Should a history of nasal symptoms be considered when estimating nasal patency?

Maija T. Laine-Alava, DDS, PhD; Ulla K. Minkkinen, DDS

Abstract: The purpose of this study was to determine if a history of certain nasal symptoms and ear, nose, throat, or lung disease should be taken into consideration when measuring patency of the nasal airway. The pressure-flow technique was used to measure nasal cross-sectional area and resistance in 249 healthy and nasally asymptomatic 16- to 82-year-old individuals. The subjects were also asked to complete a questionnaire of possible airway problems. The results showed that there were statistically significant differences in minimum nasal cross-sectional area and upper airway resistance between males and females, between individuals with and without allergic rhinitis, and between smokers and nonsmokers. However, these differences were too small to be of physiological or clinical importance. Therefore, when determining nasal cross-sectional area and resistance in individuals with a history of upper or lower airway problems, measurements can be assumed to be accurate, irrespective of other factors, as long as they are made during an asymptomatic period.

Key Words: Dentofacial development, Nasal cross-sectional area, Nasal patency, Nasal resistance, Nasal symptoms, Pressure-flow technique

Posterior rhinomanometry is commonly used to measure nasal patency in adults as well as in children from 5 to 6 years on. Information about nasal airway size is valuable not only in the ENT clinic, but also in orthodontic practices; several studies have indicated that a relationship exists between impaired nasal breathing and deleterious dentofacial growth and development.[1-5] However, the nature of this relationship has been debated for decades and contradictory opinions on this issue are numerous.[6-9]

Several studies[10-16] have shown that age is a factor that has to be taken into consideration when measuring the patency of the nasal airway in children. Nasal airway seems to grow until 16 years of age.[10,14,17] Previous studies of the effects of relative body size (expressed as body mass index or BMI) and sex on nasal airway size and resistance appear to conflict.[10-12,14,16,18-20]

The mucosa of the nasal airway responds to changes in temperature, smoke, pollutants, dusts, and pollens and other allergens or irritants by congesting and decongesting, causing short-term changes in nasal resistance and giving rise to various types of nasal symptoms.[18,21-24] It has also been suggested that the respiratory tract is a unit, from the oronasal cavities to the lungs; disease or inflammation in one part of the airway may also manifest in physiological changes in other locations along the tract.[21] Therefore, the purpose of this study was to examine the effects of a history of frequent nasal symptoms, nature and occurrence of nasal symptoms, asthma, recurrent ENT or lung infections and tobacco-smoking on nasal airway patency, considering also the effects of age, BMI, and sex. In other words, does a history of frequent airway problems have an association with nasal airway size or resistance during the time subjects are healthy and asymptomatic? We wanted to know if there is certain anamnestic information that should be taken into consideration when measuring the variables that may reflect nasal airway impairment, namely, the size and the resistance of the nasal airway.

Materials and methods

The subjects for this study were 249 adolescents and adults (151 females and 98 males), aged 16 through 82

Author Address
Ulla Minkkinen, DDS
University of Kentucky
Department of Physiology
MS508C Medical Center
Lexington, KY 40536-0084
Email: ukmink0@pop.uky.edu

Maija T. Laine-Alava, orthodontic graduate program, University of Kentucky College of Dentistry, Lexington, Ky.

Ulla K. Minkkinen, University of Kentucky, Department of Physiology, Lexington, Ky., and University of Kuopio, Department of Oral and Dental Diseases, Kuopio, Finland.

Submitted: October 1997, **Revised and accepted:** January 1998
Angle Orthod 1999;69(2):126-132.

years. They were volunteers who came to the dental clinic of the University of Kuopio for their dental checkup, and dental students, staff, and faculty of the Department of the Dentistry. The criterion for selection was the absence of upper airway congestion due to colds or allergic rhinitis at the time of examination. Table 1 lists the means of age, body height (cm), weight (kg), and body mass index (BMI) for females and males separately. The body mass index was calculated as follows: BMI=weight/(height/100)^2. There was a statistically significant difference in weight and height between sexes, but not in BMI values.

The pressure-flow technique[25] was used to measure airflow rate and differential oronasal pressure with the subject in a seated position using a well-fitted nasal mask. No nasal decongestants were used because we wanted to measure status and function of the nasal mucosa rather than skeletal dimensions of the upper airway. Nasal airflow rate was measured with a heated pneumotachograph connected to the nasal mask. The oronasal-pressure drop was measured by differential pressure transducers connected to two catheters, 2.42 mm in diameter. 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 microcomputer for recording and analysis. Then minimum nasal cross-sectional area was calculated as follows:

$A=V/k(2\Delta P/d)^{1/2}$ and resistance as: $R=\Delta P/V$, where A=nasal area (cm^2), R= resistance (cmH_2O/1/s), V= nasal airflow (ml/s), k=0.65, d=density of air (0.001 g/cm^3) and ΔP= oronasal pressure (cmH_2O). The inspiratory values for nasal cross-sectional area and resistance are reported in this paper.

Table 1
Means of age, weight, height, and BMI in a group of 249 subjects, according to sex

	Female (n=151)	Male (n=98)	p^*	Total (n=249)
Age				
Mean	48.8 (SD 17.4)	46.2 (SD 17.2)	0.25	47.8 (SD 17.4)
Median	51	49		50
Range	16-82	16-77		16-82
Weight (kg)				
Mean (SD)	64.2 (10.6)	77.0 (11.6)	0.00	69.2 (12.6)
Height (cm)				
Mean (SD)	162.6 (5.2)	176.1 (6.3)	0.00	167.9 (8.7)
BMI				
Mean (SD)	24.3 (4.0)	24.8 (3.6)	0.27	24.5 (3.8)

* By *t*-test

Table 2
Frequencies of nasal symptoms in a group of 249 subjects aged 16 through 82 years, according to sex

Nasal symptom	Female (n=151) %	Male (n=98) %	p^*	Total (n=249) %	n
Occasional nasal secretions	34.4	29.5	0.42	32.5	80
Occasional stuffy nose	39.7	38.5	0.85	39.3	97
Seasonal rhinitis	51.0	51.0	1.00	51.0	123
I. According to etiologic factor					
Allergy	37.8	36.1	0.81	37.2	81
Stress	7.7	3.8		6.2	13
Temperature change	28.2	29.5	0.83	28.8	63
Tobacco smoke	25.8	15.3	0.07	21.7	47
II. According to number of etiologic factors					
One factor	24.8	32.3	.	27.8	67
Two factors	15.9	14.6	.	15.4	37
Three factors	6.9	3.1	.	5.4	13
Four factors	3.4	1.0	.	2.5	6
Main season of symptoms					
Summer	34.0	28.1	0.33	31.7	78
Spring	45.3	36.5	0.17	41.9	103
Fall	36.0	33.3	0.67	35.0	86
Winter	38.0	37.5	0.94	37.8	93
Not season specific	28.0	20.0	0.16	24.9	61
During one season	8.7	14.3	.	10.9	27
During two seasons	12.0	11.2	.	11.7	29
During three seasons	2.7	6.1	.	4.0	10
During four seasons	28.0	19.4	.	24.6	61

* By chi-square test

Before measuring nasal patency, each subject was asked to fill out a complete questionnaire of occurrence and nature of nasal symptoms. The questionnaire was a modification of one designed by an allergologist at the ENT clinic of Kuopio University Hospital and used in the clinic and in some previous studies.[19,22] As Table 2 shows, about half the subjects reported a history of frequent nasal symptoms, such as occasional nasal secretions or seasonal rhinitis. Almost 40% of the subjects reported the frequent sensation of a stuffy nose. The most common causes for seasonal rhinitis were allergies to pollens and dust. In addition, over 20% of the subjects reported having a runny nose due to temperature changes or tobacco smoke. Only a few reported that nasal symptoms were caused by stress. Less than 10% of the subjects reported that several (three or four) factors caused rhinitis. Spring was the most common time for nasal symptoms, but over 30% had symptoms during summer, fall, or winter. Among one-fourth of the subjects, the nasal symptoms occurred randomly throughout the year. The frequencies of occurrence of all nasal symptoms did not differ between females and males. Although over half the subjects reported having frequent or recurrent symptoms in the upper airway, all the subjects were asymptomatic at the time nasal patency was measured.

Table 3 shows general anamnestic information related to upper airways among subjects. Seven subjects had asthma. About one-fourth of the subjects reported having recurrent infections of the ears, lungs, sinuses, or throat. Sinus and throat infections were more common than ear and lung infections. Recurrent infections in more than one organ in the proximity of the upper airway were rare. There were no differences between sexes in prevalence of asthma or infections. About 20% of the studied population group smoked, with the prevalence of smoking higher in males (27.6%) than in females (17.3%). The mean duration of smoking was 17.8 years (SD=11.8) in women and 18.1 years (SD=13.3) in men; the number of years smoked ranged from 1 to 40 in both groups.

Table 3
Frequencies of asthma, recurrent infections around the upper airway and smoking in a group of 249 subjects aged 16 through 82 years, according to sex

Anamnesis	Female (n=151) %	Male (n=98) %	p^*	Total (n=249) %	n
Asthma	2.7	3.1	0.56 †	2.8	7
Recurrent infections	28.7	20.8	0.17	25.6	63
I. According to location					
Ears	5.3	2.1	0.22	4.1	10
Lungs	8.0	6.3	0.61	7.3	18
Sinuses	13.5	10.4	0.47	12.3	30
Throat	14.7	10.4	0.33	13.0	32
II. According to number of locations					
One	18.7	12.5	.	16.3	40
Two	7.3	8.3	.	7.7	19
Three	2.7	0	.	1.6	4
Prevalence of smoking	17.3	27.6	0.05	21.4	53

* By chi-square test
† By Fisher's exact test

Statistical methods

Differences in age, weight, height, and BMI between sexes were estimated by *t*-test. The chi-square test was used to determine differences in prevalence of a history of different symptoms between sexes.

Linear regression models were used to find statistically significant associations between upper airway patency, measured as cross-sectional area or resistance, and a history of upper airway problems or other variables possibly influencing nasal patency. The following variables were included in the questionnaire: frequent nasal secretions (0=no, 1=yes), seasonal rhinitis due to allergy to pollens or dust (0=no, 1=yes), stress (0=no, 1=yes), temperature change (0=no, 1=yes), tobacco smoke (0=no, 1=yes), subjective sensation of congested nose (0=no, 1=yes), season of measurement of nasal patency (1=winter, 2=spring, 3=summer, 4=fall), asthma (0=no, 1=yes), combination of recurrent infections in the proximity of the upper airway, i.e., ears, lungs, sinuses, or throat (1=recurrent infection in one of these, 2=recerrent infections in two of these, 3=recurrent infections in three of these, 4= recurrent infections in four of these, 0=no recurrent infections), and smoking (0=no, 1=yes). Age, BMI, and sex were also included in the models. Pearson's correlation coefficients were calculated between each anamnestic variable, age, BMI, and sex. All pairs of variables with a correlation coefficient of ≥0.5 were entered separately into the linear regression models. This was the case only for age and BMI (see Results).

The variables that showed a statistically significant association with nasal airway size or nasal resistance by the linear regression model were further analyzed by the analyses of variance (ANOVA). *P*-values ≤0.05 were considered statistically significant in all analyses.

Results

The means of minimum nasal cross-sectional area and resistance to airflow for 16- to 82-year-olds were 0.52 cm^2 (SD 0.14) and 2.31 $cmH_2O/l/s$ (SD 1.62), respectively.

Since the Pearson correlation coefficient between age and BMI was high (0.5), it was added to the linear regression models separately. Age is included in model A and BMI in model B. The best-fitted model A (Table 4) indicated that minimum nasal cross-sectional area was associated with the following variables: existence of frequent nasal secretions, seasonal rhinitis due to allergy, and sex. Neither age nor BMI had an effect on nasal cross-sectional area, since the best-fitted model did not change when age was replaced with BMI (model B). By further analyzing the variables in the best-fitted model by analysis of variance, it was shown that only allergic rhinitis and sex had statistically significant effects on nasal cross-sectional area (Figures 1 and 2). The mean cross-sectional area was smaller in subjects with seasonal rhinitis due to allergy than in subjects without allergic rhinitis, and surprisingly, was larger in females than in males.

The same variables (see Methods) were used to determine their relationship to nasal resistance. The linear regression model indicated that sex and seasonal rhinitis due to allergy were associated also with nasal resistance (model A, Table 5), together with smoking. Again, the model remained the same when age was replaced with BMI (model B). The analysis of variance showed that all the variables in the best-fitted model—allergic rhinitis, smoking, and sex—had a statistically significant effect on resistance (Figures 1, 2, and 3). The mean resistance was significantly higher in subjects with allergic rhinitis than in those without it, in smokers than in nonsmokers, and in males than in females.

Table 4
Relationships between minimum nasal cross-sectional area (cm^2) and history of upper airway problems as estimated by linear regression model, considering effects of age and sex (model A). The best-fitted model is given.

Independent variable	Regression coefficient	SE	Coeff./SE	p
Occasional nasal secretions	0.063	0.024	2.65	0.01
Seasonal rhinitis due to allergy	-0.053	0.022	-2.35	0.02
Sex	-0.044	0.021	-2.06	0.04

Table 5
Relationship between nasal resistance ($cmH_2O/l/s$) and history of upper airway problems as estimated by linear regression model, considering effects of age and sex (model A). The best-fitted model is given.

Independent variable	Regression coefficient	SE	Coeff./SE	p
Seasonal rhinitis due to allergy	0.442	0.227	1.95	0.05
Smoking	0.689	0.261	2.63	0.01
Sex	0.691	0.219	3.15	0.00

Discussion

Since minimum nasal cross-sectional area and nasal resistance during inspiration are of critical importance for nasal versus oral breathing,[10] only inspiratory measurements were included in this report. The number of variables was too large to be analyzed simultaneously by analyses of variance. Therefore, the linear regression analysis was first used to limit the number of variables, excluding the ones with a weak effect on nasal size or resistance. The conclusions were based on the analyses of variance.

This study attempted to assess the relationship of subjective nasal symptoms to nasal airway size and resistance, often used to assess nasal patency. One of the most common methods of measuring nasal patency is posterior rhinomanometry. The method used in this study is one application of it, a pressure-flow technique described by Warren,[25] which has been shown to have good reproducibility.[22] Information about the nature and occurrence of nasal symptoms and causes for them, as well as general information about the health of the study subjects, was purely subjective, based on the questionnaire each subject completed. For measurements of nasal breathing, all the subjects had been indoors for at least one hour before the examination and thus acclimatized to the room temperature. Since it was presumed that spring and summer are the high seasons for allergic nasal symptoms, most of the subjects were examined during fall or winter. Irrespective of the fact that some of the subjects had nasal symptoms occasionally throughout the year, all the subjects were free of nasal symptoms and decongestive medications at the time of examination. There was no association between season of examination time and nasal cross-sectional area and resistance. Therefore, these results indicate that season has no importance in determining nasal patency as long as the patient is free of nasal symptoms at the time of measurement.

To minimize the effect of age on measurements of upper airway patency, the subjects selected for this study were 16 years old or older. However, since changes in the thickness and function of the nasal mucosa with aging are possible, the

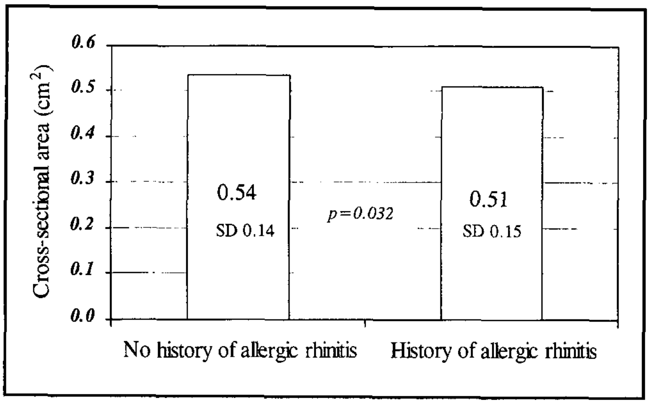

Figure 1A
Means of nasal cross-sectional area in individuals with and without allergic rhinitis, aged 16 through 82 years. Statistical significance by analysis of variance, occasional nasal secretions (0,1) and sex (0,1) as cofactors.

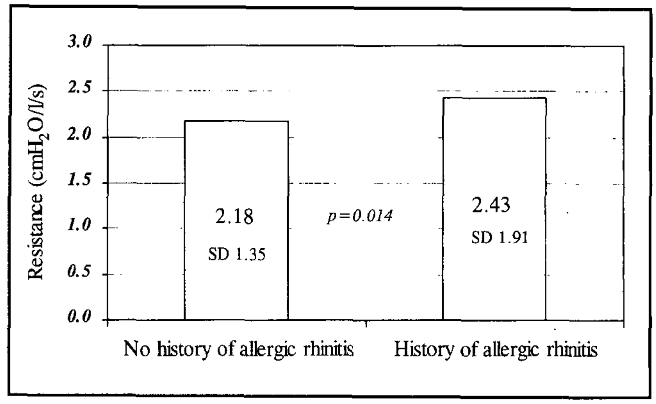

Figure 1B
Means of nasal resistance in individuals with and without allergic rhinitis, aged 16 through 82 years. Statistical significance by analysis of variance, smoking (0,1) and sex (0,1) as cofactors.

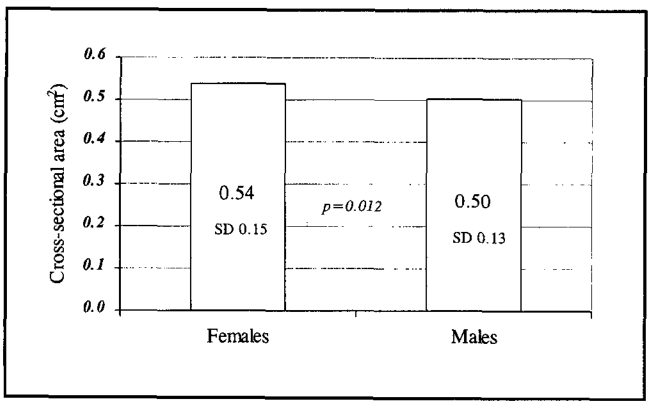

Figure 2A
Means of nasal cross-sectional area in females and males, aged 16 through 82 years. Statistical significance by analysis of variance, occasional nasal secretions (0,1) and history of allergic rhinitis (0,1) as cofactors.

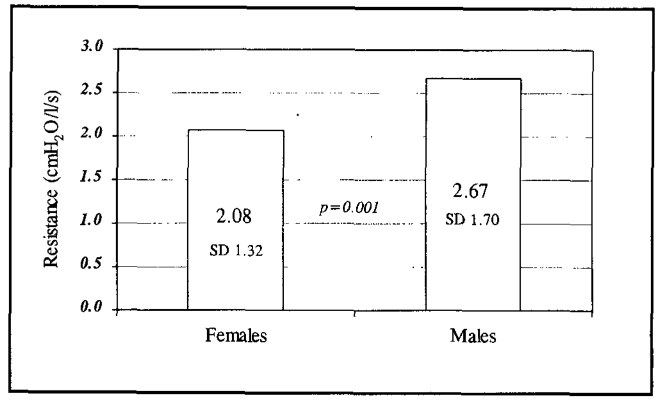

Figure 2B
Means of nasal resistance in females and males, aged 16 through 82 years. Statistical significance by analysis of variance, allergic rhinitis (0,1) and smoking (0,1) as cofactors.

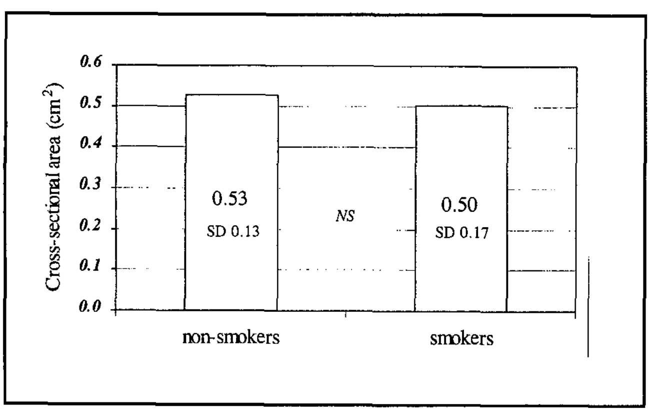

Figure 3A
Means of nasal cross-sectional area in smokers and non-smokers, aged 16 through 82 years.

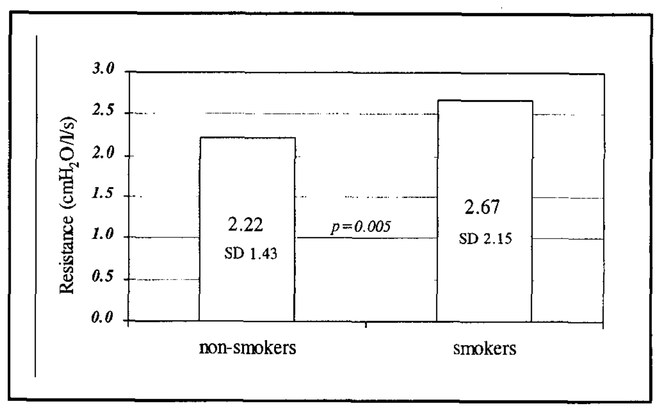

Figure 3B
Means of nasal resistance in smokers and nonsmokers, aged 16 through 82 years. Statistical significance by analysis of variance, allergic rhinitis (0,1) and sex (0,1) as cofactors.

effect of age was considered in the linear regression models. The models showed that age did not have an effect on nasal cross-sectional area or resistance. Therefore, we are able to generalize the results of these analyses to the whole age group from 16 to 82 years with confidence.

Although males were heavier and taller than females, there was no difference in relative body size, expressed as BMI. Our earlier studies[10] indicated that there is a correlation between BMI and the rate of nasal airflow in 7- to 24-year-olds, but as previously shown,[11,14,16,19,20] BMI was not related to nasal cross-sectional area and resistance. As one might presume, there was a strong correlation between age and BMI, which forced us to use two separate linear regression models. Nevertheless, the results of linear regression models, whether with age or BMI included, were identical.

Previous studies in children indicated that there is no difference in nasal cross-sectional area and resistance to airflow between sexes.[10-12,14,16] However, this current study, in a sample of individuals 16 years old or older, indicated a significant association with gender. However, differences averaging 0.04 cm^2 in size and 0.55 $cmH_2O/l/s$ in resistance have no physiological or clinical implications.

The most common cause for allergic rhinitis was dust, the second was pollen. Subjects with recurrent allergic rhinitis had slightly smaller nasal cross-sectional area and higher nasal resistance to airflow than the nonallergic subjects, even though examined when asymptomatic. About half the individuals with allergic rhinitis reported having symptoms during the season when they were examined. Therefore, it may be possible that a recently passed acute phase of rhinitis still had an effect on airway measurements, since allergic rhinitis is known to impair the patency of the nasal airway, at least temporarily.[21,26,27] Previous studies[12,28,29] have shown that resistance values below 3.5 to 4.5 $cmH_2O/l/s$ and cross-sectional area over 0.4 cm^2 of the nasal airway should provide a physiologically patent airway, without affecting the mode of breathing. The mean values we found in subjects with recurrent allergic rhinitis were not even close to these values, considered thresholds for adolescents and adults for switching to partial mouth breathing. Therefore, our results indicate that the tendency to allergic nasal symptoms has no clinically significant long-term effects on the patency of the nasal airway, even if it is clear that nasal resistance is periodically elevated during the acute symptoms. It seems that allergic people have the capacity to breathe through the nose, but may become mouth breathers when symptomatic. If the symptoms occur often, the patient may not return to nasal respiration even when symptom-free. That is why mode of respiration may not always be correlated with nasal airway patency.

Almost 40% of the subjects with allergic rhinitis also had nasal symptoms due to temperature change or tobacco smoke, which indicates a highly sensitive nasal mucosa in these subjects. Only 7% of the subjects without allergic rhinitis reported symptoms due to tobacco smoke, and about 18% of them had symptoms due to temperature change. In addition to infectious or seasonal rhinitis, the secretory activity of the nose may be increased due to vasomotor rhinitis, autonomic imbalance, or even physiological stress.[21] However, frequent nasal secretions or a tendency to runny nose due to stress showed no relationship to nasal airway size.

The individuals who reported having a frequent sensation of congested or stuffy nose, did not have significantly different means of cross-sectional area and resistance than those without these problems. As reported earlier, there is great individual variation in the level of sensation of the changes in nasal resistance: often the subjective and objective determinations of nasal obstruction do not correlate.[19,30] Some individuals are hypersensitive and feel discomfort while breathing through the nose, even if the airway is patent enough. On the contrary, there are individuals with relatively small nasal airways who are not aware of it and have no trouble breathing through the nose. The results of this study support this contradictory clinical observation.

Smoking seems to elevate nasal resistance to airflow. Earlier studies have indicated[18] that tobacco smoke can elevate the resistance, even near the 4.5 $cmH_2O/l/s$ threshold value. This was not the case in our study; the mean resistance was only slightly elevated in smokers compared with nonsmokers. The smokers had not been smoking for at least one hour before the examination; if smoking had an immediate effect on nasal mucosa, it did not show in this study. Also, comparisons with nonsmokers may be misleading, since we could not estimate the effects of possible passive smoking in the nonsmoking group. Although the relationship of the physiology of upper and lower airways is suggested,[21] this study found no association between measured nasal airway patency measured and history of asthma, lung infections, or ENT problems.

Conclusions

This study showed that a history of frequent nasal symptoms, asthma, and recurrent ENT or lung infections has no effect on nasal airway measurements of rest breathing when the individuals are measured during an asymptomatic period. Although females over 16 years of age showed statistically significantly larger nasal airway size than males, and individuals with a history of allergic rhinitis or smoking registered slightly elevated nasal resistance values compared with controls, these differences are unlikely to have any clinical importance. Therefore, when determining the normal rest breathing pattern of individuals with a history of upper or lower airway problems, the only factor to be considered is the time of measurement. They should be performed during an asymptomatic period.

Acknowledgments

The authors want to express their special thanks to Dr. Pirkko Ruoppi, MD, PhD, Department of Otolaryngology, University of Kuopio, for designing the questionnaire used in this study; to Dr. Seppo Lammi, PhD, Department of Computer Science and Applied Mathematics, University of Kuopio, for consulting in biostatistics; and to Mrs. Riitta Myllykangas for technical help during the airway measurements. This study was supported by grants from the Academy of Finland and the Finnish Dental Society.

References

1. Harvold EP, Tomer BS, Vargervik K, Chierici G. Primate experiments on oral respiration. Am J Orthod 1981;79:359-372.
2. Linder-Aronson S. Adenoids: Their effect on mode of breathing and nasal airflow and their relationship to characteristics of the facial skeleton and the dentition. Acta Otolaryngol 1970;265:1-132.
3. Solow B, Kreiborg S. Soft-tissue stretching: A possible control factor in craniofacial morphogenesis. Scand J Dent Res 1977;85:505-507.
4. Solow B, Siersbaek-Nielsen S, Greve E. Airway adequacy, head posture, and craniofacial morphology. Am J Orthod 1984;86:214-223.
5. Vargervik K, Miller AJ, Chierici G, et al. Morphologic response to changes in neuromuscular pattern experimentally induced by altered modes of respiration. Am J Orthod 1984;85:115-124.
6. Watson RM, Warren DW, Fisher ND. Nasal resistance, skeletal classification, and mouth breathing in orthodontic patients. Am J Orthod 1968;54:367-379.
7. Vig PS, Sarver DM, Hall DJ, et al. Quantitative evaluation of nasal airflow in realtion to facial morphology. Am J Orthod 1981;79:263-272.
8. Hartgerink DV, Vig PS. Lower anterior face height and lip incompetence do not predict nasal airway obstruction. Angle Orthod 1989;59:17-23.
9. Kluemper GT, Vig PS, Vig KWL. Nasorespiratory characteristics and craniofacial morphology. Eur J Orthod 1995;17:491-495.
10. Laine-Alava MT, Minkkinen UK. Variation of nasal respiratory pattern with age during growth and development. Laryngoscope 1997;107:386-390.
11. Laine T, Warren DW. Effects of age, gender, and body size on nasal cross-sectional area in children. Eur J Orthod 1991;13:311-316.
12. Parker LP, Crysdale WS, Cole P, Woodside D. Rhinomanometry in children. Int J Pediat Otorhinolaryngol 1989;17:127-137.
13. Principato JJ, Wolf P. Pediatric nasal resistance. Laryngoscope 1985;95:1067-69.
14. Saito A, Nishihata S. Nasal airway resistance in children. Rhinology 1981;19:149-154.
15. Warren DW, Hairfield MW, Dalston ET. Effects of age on nasal cross-sectional area and respiratory mode in children. Laryngoscope 1990;100:89-93.
16. Vig PS, Zajac DJ. Age and gender effects on nasal respiratory function in normal subjects. Cleft Palate Craniofac J 1993;30:279-284.
17. Warren DW, Duany LF, Fischer ND. Nasal pathway resistance in normal and cleft lip and palate subjects. Cleft Palate J 1969:134-140.
18. Dessi P, Sambuc R, Moulin G, Ledoray V, Cannoni M. Effects of heavy smoking on nasal resistance. Acta Otolaryngol 1994;114:305-310.
19. Laine MT, Warren DW. Perceptual and respiratory responses to added nasal airway resistance loads in older adults. Laryngoscope 1995;105:425-428.
20. Togawa K, Nishihira S. Statistical analysis of changes of pediatric nasal patency with growth. Laryngoscope 1988;98:219-225.
21. Cole P. The respiratory role of the upper airways. St. Louis: Mosby, 1992:3-48.
22. Laine MT, Huggare JA, Ruoppi P. A modification of the pressure-flow technique for measuring breathing of cold air and its effects on nasal cross-sectional area. Am J Orthod Dentofac Orthop 1994;105:265-269.
23. Leff AR, Schumacker PT. Respiratory physiology, basics and applications. Philadelphia: Saunders 1993: 155-157.
24. Cole P, Haight JSJ, Cooper PW, Kassle EE. A computed tomographic study of nasal mucosa: effects of vasoactive substances. J Otolaryngol 1983;12:58-60.
25. Warren DW. A quantitative technique for assessing nasal airway impairment. Am J Orthod 1984;86:306-314.
26. Sassouni V, Friday GA, Shnorhokian H, Beery QC, Zullo TG, Miller DL, et al. The influence of perennial allergic rhinitis on facial type and a pilot study of the effect of allergy management on facial patterns. Ann Allergy 1985;54:493-497.
27. Trask GM, Shapiro GG, Shapiro PA. The effects of perennial allergic rhinitis on dental and skeletal development: A comparison of sibling pairs. Am J Orthod Dentofac Orthop 1987;92:286-293.
28. McCaffrey TV, Kern EB. Clinical evaluation of nasal obstruction. Arch Otolaryngol 1979;105:542-545.
29. Warren DW, Hairfield WM, Seaton D, Morr KE, Smith LR. The relationship between airway size and nasal-oral breathing. Am J Orthod Dentofac Orthop 1988;93:289-293.
30. Jones AS, Willatt DJ, Durham LM. Nasal airflow: resistance and sensation. J Laryngol Otol 1989;103:909-911.