, as well as values considerably longer in our young adult men than described for the control group of Riley et al.[19] Similarly, the young adult men in our sample had a much greater vertical position of the hyoid than reported by Riley et al.[19] Certainly, the range of values for the vertical position of the hyoid was quite marked in our subjects. These differences between studies are notable, as both PNS-P and vertical position of the hyoid have been related to OSA syndrome;[19] however, our results indicate that these two cephalometric parameters may not be critical features predisposing sleep apnea in normal weight young subjects.

Correlations

The lack of significant correlations between cephalometric measures and measures of respiratory disturbance do not appear to result from restriction of range of the cephalometric measures. Subjects with mandibular deficiency (low values on SNB), maxillary deficiency (low values on SNA), inferiorly positioned hyoid bone (high values on MP-H), long soft palate (high values on PNS-P), small posterior airway space

(low values on PAS), and high anteroposterior discrepancy (high values on ANB) were represented in the sample, yet none had significant respiratory disturbance during sleep. These particular landmarks have been shown to be of interest in OSA patients.[19] Each of the three subjects with RDI values of 4 or more had at least two cephalometric values greater than 1 SD from the mean value for their subgroup. This was not unusual, however, since all three subjects with RDIs of zero also had at least two values 1 SD from their subgroup means.

The data included in the tables may provide useful reference points for clinical studies of children and adolescents in whom sleep apnea is suspected, particularly since such clinical studies are normally based on first-night polysomnography. Furthermore, these values represent developmentally appropriate grouping of the data. We caution the reader that these data are from normal-weight, healthy volunteers who were sleeping at their usual times. Particularly in children, an attempt was made to provide a time in bed close to their usual requirement; in adult subjects, time in bed was maintained at 8 h. A further caveat is that the sample was largely white (86%). Racial/ethnic analyses were not possible, which may limit the ability to generalize to other populations. However, in the small group of nonwhite subjects, no consistent trends by racial/ethnic group were noted.

Finally, although the results of this study demonstrate again the very low levels of apnea and hypopnea in normal children, other studies have suggested that clinical symptoms of increased upper airway resistance may be seen in children without complete apnea or significant drops in SaO_2.[11] Guilleminault et al[12] have recently suggested that upper airway resistance, without snoring, desaturation, or clinical symptoms, may be more prevalent than heretofore believed and may be the first step toward sleep apnea abnormalities. One of the correlates of this resistance is an increase in transient arousals. Hence, the normative data provided in this study may be clinically useful for comparing subjects on this variable.

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