European Journal of Orthodontics 26 (2004) 397–401
European Journal of Orthodontics vol. 26 no. 4

Evaluation of nasal airway resistance during rapid maxillary expansion using acoustic rhinometry

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SUMMARY The purpose of this study was to evaluate nasal airway resistance (NAR) during rapid maxillary expansion (RME) using acoustic rhinometry (AR). The sample comprised 22 children (13 girls and nine boys) with maxillary constriction. The mean age was 12.9 ± 1.54 years and all patients were found to have normal nasal cavities following anterior rhinoscopic examination. A modified bonded splint type RME appliance was used for expansion. AR was used to measure NAR before (T_1), during (T_2) and after (T_3) expansion, and at the end of retention (T_4). Each AR recording was performed, for each patient, with and without the use of a decongestant. Subjective evaluation of reported changes in nasal breathing were also undertaken at T_3.

The results showed that NAR was significantly reduced with the use of RME, with the main decrease observed during expansion ($P < 0.05$). The use of a decongestant was not found to have any effect on the results. Subjective evaluation showed that 59 per cent of patients considered that their nasal breathing had improved following RME.

Introduction

Maxillary arch constriction or maxillary width deficiency, concomitant with a high palatal vault, is a manifestation of a skeletally developed syndrome that causes some rhinologic problems and has certain negative effects on the dentofacial pattern. Some of the more typical features of this syndrome are: (1) a decrease in nasal permeability resulting from nasal stenosis, (2) elevation of the nasal floor, (3) mouth breathing, (4) bilateral dental maxillary crossbite combined with a high palatal vault and (5) a decrease in nasal airway size due to enlargement of the nasal turbinates (Laptook, 1981). In addition, airway obstruction, which can occur as a result of adenoid tissue or nasal septal deviation, is associated with characteristic changes in craniofacial morphology (McDonald, 1995).

The dental manifestations of the resultant malocclusion are generally treated orthodontically by rapid maxillary expansion (RME). This procedure, introduced by Angell (1860), gained more attention during the 1960s and has been successfully used in both children and young adults (Da Silva Filho *et al.*, 1995). Although the main objective of RME is to correct transverse deficiencies of the maxillary arch, its effects are not limited to the upper jaw. The maxilla is connected with 10 further bones in the craniofacial complex and, therefore, RME may directly or indirectly affect these structures. These may include the mandible, nasal cavity, pharyngeal structures, temporomandibular joint, middle ear, and pterygoid process of the sphenoid bone (Ceylan *et al.*, 1996). The reported direct benefits of RME have included: improved breathing, correction of dental crossbites with relief of dental crowding (Hartgerink *et al.*, 1987; Da Silva Filho *et al.*, 1995), and improved conductive hearing loss due to middle ear and eustachian tube problems (Gray, 1975; Laptook, 1981).

Nasal airway resistance (NAR) accounts for approximately 50 per cent of total airway resistance. The nasal valve region is the narrowest segment of the nasal airway and is the major flow-resistive segment (McCaffrey, 1993). NAR is a measure of airway adequacy (McDonald, 1995). It can be recorded by rhinomanometry, that is the simultaneous measurement of transnasal pressure and airflow (Pallanch, 1998). Acoustic rhinometry (AR) can be used to evaluate nasal breathing and NAR objectively (Pallanch, 1998). The method appears to be sensitive and more reproducible than rhinomanometric methods (Fouke and Jackson, 1992).

There is a lack of scientific evidence concerning the effects of dental arch expansion on nasal airway dimensions and airflow. Although it is relatively easy to measure intermolar or intercanine width changes as a result of orthodontic treatment, these cannot be extrapolated to changes in nasal airway dimension and related airflow (Hartgerink *et al.*, 1987). The measurement of NAR could be useful in determining the effects of interventions, such as RME, on the nasal airway. To date, no reports using the AR method, as a measure of NAR, have been reported in the orthodontic literature. The aim of this study was to evaluate NAR using AR in a group of orthodontic subjects before, during, and after RME and to re-assess the response 8 months post-expansion.

Subjects and methods

Selection of patients and controls

Thirty patients were initially recruited to the study. However, four subjects failed to return for measurements and a further four patients did not respond to RME therapy and were eliminated from additional analyses. Thus, 22 patients completed the study (13 females and nine males, mean age 12.9 ± 1.54, range 10.1–15.2 years). All were seen at the Orthodontic Clinic of Cumhuriyet University during the period February–September 2002. The patients were enrolled into the study if there was a transverse maxillary deficiency with a bilateral crossbite and no history of nasal disease. Furthermore, the presence of an adequate nasal cavity space was confirmed using anterior rhinoscopic examination by a single qualified otolaryngologist.

RME appliance

A modified bonded splint type RME appliance (Figure 1), with full occlusal coverage, was selected to provide control of the vertical dimensional changes that occur in growing patients during maxillary expansion (Alpern and Yurosko, 1987). A hyrax screw (GAC International, Islandia, New York, USA; 17-002-01) was placed across the interpremolar region. Glass ionomer cement was used for cementation (Ketac-Cem, Espe Dental Ag, Seefeld, Germany). Small relief holes were placed in the appliance to provide cement flow and full seating. All patients were instructed to activate the screw twice a day for the first week (0.5 mm) and then once a day (0.25 mm), until the posterior crossbite was eliminated. Sutural opening was confirmed, during active expansion (T_2), by the presence of a median diastema and also by radiographic examination. The intercanine and intermolar widths were recorded from T_1 and T_3 models with callipers. The measurements were carried out between the incisor tips of the canines and the deepest points of central sulci of the upper first molar teeth for intercanine and intermolar dimensions, respectively.

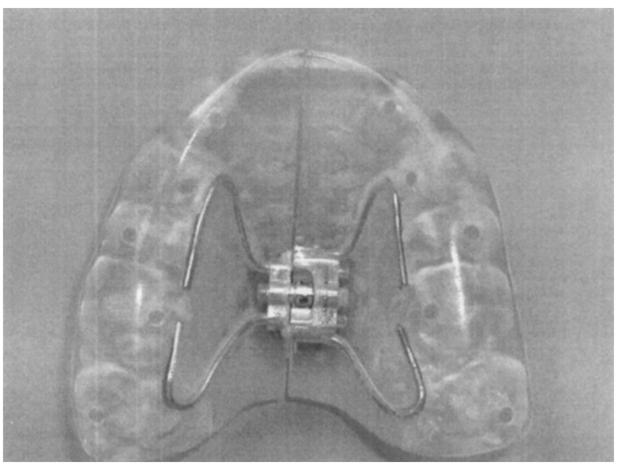

Figure 1 The modified bonded rapid maxillary expansion appliance.

AR

AR analyses sound waves which are reflected within the nasal cavity. Acoustic pulses, which are generated by a spark, pass through the wave tube and enter the nasal passage through the nosepiece of the AR device. The sound, which is reflected as a wave, impacts against structures in its passage. These reflected waves are detected by a microphone and are then amplified, low-pass filtered, and digitized. The processed data are then converted into an area–distance plot using a computer (Hilberg *et al.*, 1989). A schematic diagram of the AR device is shown in Figure 2.

Method of recording

All AR measurements were performed by the same otolaryngologist (EIC) at the following time periods: T_1, T_2, and T_3. The final measurement (T_4) was obtained after ossification of the suture was confirmed radiographically approximately 8 months after the end of retention. The timing of the T_3 and T_4 measurements was determined by the same orthodontist (OS), with patients receiving monthly follow-up appointments. All AR measurements were carried out at the same room temperature (20°C) and at a constant humidity. The patients were allowed to rest for 30 minutes before the recordings commenced and the device was calibrated

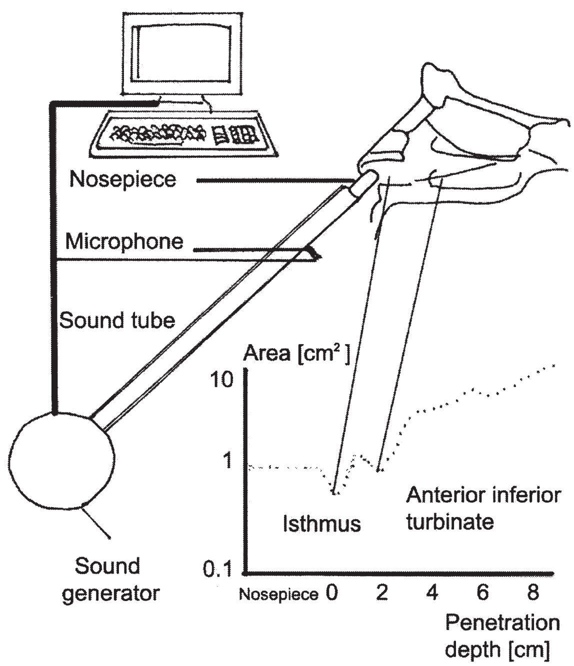

Figure 2 A diagram of the acoustic rhinometry device.

Table 1 Descriptive statistics (mean ± standard deviation) for the nasal airway resistance measurements (cm H_2O/l/minute).

	T_1	T_2	T_3	T_4
Non-decongestant (*n* = 22)	0.068 ± 0.053	0.045 ± 0.026	0.044 ± 0.033	0.046 ± 0.045
Decongestant (*n* = 22)	0.054 ± 0.037	0.038 ± 0.022	0.032 ± 0.014	0.026 ± 0.008

T_1, before treatment; T_2, during active expansion; T_3, expansion completed; T_4, end of the observation period.

during this period. After calibration, the nosepiece was placed to the nostril with the patient seated. NAR was measured, four times for each nostril, prior to the application of any decongestant. Following this, a decongestant nasal spray (Iliadin® Merck KGaA, Darmstad, Germany; 0.5 mg oxymetazoline hydrochloride/ml) was applied to the nostrils and the process of measurement repeated after a time delay of 10 minutes for the decongestant to take effect. Thus, NAR was determined for each side of the nose and the total resistance calculated using Ohm's law equation for parallel resistors: $1/R_T = 1/R_r + 1/R_l$, where R_T = total nasal resistance, R_r = nasal resistance on the right side, R_l = nasal resistance on the left side.

Subjective assessment

A structured questionnaire to interview patients was undertaken by the otolaryngologist in conjunction with the orthodontist, after expansion had been completed (T_3). The questionnaire was designed to obtain detailed information on the patterns of nasal breathing and specifically any changes that had been noted following RME. The patients were asked to record their response as 'better', 'unchanged' or 'worse'.

Error study

Models from 13 randomly selected subjects were re-measured by the same orthodontist after approximately 6 months in order to determine the method error. The error of single measurements (Dahlberg's formula) was found to be 0.19 mm for intercanine and 0.24 mm for intermolar measurements. Method error $=\sqrt{\Sigma d^2/2n}$ where *d* is the difference between two measurements of a pair and *n* is the number of subjects (Dahlberg, 1940).

AR measurements

The mean of at least 10 successive rhinograms was taken automatically by the AR device. All measurements were repeated four times.

Statistical method

The SPSS package 8.0 (Statistical Package for the Social Sciences, Chicago, Illinois, USA) was used to analyse the results. An analysis of variance was used to determine any difference in nasal resistance values with the use of the decongestant. A least significant differences (LSD) test was used to evaluate differences between the time intervals for different measurements. The LSD test is equivalent to multiple *t*-tests. The modification is that a pooled estimate of variance is used rather than the variance common to two groups being compared.

Results

The mean duration of active expansion and retention was 27.7 ± 4.6 days and 8 ± 2.2 months, respectively. The mean intercanine expansion was 5.02 ± 1.52 mm and the mean intermolar expansion was 5.97 ± 2.40 mm at T_3.

The means and standard deviations of measurements for changes in NAR are shown in Table 1. The values for the percentage reduction changes in NAR between the initial and the end of the active expansion period (T_1 and T_3) were 40.7 and 35.2 for the decongestant and non-decongestant groups, respectively. A more significant reduction in NAR was observed between T_1 and T_4 measurements (51.8 and 32.3 per cent for the decongestant and non-decongestant groups, respectively). However, the difference between the groups was not statistically significant (f = 2.808, P = 0.101). Furthermore, no statistically significant difference could be detected in NAR with the use of a nasal decongestant (f = 0.040, P = 0.526). This is illustrated by the nearly parallel lines in Figure 3. Significant differences were found between the measurements undertaken at different time periods (f = 23.772, P = 0.00). The most notable statistical difference was observed between the start of treatment (T_1) and T_2, T_3, and T_4 ($P < 0.05$), using LSD. However,

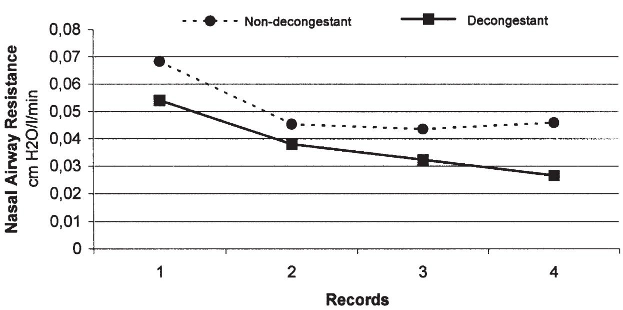

Figure 3 A graphical representation of the observed changes in nasal airway resistance with and without the application of a nasal decongestant, prior to performing acoustic rhinometry.

Table 2 Evaluation of subjective results on nasal breathing at T_3 ($n = 22$).

	No. of patients	Percentage
Better	13	59
No change	9	41
Worse	0	0

the differences between T_2 with T_3 and T_4 measurements were not found to be statistically significant ($P = 0.436$, $P = 0.265$, and $P = 0.632$, respectively).

Subjective evaluation (see Table 2) revealed improved nasal breathing in 13 patients, with the remaining nine reporting no improvement at T_3.

Discussion

It is commonly assumed that constriction of the maxillary dental arch causes nasal stenosis and oral respiration. Furthermore, nasorespiratory function has been reported to exert a dramatic effect upon the development of the dentofacial complex (Linder-Aronson, 1970). Specifically, it has been stated that chronic nasal obstruction leads to mouth breathing, which causes altered tongue and mandibular positions. If this occurs during a period of active growth, the outcome is the development of 'adenoid facies' (Linder-Aronson, 1974; O'Ryan *et al.*, 1982). There is, however, some controversy in the literature with regard to the existence of a relationship between nasorespiratory function and dentofacial morphology. A critical review by O'Ryan *et al.* (1982) failed to support a consistent relationship between obstructed nasorespiratory function and adenoid facies or long-face syndrome. Nevertheless, procedures such as nasopharyngeal surgery, allergy treatment, and RME continue to be advocated to eliminate the effects of nasal obstruction on facial form. RME has been used for both dental and rhinological purposes in the belief that clinically significant and predictable reductions in nasal resistance to airflow occur (Hartgerink *et al.*, 1987).

Age-related decreases in NAR, of approximately 0.1cm H_2O/l/second/year, have previously been reported (Principato and Wolf, 1985). These findings are supported by Melsen (1975), who showed that internal resorption of the bony nasal cavity occurs up to 15 years of age. Thus, growth will have a small but positive effect in decreasing nasal resistance as it will be accompanied by a concomitant increase in the width and area of the nasal cavity. In addition, atrophy of lymphoid tissue during growth and development is also thought to contribute to a decrease in nasal resistance (Massler and Zwemer, 1953).

A reasonable assumption may be that maxillary contraction produces a narrow nasal valve. RME may result in expansion at the anterior nares contributing to reductions in nasal resistance (Warren *et al.*, 1987; Hartgerink *et al.*, 1987). In addition, the high forces resulting from RME probably induce remodelling of the bones of the nasal cavity (Walters, 1975). The nasal valve is the region of the nasal airway extending from the caudal end of the upper lateral cartilage to the anterior end of the inferior turbinate. It is usually located approximately 1.3 cm from the nares (Santiago-Diez de Bonilla *et al.*, 1986). In the present study, mean intercanine and intermolar expansion of between 5 and 6 mm was achieved following RME. It can be concluded that it is the increase in intercanine width that accounts for the significant decrease in nasal resistance observed, in the short term, due to the direct effect exerted on the nasal valve area. Wertz (1968) also could not justify expansion unless an obstruction was present in the antero-inferior aspect of the nose, the area most affected by maxillary expansion. In the present study, NAR decreased following RME, with or without the application of a nasal decongestant. While a considerable reduction was found immediately following RME (T_2), no significant changes were observed at T_2 with T_3 and T_4. Thus, the reduction in NAR achieved at the end of T_2 remained stable during the 8 month observation period. In addition, subjective assessment revealed that 59 per cent of patients reported an improvement in nasal breathing at T_3. These findings support those of Hershey *et al.* (1976), in which a 45 per cent decrease in NAR following RME remained stable after 1 year.

The role of nasal decongestants in reducing NAR has been stressed by a number of authors. Berkinshaw *et al.* (1987) showed that with the use of a nasal decongestant, nasal resistance measurements were more reliable and less variable. Ohki *et al.* (1991) demonstrated that differences in total nasal resistance between various facial groups were more marked when noses were decongested. In view of the fact that the reproducibility of nasal resistance measurements in the decongested noses was very good, this technique has been recommended in studies designed to assess skeletal deformities such as a deviated nasal septum (Jones *et al.*, 1987). In contrast to these findings, the present study could not demonstrate any significant reduction in NAR following the application of a nasal decongestant.

Normal subjects show little individual variation in mean nasal resistance during the course of a day, with a reported coefficient of variation (CV) in the order of less than 15 per cent (Cole *et al.*, 1980). However, in one study using repeat rhinomanometric measurements after a period of 6 months, the CV was found to decrease to 7.7 per cent (Canbay and Bhatia, 1996). Hilberg *et al.* (1989) reported that AR provides greater reproducibility compared with rhinomanometry. In addition, the technique is quick to perform, painless, and non-invasive, requiring minimal patient co-operation. It is potentially useful for characterizing the geometry of the nasal cavity, for quantifying the dimensions of any nasal obstructions, and for assessing treatment outcomes (Buenting *et al.*, 1994; Hamilton *et al.*, 1995).

The use of RME in the present study achieved approximately 5–6 mm of arch expansion, which was accompanied by a 35 per cent reduction in NAR. However, given the relatively small sample size, the short observation period, and the absence of a matched control group, these findings alone are not sufficient to suggest that maxillary expansion therapy should be applied for the purpose of improving NAR.

Conclusions

1. The use of RME was accompanied by reductions in NAR, that remained stable during an 8 month follow-up period.
2. The use of a nasal decongestant offered no further advantage in reducing NAR.
3. Fifty-nine per cent of the patients reported subjective improvement in nasal breathing following RME.

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