

Upper airway resistance during growth: *A longitudinal study of children from 8 to 17 years of age*

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ABSTRACT

Objective: To study upper airway breathing in 115 children annually from 8 to 17 years of age with the hypothesis that upper airway respiratory needs increase steadily during growth and show sexual dimorphism.

Material and Methods: To calculate nasal resistance, airflow rate (mL/s) and oronasal pressures (cmH₂O) were measured during rest breathing in a seated position using the pressure-flow technique.

Results: Median values of oronasal pressure ranged at different ages in girls from 0.88 to 1.13 and in boys from 0.92 to 1.44 cmH₂O, being 0.95 and 0.93 cmH₂O at the age of 17 years, respectively. The gender differences were statistically significant in four age groups ($P < .05$ by the Mann-Whitney test). Mean values of nasal resistance decreased from 8 to 17 years of age in girls from 4.0 (± 3.27) to 2.4 (± 2.30) and in boys from 3.3 (± 2.48) to 1.5 (± 0.81) cmH₂O/L/s. However, there was an increase in resistance in 11-year-old girls and 12-year-old boys and at the age of 15 in both genders ($P < .05$ by paired t -test).

Conclusions: Respiratory efforts stabilize oronasal pressure to maintain vital functions at optimal level. Nasal resistance decreased with age but increased temporarily at the prepubertal and pubertal phases, in accordance with other growth and possibly hormonal changes. When measuring upper airway function for clinical purposes, especially in patients with sleep apnea, asthma, allergies, cleft palate, or maxillary expansion, the measurements need to be compared with age- and gender-specific values obtained from healthy children. (*Angle Orthod.* 2016;86:610–616.)

KEY WORDS: Nasal resistance; Nasal obstruction; Upper airways; Oronasal pressure; Pressure-flow technique

INTRODUCTION

Newborn babies breathe entirely through their nose and also have the ability to breathe while swallowing.

At the age of about 6 months, the respiratory tract must be closed during swallowing solid or liquid food,^{1,2} and normal rest breathing is entirely through the nose. If the nasal tract is congested, the response to increased upper airway resistance is to part the lips and open the mouth slightly. Partial oral breathing due to impaired nasal breathing affects dentofacial growth in some individuals^{3–5} and increases the risk for upper airway allergies, asthma,⁶ and sleep apnea.⁷ The perception of nasal obstruction and breathing difficulty occurs more readily in the supine position and is associated with greater oral and sleep disordered breathing,⁸ especially in subjects with allergies.⁹ Oral breathing may also complicate treatment of sleep apnea due to difficulties of using continuous positive airway pressure (CPAP) therapy.¹⁰ In children with cleft palate, an obstructed nasal airway may be of some help in producing plosive consonants during speech¹¹ but has been reported to increase risk for upper airway and ear infections.¹²

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Accepted: August 2015. Submitted: May 2015.

Published Online: October 6, 2015

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Table 1. Descriptive Statistics of Differential Oronasal Pressure (cmH₂O) During Inspiratory Phase of Rest Breathing From 8 to 17 Years of Age With Comparisons Between Girls and Boys

Age (y)	Girls			Boys			P value*
	N	Median	(Quartile)	N	Median	(Quartile)	
8	29	0.88	(1.39, 0.77)	28	1.44	(2.43, 0.98)	.01
9	61	1.13	(1.46, 0.65)	43	1.06	(1.66, 0.78)	.47
10	61	0.89	(1.20, 0.68)	52	1.20	(1.67, 0.80)	.03
11	62	1.10	(1.48, 0.74)	47	1.18	(1.55, 0.74)	.63
12	63	0.88	(1.21, 0.65)	47	1.02	(1.68, 0.67)	.09
13	59	0.77	(1.23, 0.57)	44	1.12	(1.58, 0.81)	.02
14	56	0.72	(0.98, 0.47)	44	0.92	(1.20, 0.75)	.01
15	57	0.89	(1.08, 0.61)	44	1.03	(1.38, 0.70)	.06
16	49	0.92	(1.13, 0.68)	34	0.99	(1.38, 0.72)	.23
17	29	0.95	(1.13, 0.73)	16	0.93	(1.13, 0.63)	.95

* P values by Mann-Whitney test.

In assessing upper airway obstruction, a medical history and clinical evaluation are essential for formulating a diagnosis, yet in some instances they are not sufficient to determine the problem. Actual dynamic measurements during rest breathing and comparisons with age-related values in healthy subjects may be necessary. Zapletal and Chalupová¹³ emphasized the need for reliable reference values for pediatric patients with nasal and other respiratory problems. There are only a few cross-sectional studies on nasal patency in healthy children^{14–17} but no longitudinal studies. In this follow-up study of the same children from 8 to 17 years of age, it was hypothesized that upper airway respiratory needs increase steadily during growth and show sexual dimorphism.

MATERIALS AND METHODS

Permission for the study was obtained from the Research Ethics Committee of the University of Kuopio and Kuopio University Hospital, Kuopio, Finland, and consent forms were signed by the parents.

In a 9-year follow-up study, 115 children from 8 to 17 years of age, including all children in the first and second grades in a municipality of 3800 inhabitants, were examined annually in early winter. This rural community, where most of the population has lived for many generations, provided a homogeneous population with low activity of moving out of the area, which is of critical importance in longitudinal study design. A detailed description of the sample has been published,¹⁸ and distribution of the study subjects according to age cohort and gender is given in Table 1. The only criterion for selection was absence of nasal congestion due to respiratory infection or allergic rhinitis at the time of examination. Each year the subjects filled out a questionnaire related to general health, described previously in detail.¹⁹

The pressure-flow technique (Microtronics Co, Iola, Kan), which has shown good reproducibility,²⁰ was

used to measure nasal airflow rate (mL/s) and differential oronasal pressures (cmH₂O) during rest breathing in a seated position. The equipment was calibrated each time it was relocated. Nasal airflow rate (mL/s) was measured with a heated pneumotachograph connected to a well-adapted nasal mask. Differential pressure transducers connected to two catheters measured the oronasal pressure (cmH₂O/L/s) drop. The first catheter was placed midway into the subject's mouth and then the subject was asked to close the lips and breathe through the nose. The second catheter was placed within the nasal mask. The airflow and oral and nasal pressure measurements were recorded and analyzed with software (Perci-PC and Perci-SARS, Microtronics, CO, Iola Kan), used also to calculate nasal resistance as follows:

$$R = \Delta P / V,$$

where R = nasal resistance (cmH₂O/L/s), ΔP = oronasal pressure (cmH₂O), and V = nasal airflow (mL/s).

The Mann-Whitney test was used to compare differences in oronasal pressures and nasal resistance between boys and girls. Because there were several statistically significant differences in oronasal pressure between genders at different ages, changes in nasal resistance between consecutive ages were analyzed by the paired *t*-test separately among girls and boys. A *P* value of <.05 was considered statistically significant.

RESULTS

Median values for oronasal differential pressures (Table 1) ranged from 0.72 to 1.13 for females and 0.92 to 1.44 cmH₂O for males with values for both decreasing with age. The values were smaller for girls compared with those of boys except at the ages of 9 and 17 years, when they evened out to 0.95 in girls and 0.93 cmH₂O in boys, respectively (*P* = .95). The differences between genders were statistically

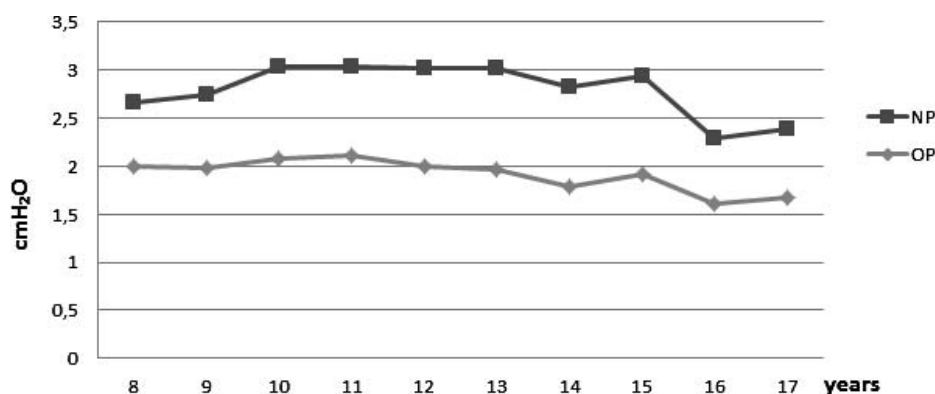


Figure 1. Means of oral pressure (OP) and nasal pressure (NP) in different cohorts from 8 to 17 years in girls.

significant at the ages of 8, 10, 13, and 14 years ($P = .01, .03, .02$, and $.01$, respectively). Therefore, the results regarding upper airway resistance were analyzed for each gender separately.

Figures 1 and 2 illustrate the almost constant nature in difference between oral and nasal pressures during growth in both genders.

Figure 3 illustrates the increase in mean airflow rate during growth from 434 to 579 mL/s in males and from 349 to 471 mL/s in females.

Figures 4 and 5 show the higher values of nasal resistance during inspiratory rest breathing compared with expiratory rest breathing. Mean values of nasal resistance decreased during inspiration (Table 2) with ages 8 to 17 years in females from $4.0 (\pm 3.27)$ to $2.4 (\pm 2.30)$ but showed the lowest value of $1.9 (\pm 0.93)$ at age 14. In males, a mean resistance of 3.3 with wide variation was seen from 8 to 12, decreasing to $1.5 (\pm 0.81)$ cmH₂O/L/s in 17-year-olds. Although females had higher values for upper airway resistance than did males, the difference was statistically significant only at age 13 ($P = .05$). Nasal resistance did not decrease

uniformly during growth as there was some inconsistency from ages 10 to 13 and again from ages 15 to 17 in both genders. The differences between consecutive ages were statistically significant between 11 and 12 as well as between 12 and 13 years in females but only between 8 to 9 years in males.

DISCUSSION

Consideration of general health and especially that of the upper airway is critically important in studies of respiratory function. Our earlier studies have shown that when individuals with acute nasal congestion due to infections or the acute phase of upper airway allergies are excluded, factors included in the medical history related to general health; nasorespiratory diseases and symptoms; status of the adenoids and tonsils; and smoking habits are associated with measurements of rest breathing in older adults but not in children or adolescents.^{21,22} Therefore, information in the medical history was not included in the analyses of this study on 8–17-year-olds.

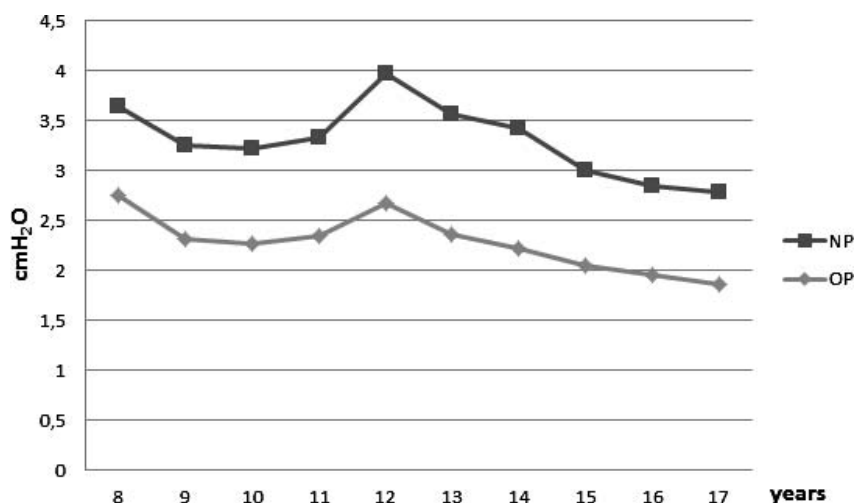


Figure 2. Means of oral pressure (OP) and nasal pressure (NP) in different cohorts from 8 to 17 years in boys.

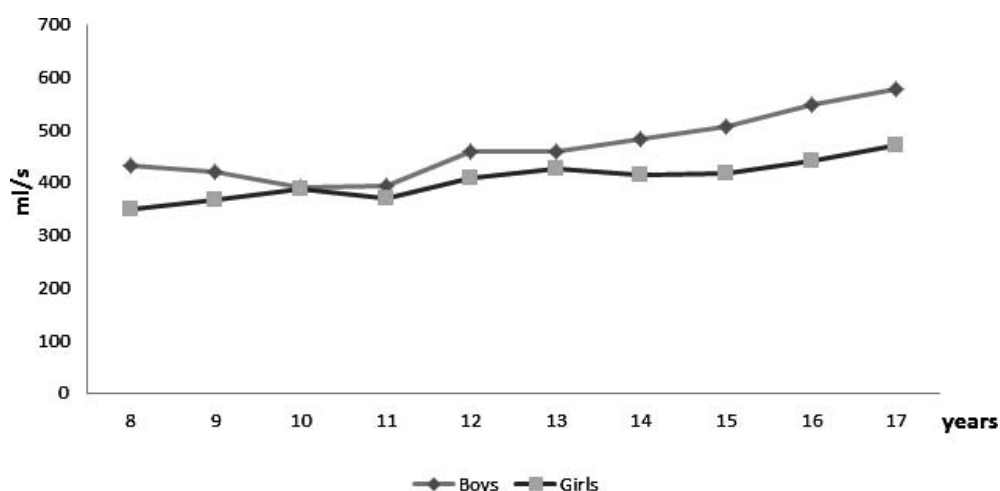


Figure 3. Airflow rate (mL/s) during inspiration in girls and boys from 8 to 17 years of age.

Findings on the association between body size and respiratory variables are contradictory. Zapletal and Chalupova¹³ reported a linear correlation between inspiratory resistance and body height in 2–19-year-olds. Kobayashi et al.^{16,17} found a tendency that resistance decreased with increasing height in school-children but the correlations between resistance and weight, height, body surface or body mass index ($BMI = \text{Weight (kg)} / [\text{Height (m)}]^2$) were weak. Kim et al.²³ reported that in the adult population, lower body weight was related to increasing total nasal resistance in women but not in men. In contrast, Saito and Nishihata¹⁴ did not find a significant correlation between nasal resistance and height or weight in 5–17-year-olds. Our earlier research on 7–15-year-old children,¹⁵ as well as data on 7–24-year-olds,¹⁸ indicated no association between BMI and upper airway function. Therefore, BMI was not included in analyzing the present data.

The methods of assessing upper airway obstruction morphologically have progressed from lateral and anteroposterior cephalometric radiographs and other 2-D methods to 3-D methods such as cone beam computed tomography.²⁴ The smallest cross-sectional area of the nose has the greatest influence on the magnitude of nasal resistance during breathing. Acoustic rhinomanometry provides a reasonably quick and easy method of measuring the smallest anatomical cross-sectional area of the nose, especially in young children.^{25,26} However, an aerodynamic approach, as used in this study, provides a more important active physiologic measure of the airway. That is, during breathing, the respiratory sensory system monitors variables such as pressure and airflow rather than just the anatomical features that influence breathing dynamics.²⁷ Thus, the measurement of resistance, while significantly affected by the

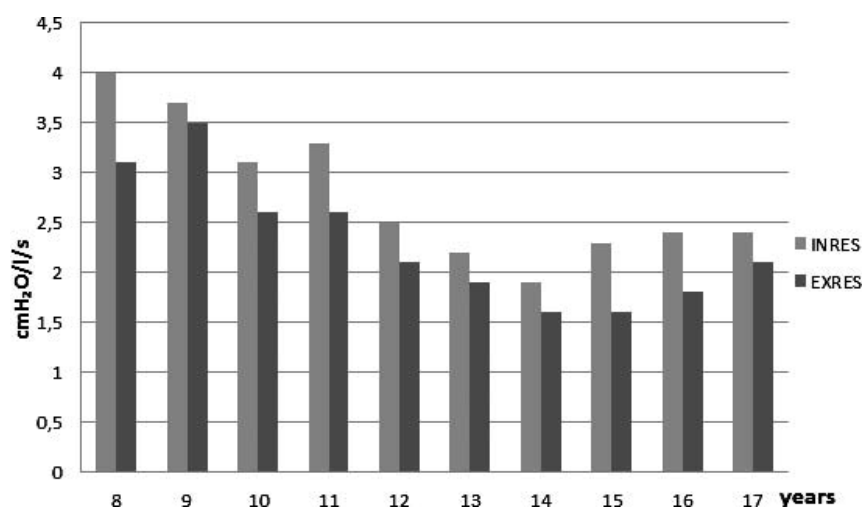


Figure 4. Means of nasal resistance (cmH₂O/L/s) during inspiration (INRES) and expiration (EXRES) from 8 to 17 years of age in girls.

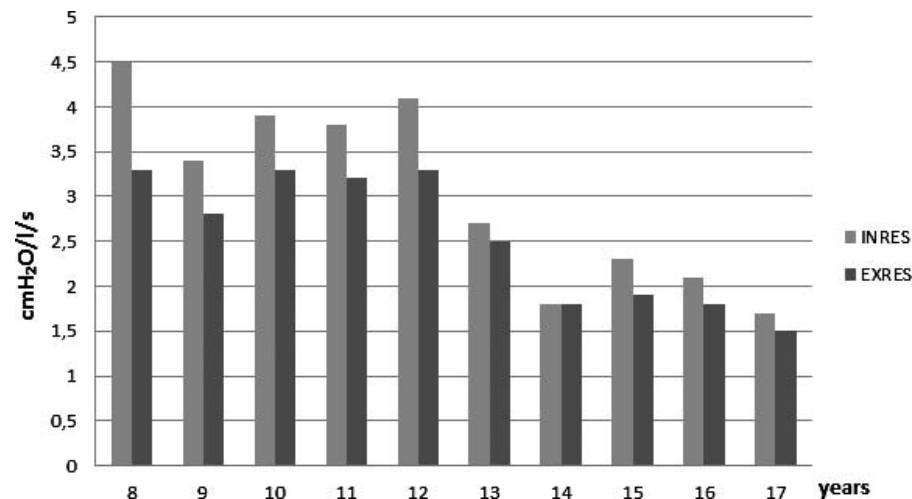


Figure 5. Means of nasal resistance (cmH₂O/l/s) during inspiration (INRES) and expiration (EXRES) from 8 to 17 years of age in boys.

smallest cross-sectional area of the airway, is influenced by the length of the airway as well.

Our present results indicate that nasal airflow rate increased during growth in both genders while oronasal differential pressure remained rather stable. Both variables showed inconsistency in prepubertal or early pubertal phases and differences between genders. Nasal resistance, calculated from these two measured variables, decreased with increasing age in both females and males but showed some inconsistency from 10 to 13 and from 15 to 17 years of age. The amount of annual decrease in nasal resistance was somewhat larger in young children compared with adolescents. Inconsistent changes in nasal patency occur at the same time as the most significant somatic growth, changes in nasal and orofacial morphology, and development of the permanent dentition.^{17,28–30} Among changes in size and shape of the respiratory and vocal tracts, laryngeal descent, associated with hyoid descent, is greater in males, resulting in relatively longer airways.^{31,32} No gender differences in nasal resistance have been found for children,^{13,14,16}

while Kim et al.²³ reported lower resistance for females and also a decrease in resistance with age among adults. Although upper airway resistance decreases with age in children, Saito and Nishihata¹⁴ found a temporary increase between ages 13 and 14, paralleling our findings. In our sample of 8–17-year-old children, age resistance increased rather than decreased earlier in females compared with males. The hormonal factors affecting changes in nasal resistance are still unclear. In the peripubertal stage, growth and sex hormones may affect the growth of the nasal airway, perhaps due to their effect on the nasal mucosa. The differences in nasal resistance around puberty between males and females may be explained by difference in the time that puberty occurs. In summary, we recommend that resistance suggesting possible nasal pathology be compared with age-specific values obtained from healthy children and compared by gender.

In diagnosing obstructive sleep apnea, the main emphasis in respiration is in the pharyngeal area. As early as 1975, Koski and Lähdemäki³³ had suggested

Table 2. Nasal Resistance (cmH₂O/L/s) During Inspiratory Phase of Rest Breathing in Children From 8 to 17 Years of Age With Comparisons at Two Consecutive Ages Among Girls and Boys

Age (y)	Girls			Boys			Age Cohorts Compared	P value*	
	N	Median	Mean (SD)	N	Median	Mean (SD)		In Girls	In Boys
8	29	3.0	4.0 (3.27)	28	2.8	3.3 (2.48)			
9	61	2.7	3.7 (2.92)	43	2.4	2.8 (1.82)	8 vs 9	.13	.02
10	61	2.4	3.1 (2.21)	52	2.8	3.3 (3.92)	9 vs 10	.50	.32
11	62	2.9	3.3 (1.55)	47	2.4	3.2 (3.11)	10 vs 11	.45	.96
12	63	2.2	2.5 (1.17)	47	1.9	3.3 (6.36)	11 vs 12	<.01	.33
13	59	1.9	2.2 (1.67)	43	2.0	2.5 (1.53)	12 vs 13	.03	.30
14	56	1.8	1.9 (0.93)	43	1.5	1.8 (1.03)	13 vs 14	.17	.19
15	57	2.0	2.3 (1.14)	44	1.7	1.9 (1.5)	14 vs 15	.07	.64
16	49	2.1	2.4 (1.61)	34	1.7	1.8 (1.09)	15 vs 16	.38	.14
17	29	1.9	2.4 (2.30)	16	1.4	1.5 (0.81)	16 vs 17	.31	.14

* P values by paired t-test.

that dorsal rotation of the mandible in children with large tonsils was primarily a physiological response to maintain adequate pharyngeal airspace. Nasal resistance in patients with obstructive sleep apnea syndrome is reported to be higher than that of normal controls,^{34,35} the nasal obstruction resulting primarily from structural abnormalities or inflammatory mucosal disease. Eliminating pharyngeal obstruction during sleep is the main focus of treating sleep-disordered breathing, but nasal obstruction can complicate treatment when oral appliances or CPAP are used.

Switching to partial oral breathing in response to increased nasal resistance is not well understood. In our earlier study of 59–82 year old adults, breathing behavior was assessed under various nasal resistance loading conditions.²¹ The load was detected at an average resistance of 4.56 (SD 2.30) cmH₂O/L/s, but modification of respiration occurred well before that by decreasing airflow rate and volume. The threshold value was about 2.5 times rest breathing resistance of 1.75 cmH₂O/L/s. Correspondingly, if the same proportion were applied to the children and adolescents in this study, females from 13 and males from 14 years of age on would have the same threshold as adults. Young children have a much higher resistance at rest breathing, and the switching point is difficult to define even when using several methods simultaneously.³⁶ However, not only increased resistance, but individual perception of resistance seems to define the threshold for switching from nasal to partial oral breathing, while modification of rest breathing effort begins even before the perception of a problem.^{21,37}

CONCLUSIONS

- In children and adolescents, oronasal differential pressures differed by gender but the difference was small (0.10 cmH₂O). Changes in respiratory effort, that is, airflow rate stabilized pressures even while growth changes occurred.
- Higher resistance values during inspiratory breathing suggests that expiratory breathing is more passive compared with more active effort during inspiration. This probably influences the need for partial oral breathing in response to an impaired nasal airway.
- Nasal resistance was slightly higher for females compared with males, and it decreased with age but was inconsistent just before puberty as well as during the final years of growth. Hormonal changes might be a factor. Gender differences in nasal resistance may be affected by the difference in the time puberty occurs in males and females.
- Comprehensive evaluation of respiratory parameters associated with breathing provide important diagnostic information when assessing treatment options

as well as treatment outcomes, especially for patients with sleep apnea, asthma, allergies, cleft palate, or a deficient maxilla. We suggest that nasal resistance values are useful for evaluating nasal impairment but should be assessed by comparing age and gender-specific values obtained from healthy children.

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