A longitudinal study of nasal airway size from age 9 to age 13

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Abstract: In order to define nasal breathing for diagnostic purposes, reference values of normal nasal airway size in children are needed. The purpose of this study was to examine longitudinally changes in nasal airway size that occur with age. Minimum nasal cross-sectional areas of 82 children were measured by the pressure-flow technique at 1-year intervals, from age 9 through age 13. A mixed factorial ANOVA showed that the effect of age on nasal airway size was statistically significant ($p< 0.001$) and the effect of gender was nonsignificant. Although the mean nasal size increased from 0.4 cm^2 to 0.5 cm^2, it also decreased at some point between 9 and 13 years. The results suggest that the adult nasal size may be reached earlier than previously reported in cross-sectional studies.

Key Words: Dentofacial development, Nasal cross-sectional area, Nasal patency, Longitudinal study, Pressure-flow technique

The effects of impaired nasal breathing on craniofacial growth and the development of the dentition have been studied for decades. Most clinicians now believe that aberrant growth of the dentofacial complex is the result of both genetic and environmental factors.[1,2] One popular explanation of the relationship between impaired nasal respiration and dentofacial growth is that nasal airway inadequacy results in oral-nasal breathing that yields postural changes that alter dentofacial growth.[1-5]

Several clinicians and researchers have recommended that an assessment of mode of breathing and nasal patency be included in the orthodontic evaluation.[6-8] Oral-nasal breathing often results from septal deviations, enlarged adenoids, or mucosal swelling due to upper airway allergies or other nasopharyngeal pathologies. However, mouth breathing may be the result of habit, with or without any impairment of the upper airway.[9] Thus, diagnosing the presence of nasal airway impairment and determining whether oral-nasal mode is habitual or obligatory are clinically important.

It has been suggested[10] that in adults, the change from nasal to oral-nasal breathing occurs at nasal cross-sectional areas below 0.4 cm^2. This threshold, however, is not applicable to children since nasal cross-sectional area is known to change with age, thus complicating the diagnosis of nasal patency. Several cross-sectional studies have indicated that nasal cross-sectional area increases with age during growth.[11-15] However, as follow-up studies of somatic growth and maturation have indicated, timing of onset and completion as well as velocity and magnitude of growth, along with various events of puberty, can vary widely between individuals.[16,17] These variations can rarely be observed by a cross-sectional study. No longitudinal study of the growth of the nasal airway in a healthy population has been published and, therefore, the age at which nasal airway growth ceases has not been determined. The purpose of this study was to examine longitudinally changes in nasal airway size with age. This report includes the years of prepubertal growth, from age 9 through 13.

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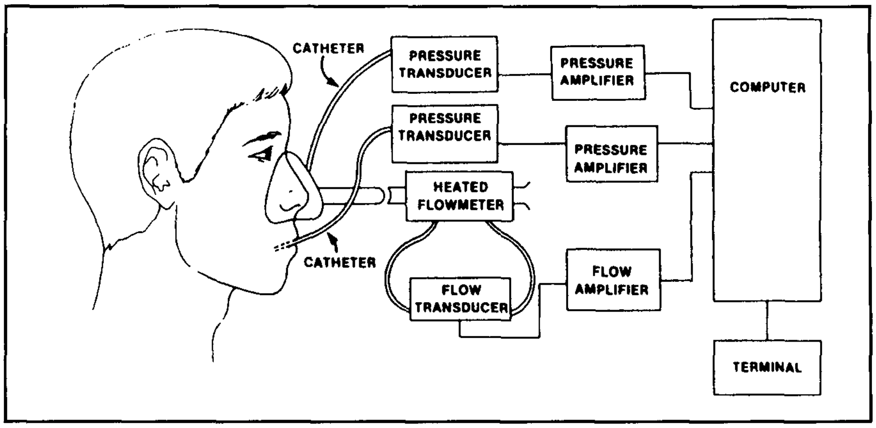

Figure 1
Technique for assessing nasal cross-sectional area

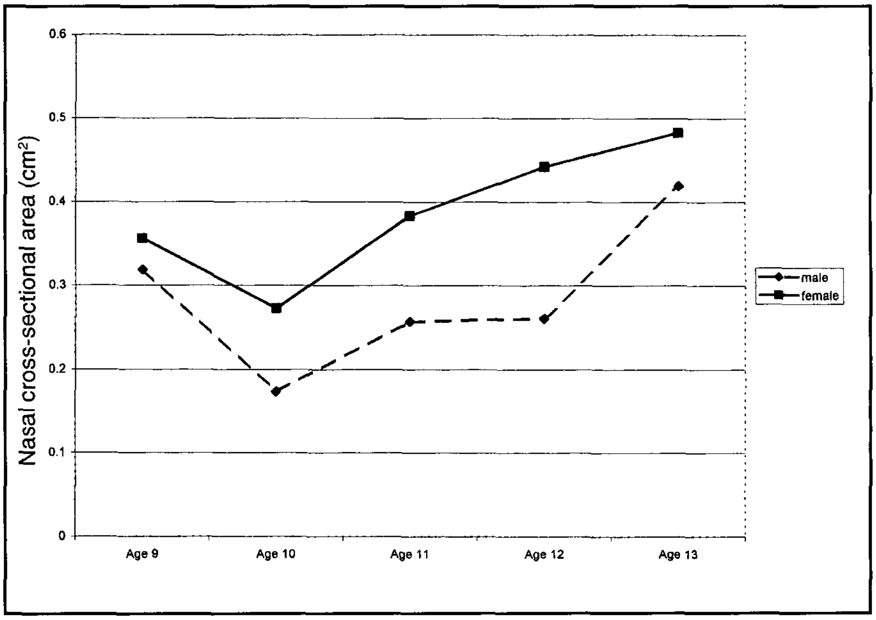

Figure 2
Examples of individual longitudinal data of nasal airway size (cm²) with age

Materials and methods

The sample consisted of 82 schoolchildren, 47 girls and 35 boys, from five elementary schools in the county of Vimpeli in western Finland. The minimum nasal cross-sectional area of these children was measured at 1-year intervals, from age 9 through 13. The only criterion for selection was the absence of nasal congestion due to respiratory infection or allergic rhinitis at the time of examination. If a child had symptoms, his or her measurements were excluded from the data. A few children were absent each year. Those who were not measured at 9 or 13 years were excluded from the study. All five measurements were sampled in 85% of the children. Each year the participants also filled out a questionnaire related to their general health.

A portable version of the equipment for the pressure-flow technique[14] was built at the Department of Orthodontics, University of Kuopio. Minimum nasal cross-sectional areas of the students were measured each year in January or February at the Vimpeli schools. The equipment was calibrated before each use. Nasal airflow rate was measured using a heated pneumotachograph connected to a well-adapted nasal mask (Figure 1). Differential pressure transducers connected to two catheters measured the oral-nasal pressure drop. The first catheter was positioned midway in the subject's mouth and the subject was asked to close his or her lips. The second catheter was placed within the nasal mask. The resulting airflow and pressure measurements were transmitted to a portable microcomputer for recording and analysis. Minimum nasal cross-sectional area was calculated as follows:

$$A = \overset{o}{V} / K(2\Delta P / d)^{1/2}$$

where A=nasal cross-sectional area (cm^2), $\overset{o}{V}$=nasal airflow (ml/s), k=0.65, d=density of air (0.001g/cm^3) and ΔP=oral-nasal pressure (cmH_2O). No nasal decongestants were used during the measurements so that the functional size rather than size of the bony cavum of the nasal airway was measured.

Statistical methods

A mixed factorial ANOVA was used to determine the effects of age and gender on nasal minimum cross-sectional area, with age as a within-subject factor and gender as a between-subject factor. A Sidak pairwise comparison test was used to evaluate the difference in nasal cross-sectional area between the age points. Age at the smallest cross-sectional area value was determined and then the smallest value was subtracted from the value at ages 9 and 13. The mixed factorial ANOVA was also used to determine the difference between these three values, i.e., nasal cross-sectional area at age 9, age 13, and the lowest value. *P*-values ≤ 0.05 were considered statistically significant.

Table 1
Means, standard deviations, 95% confidence intervals, and medians for nasal cross-sectional area (cm^2) in 82 children from 9 through 13 years of age. Statistical difference of means at different ages given in *p*-values (by ANOVA, gender as a cofactor)

	Mean	SD	95% Confidence interval for mean	Median	p^{9}	p^{10}	p^{11}	p^{12}	p^{13}
Age 9	0.40	0.14	0.37 to 0.43	0.39	-	0.52	0.84	0.02	0.001
Females	0.39	0.15	0.35 to 0.43	0.40					
Males	0.41	0.13	0.36 to 0.45	0.39					
Age 10	0.42	0.14	0.39 to 0.45	0.43	0.52	-	0.56	0.12	0.001
Females	0.44	0.14	0.40 to 0.48	0.45					
Males	0.41	0.14	0.36 to 0.45	0.41					
Age 11	0.41	0.12	0.38 to 0.43	0.39	0.84	0.56	-	0.02	0.001
Females	0.40	0.11	0.37 to 0.44	0.38					
Males	0.41	0.13	0.36 to 0.46	0.40					
Age 12	0.46	0.14	0.43 to 0.50	0.46	0.02	0.12	0.02	-	0.02
Females	0.47	0.13	0.43 to 0.51	0.45					
Males	0.45	0.16	0.39 to 0.51	0.47					
Age 13	0.51	0.16	0.48 to 0.55	0.50	0.001	0.001	0.001	0.02	-
Females	0.51	0.14	0.47 to 0.55	0.51					
Males	0.51	0.19	0.45 to 0.58	0.48					

p^{9} = significance of difference from the measurement at age 9
p^{10} = significance of difference from the measurement at age 10
p^{11} = significance of difference from the measurement at age 11
p^{12} = significance of difference from the measurement at age 12
p^{13} = significance of difference from the measurement at age 13

Results

Table 1 lists the mean of nasal cross-sectional areas from 9 to 13 years of age. According to the mixed factorial ANOVA, the effect of age was statistically significant ($p<0.001$), while there was no difference between genders. Also, the interaction between age and gender was nonsignificant. The pairwise comparison test showed that the means of 9 through 12 years were not significantly different from each other, but that nasal cross-sectional area at age 13 was significantly larger than at age 9, 10, or 11 ($p\leq0.01$).

However, the individual longitudinal data (Figure 2) showed a trend for nasal cross-sectional area to decrease at some point between the ages of 9 and 13, before the area continued growing. Therefore, the age of the smallest nasal cross-sectional area was determined for each subject and then the differences between the value of the smallest cross-sectional area and values at ages 9 and 13 were determined (Table 2).

The mean of the smallest cross-sectional area occurred about age 10 in both girls and boys. However, as Figure 3 illustrates, the smallest cross-sectional area occurred at age 9 in almost 40% of the girls, and by the age of 11 in most (84%) of them; in boys, it occurred somewhat later, most frequently at age 10 (30%), but after they turned 11 in 45%.

On average, the smallest cross-sectional area between ages 9 and 13 was 0.30 cm^2 for both girls and boys (Table 2). It was about 0.20 cm^2 smaller than the average cross-sectional area at age 13 and 0.10 cm^2 smaller than at age 9. The differences between the means of the smallest cross-sectional area, the area at age 9, and the area at age 13 were all statistically significant ($p<0.001$ in each comparison) by mixed factorial ANOVA, effect of gender being nonsignificant. These results suggests that although nasal cross-sectional area increases from age 9 to 13, it also tends to decrease at some point during that time.

Discussion

This longitudinal study follows the changes in nasal airway size with age from 9 years on, until the nose achieves its adult size. This specific report included five prepubertal years. The study sample consisted of children of one whole age cohort in Vimpeli, a county in western Finland, who were followed from age 9 until 13. Vimpeli was selected because it is a small rural county with five elementary schools within a reasonable distance and a population that is very stable. Although the study population is a nonrandom sample, it is a representative sample of Finnish children, as the Finnish population is highly homogenous.

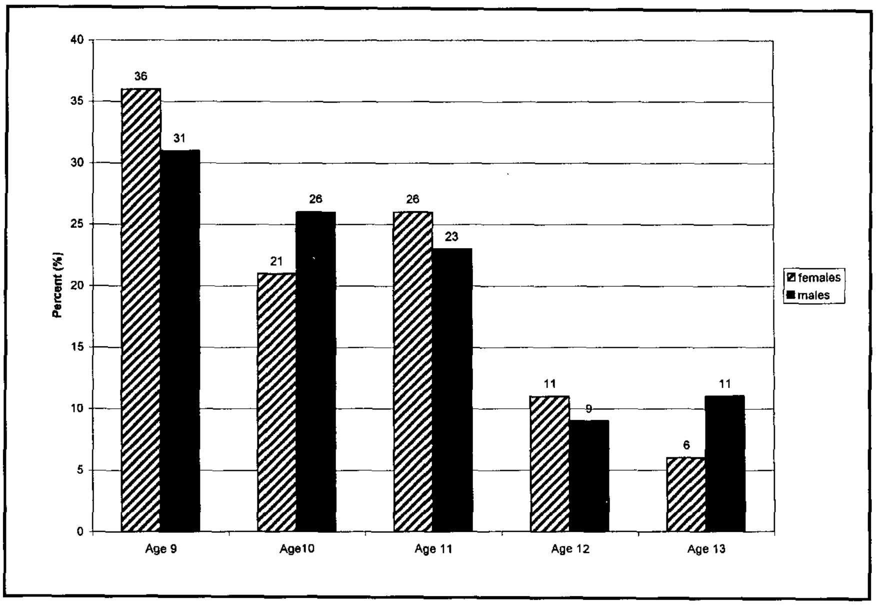

Figure 3
Frequency distribution of occurrence of smallest minimum nasal cross-sectional area (cm^2) by age in females and males from age 9 to age 13

According to the questionnaires, 20% of the children were allergic to some substances, but, as our earlier results have shown, history or symptoms of upper airway disease do not affect rest breathing variables if measurements are made during an asymptomatic period.[18] Middle winter is the season of lowest incidence of allergic symptoms. Previous studies have indicated that cold air influences head posture, nasal patency, and nasal airflow rate,[19,20] but these effects are transient and return to normal after acclimatization to room temperature. All the children in this study had been indoors for at least 45 minutes before the examination and thus acclimatized to the room temperature. No nasal decongestants were used during the measurements so that the functional size rather than the size of the bony cavum of the nasal airway was measured.

The age-specific means observed for nasal cross-sectional area are relatively higher than those reported in earlier cross-sectional studies.[9,11-15,21] Mean nasal cross-sectional area seemed to be fairly constant, around 0.40 cm^2, from 9 to 11 years of age, with further growth around 12 to 13 years. However, when looking at the individual longitudinal data, this linear growth pattern did not seem to fit. As illustrated with individual examples in Figure 2, nasal cross-sectional area seemed to decrease at some point between the ages of 9 and 13. This special feature of growth of the nasal airway is hidden if changes with growth are assessed as mean values. Children grow and develop differently, some faster and others more slowly. Somatic growth follows gaussian distribution in the population, with a standard deviation of 1 year.[17] Therefore, in this study, we determined the age at which a decrease in nasal cross-sectional area first occurred. Then, by comparing nasal area size at that time with the values at ages 9 and 13, the significance of the change was clearly evident.

More important, however, is the reason why a transient decrease in nasal cross-sectional area should occur in the period of active adolescent growth. Since the size of the bony nasal cavum cannot decrease, the change in airway size must be due to a change in the volume of soft tissues lining the interior of the nasal cavum. Extensive studies over several decades have indicated that adenoid tissue, distributed on the upper and posterior walls in the nasopharynx, can alter the dimensions of the upper airways and thus have an effect on mode of breathing.[7,17,22-26] Adenoidectomy reduces the incidence of mouth breathing and increases nasal airflow rate.[7,22] Only three of the 82 subjects involved in this study had undergone adenoidectomy and, in all three, the adenoidectomy had been performed before age 9, i.e., before the first measurement.

Controversial theories of the growth of the adenoid tissue exist. One theory suggests that the adenoids are minimal in size at birth and undergo gradual enlargement until age 10 to 12, after which a reduction in size occurs through the teenage years.[17,24,26] Another, however, suggests that the adenoids are largest at the ages of 2 to 7 years, decreasing in size thereafter through childhood and adolescence.[26] The latter theory is supported by a longitudinal study by Linder-Aronson and Leighton,[23] who followed the thickness of the soft tissue on the nasopharyngeal wall in 53 children from 3 to 16 years of age. They found that the thickness increased at 5 years and then decreased until age 10. The most interesting finding, however, was that there was a slight increase in lymphoid tissue on the nasopharyngeal wall at 10 to 11 years of age, decreasing again after 11 years. Both theories appear to support our present finding of a drop in nasal airway size during the prepubertal period, since both indicate that the adenoid size is greatest around age 10. This prepubertal increase in lymphoid tissue could

Table 2
Means, 95% confidence intervals, standard deviations (SD), and medians for age at the smallest nasal cross-sectional area (years), for minimum nasal cross-sectional area (cm^2), for difference between area at age at 13 and smallest area (cm^2), and for difference between cross-sectional area at age 9 and smallest area (cm^2) in 82 children (47 girls, 35 boys) measured annually from age 9 though age 13

	Mean	95 % confidence interval for mean	SD	Median
Age of smallest area	10.4	10.1 to 10.7	1.30	10
Females	10.2	9.9 to 10.6	1.27	10
Males	10.6	10.1 to 11.03	1.33	10
Smallest area	0.30	0.28 to 0.32	0.11	0.30
Females	0.30	0.27 to 0.33	0.10	0.30
Males	0.30	0.26 to 0.34	0.11	0.31
Difference between area at age 13 and smallest area	0.21	0.18 to 0.25	0.15	0.22
Females	0.21	0.18 to 0.25	0.13	0.24
Males	0.21	0.15 to 0.27	0.17	0.22
Difference between area at age 9 and smallest area	0.10	0.08 to 0.12	0.11	0.08
Females	0.09	0.06 to 0.13	0.12	0.05
Males	0.11	0.07 to 0.14	0.11	0.09

be a reflection of changing levels of sex hormones. On the other hand, model studies of upper airway breathing have demonstrated that the adenoid mass of the nasopharynx must be extremely large to affect airway resistance and minimum nasal cross-sectional area.[27] That is, the obstruction at the nasopharyngeal isthmus must be considerably smaller than the opening at the nasal valve to greatly influence nasal airway resistance. Since the opening at the valve is about 0.40 to 0.50 cm^2 in adolescents, the adenoid mass would have to extrude within about 2 to 3 mm of the soft palate to have a substantial effect on airway diameter.[27]

If the adenoids are not the cause, then the decrease in size must be due to changes in the nasal mucosa. Even though nasal airway is stabilized by cartilage and bone, it is lined with dynamic erectile tissue whose thickness can be regulated by the fluid content and volume of blood flowing through it.[28] Therefore, the rising levels of sex hormones (gonadotropins) during the prepubertal period may have an effect on the nasal mucosa. Gonadotropins are secreted during fetal life, but decline to a lower level after early infancy and persist until the onset of puberty. During prepuberty, significant amounts of luteinizing hormone (LH), follicle stimulating hormone (FSH), estradiol (E_2), and testosterone (T) are secreted, before physical changes occur in the body.[16]

No significant difference in the change of nasal airway size was indicated between genders, which is in substantial agreement with earlier cross-sectional reports of nasal airway size in males and females.[11,12,15,21] Still, there was a trend for the drop in nasal airway size to occur earlier in girls than in boys, even though the difference between genders was statistically nonsignificant. This finding indicates that there is no gender difference in timing of adenoidal or mucosal changes in the nasal airway, even though it does not exclude the possibility of a different mechanism or effector for males and females. Although there is a significant difference in the timing of the growth spurt between genders, there is only a slight difference in timing of puberty, which occurs around age 11 in females and approximately half a year later in males.[16,17] However, there is a distinct difference between genders in the concentrations of different hormones secreted. For example, prepubertal females release more FSH and E_2 than males, whereas males produce more T than females.[16,17] In addition to its reproductive effects, E_2 also causes salt- and water-retention.[30] T has direct effects on testes, the pituitary gland, and muscles, but it also acts on other organs after conversion to E_2.

Although it is tempting to correlate hormonal changes with changes in the volume of the nasal mucosa, no evidence for this mechanism currently exists. E_2 does cause fluid retention in tissues, but why would the effect on nasal mucosa be transient when E_2 levels remain elevated after the initiation of puberty? It is not known whether steroid hormone receptors exist in the nasopharyngeal mucosa or act directly or through another effector. The difference in distribution of steroid receptors between genders is also unknown. Thus, the only conclusion that can presently be drawn is that volume changes in the adenoidal tissues or in the nasal mucosa must exceed growth of the bony nasal cavum during the prepubertal years.

Earlier cross-sectional studies have suggested that the nasal cross-sectional area reaches the adult nasal size around age 15 to 16,[11-14] the normal mean nasal airway size being somewhere between 0.50 and 0.60 square cm.[12,14,15,30] The present longitudinal study suggests that adult size may be reached earlier than indicated by cross-sectional studies, since the mean nasal cross-sectional area was already 0.51 cm^2 in the 13-year-olds. Further follow-up of this group will show if growth of the functional nasal airway continues or ceases after 13 years of age.

Conclusions

This longitudinal study of 82 children indicates that, although nasal airway size increases from age 9 to 13, it also decreases transiently at some point between 9 and 13 years, possibly reflecting the prepubertal hypertrophy of lymphoid or erectile tissues in upper airways. No significant difference was seen in timing or magnitude between genders. Further study of this group will indicate when growth changes cease to affect nasal airway size.

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