University of Alberta

Exploratory Work on the Effect of Rapid Maxillary Expansion on Nasal Airway Dimensions

by

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Dedication

For Mom

Abstract

Objectives: To investigate whether any changes in nasal cavity dimensions or subjective report of nasal symptoms exist after rapid maxillary expansion using two types of expansion appliances, comparing results with an untreated control group.

Methods: Subjects were randomly assigned into one of three groups: tooth-borne or bone-anchored expander or untreated control. Acoustic rhinometry was used to measure minimal cross-sectional area and volume of the nasal cavity over three timepionts for treatment subjects and two timepoints for control subjects, taken along with the NOSE Instrument survey.

Results: No significant changes in nasal cavity dimension or subjective reports were found in subjects treated with tooth- or bone-anchored appliances compared to control subjects over three timepoints. In addition, non-significant correlation was observed between nasal airway dimensional change and subject symptoms.

Conclusions: Rapid maxillary expansion does not result in change of i) nasal airway dimensions or ii) the sensation of nasal symptoms.

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1.1 Statement of the Problem and Introduction

Since first introduced by Angell in 1860 [1], rapid maxillary expansion (RME) has been utilized in orthodontics with the goal of increasing maxillary transverse dimension. Undoubtedly, this method is effective in laterally separating the maxillary bones and widening the maxillary dentition [2]. This technique is commonly employed in those individuals in whom a constricted maxillary dentition exists, with or without a posterior cross-bite. There has been recurrent debate surrounding the efficacy of this treatment modality in changing airway dimensions in order that increased nasal airway volume and decreased resistance to airflow results; many techniques have been utilized to assess nasal changes after RME treatment [3].

Acoustic rhinometry (AR) is a static method used to assess nasal airway geometry. It has more recently been considered for routine use in the medical and dental communities [4]. The equipment is compact and relatively inexpensive, and the measurement technique is minimally invasive, painless and requires very little patient cooperation. Airway considerations are a continual topic of focus in the specialty of orthodontics, and of interest is whether any changes in nasal airway dimensions do result from RME, using a non-invasive, reliable and accurate method of evaluation.

1.2 Significance of the Study

This research is a pilot study; the results of the final study will contribute notably to the practice of clinical orthodontics. Many treatment decisions in daily clinical practices are made anecdotally, and the justification as to whether or not to use RME in a patient in order to improve nasal patency is a common occurrence. Individual patient variation is a reality and responses to treatment equally vary; the purpose of this research is to further elucidate historical assumptions regarding changes to the nasal airway. This study was focused on investigating whether any changes in minimal cross-sectional area and nasal cavity volume exist after rapid maxillary expansion using two types of expansion appliances (tooth-borne vs. bone anchored) comparing results with an untreated control group.

1.3 Research Questions

1) Does minimum cross-sectional area and nasal cavity volume differ before and after rapid maxillary expansion compared to control subjects using acoustic rhinometric assessment?
2) Is there subjective change in nasal symptoms after RME?

1.4 Null Hypotheses

The hypotheses of interest were whether minimum cross-sectional area, volume and subjective report of nasal function changed over time due to expansion therapy, namely:

H_o: There is no difference in mean minimum cross-sectional area and volume between groups at each timepoint.

H_o: There is no difference between groups in change in minimum cross-sectional area and volume between timepoints T0 and T1.

H_o: There is no difference between groups in change in minimum cross-sectional area and volume between timepoints T0 and T2.

H_o: There is no subjective change in nasal symptoms due to RME.

H_o: Mean minimum cross-sectional area and volume are the same at all time points.

H_o: Mean minimum cross-sectional area and volume are the same for each treatment group.

H_o: Differences in minimum cross-sectional area and volume between treatment groups are the same at all time points.

1.5 Literature Review

1.5.1 Rapid Maxillary Expansion

1.5.1.1 Convention in Orthodontics

Maxillary expansion has remained a treatment modality in orthodontics since first introduced by Emerson C. Angell in 1860 [1]. Not surprisingly, the efficacy of the procedure was originally challenged by prominent members of the dental community [5-11], and its initial use was not widespread in North America. Following Haas' reintroduction of the technique in the 1960's [2,12], the method has evolved into one of common use in which distinct rates are defined (slow vs. rapid), specific protocols are utilized, and the appliance design itself vastly varies.

1.5.1.2 Indications and Contraindications

Rapid maxillary expansion (RME) is the process utilised in order to physically separate the maxillary bones by means of opening the mid-palatal suture as a result of laterally-directed force application. Proposed indications for this type of therapy are: skeletal and/or dental maxillary transverse constriction [13-18] (with or without posterior cross-bite), cleft palate therapy [14-19], antero-posterior maxillary deficiency [14-16,18,19], maxillary arch length deficiency [15,16,18,20-22], nasal airway incapacities [14-17,23], and mouth breathing habits [19]. In

addition, Gray [17] suggested RME is indicated in individuals with any combination of poor nasal airway, septal deformity, recurrent ear or nasal infection, allergic rhinitis and asthma, and prior to septoplasty. There is general agreement that if a functional shift exists due to maxillary constriction that early expansive treatment is warranted, and there is a school of practice that uses RME in conjunction with maxillary protraction headgear [24]. In 1980, Haas stated there were no contraindications to the process "in a child of reasonable physical and mental health" [16]. Alpiner [19], Brogan [25] and Bishara [18] suggest poor patient or parent cooperation as a contraindication to RME, as well as single tooth cross-bites and skeletal asymmetries or disharmony.

1.5.1.3 Treatment Considerations

The method of rapid maxillary expansion is commonly used to treat maxillary constriction in growing individuals; it is believed that in order to obtain true separation of the maxillary bones it is important to apply lateral orthopaedic forces at a younger age, as increasing rigidity of the facial skeleton with advanced age can restrict bony movement. Melsen [26] discussed the increasing interdigitation of the suture with age, and Proffit [13] maintains that high success rates in opening of the mid-palatal suture are possible until age fifteen.

Common opinion exists that after the pubertal growth peak RME produces less skeletal expansion and more dental movement [27], and because of this many practitioners are treating individuals of adult age who require maxillary expansion with a slower expansion protocol [28].

In the coronal plane, it is written that RME separates the maxillae in a triangular pattern, with the base being at the level of the nasal floor and the apex located at the fronto-maxillary suture [15,25,29]. From an occlusal view both a parallel pattern of lateral separation [15,30] as well as a wedge-shaped separation (increased transverse changes in the anterior regions) [31,32] have been proposed. At the cellular level, the suture undergoes an initial inflammatory reaction in response to expansion followed by a proliferative repair process which results in regeneration of the suture [33].

The immediate response of the maxillae to RME has traditionally been viewed as being one according to Wertz [31] and Haas [15], in which the alveolar processes bend and move laterally along with their respective maxillary bones; once the lateral forces of expansion cease, the residual forces then dissipate [34] and these buccal segments would upright. A meta-analysis by Lagravere *et al* [35] concluded that expansion has both skeletal and dentoalveolar components; a recent case report by Podesser *et al* [36] using CT

measures found expansion of the skeletal structures along with tipping of the first molars.

Originally it was thought that if a rigid appliance was utilized for force application to teeth, that dental tipping would not be a concern. Haas [15] advocated palatal soft tissue coverage over an all-wire framework as he believed this optimized skeletal anchorage and avoided undesirable displacement of dental anchorage units. Long-term dental changes were assessed in a review by Lagravere *et al* [37], which reported molar tipping as a result of the procedure, but in despite of this clinically significant maxillary molar and cuspid width increases were found for both adolescents and adults. Long-term skeletal results after RME have been assessed by the same group [38], who found transverse skeletal maxillary increase to be approximately twenty-five percent of the total appliance activation in pre-pubertal adolescents, but non-significant in post-pubertal adolescents with traditional RME therapy.

Historically patients with anterior open bites, steep mandibular planes and convex profiles were considered poor candidates for RME, due to the observed downward and forward movement of the maxilla, downward and backward rotation of the mandible, decreasing effective mandibular length and increasing vertical dimension of the lower face [15,18,19]. Currently however, the side-

effects originally thought to result from RME in the vertical and antero-posterior dimension have been discounted for the majority of patients as a transient consequence [38-42].

1.5.1.4 Side-Effects

Potential undesirable side-effects of RME should be considered when an option to treat arises. Depending on appliance design, soft tissue inflammation may result due to proximity of the appliance to the gingival tissues, or due to food and plaque entrapment around the appliance and the fact that some patients may have difficulty maintaining adequate hygiene in these areas. It is common for patients to feel discomfort especially in the early stages as a result of RME therapy; this may be dependent on the amount of daily expansion [43]. Practitioners opposed to RME treatment have concern regarding the periodontal implications as a result, especially since forces are commonly applied to maxillary first molars which have three roots and increased vulnerability to periodontal disease progression once the furcation area is involved [44]. Greenbaum and Zachrisson [45] found that RME patients experienced increased alveolar bone loss on the first maxillary molar compared to slow-maxillary expansion patients and a control group, evaluated after a three month retention phase; this is similar

to finding by Garib *et al* [46] who additionally found an increased susceptibility to bone dehiscences on anchor teeth where thin buccal plates exist initially. However more recently, Ballanti *et al* [47] used CT scans in growing individuals before and after RME as well as after a six month retention phase. They concluded that a significant increase in transverse maxillary dimension was achieved, and although the buccal plate thickness did decrease significantly after active expansion, it did recover after the retention period of six months. In addition they observed increasing thickness of palatal bone, and concluded that in growing subjects RME therapy results in transverse dimensional increase in the maxillary dentition without permanent damage to the periodontal support.

Expansive forces applied to teeth results in compression of the buccal periodontal ligament which, if in excess of orthodontic forces, will transmit orthopedically to the lateral separation of the maxillae before tooth movement can occur [13]. Due to the nature of the lateral forces applied to the anchorage teeth during RME, compressive forces are transmitted to buccal periodontal ligament space resulting in occlusion of blood vessels and tissue ischemia [48]. Studies involving microscopic histological examination of extracted teeth that had previously been subjected to expansive force have shown repair where root resorption had occurred [49-53].

Due to the high inherent instability and relapse potential after RME therapy, it is common to overcorrect in the transverse dimension. It is recommended that the expansion be continued until the maxillary lingual cusps occlude with the lingual inclines of the buccal cusps of the mandibular molars. In addition, the appliance should be maintained passively for approximately three months to aid in stability in the transverse dimension [13]. Long-term stability of transverse skeletal maxillary increase has been found to be greater in skeletally less-mature individuals (pre-pubertal growth peak) than skeletally mature individuals (pubertal and post-pubertal growth peak) [38].

1.5.1.5 Bone-Borne Expanders

As previously mentioned, many appliances are used to complete the RME process. Most recently, bone-borne expansion appliances have been introduced; these appliances are inserted by various means directly into the cortex of the palatal aspect of the maxillary bones. These appliances are minimally invasive and have been reported to overcome the limitations and the negative side-effects associated with traditional tooth-borne and tooth-tissue-borne appliances [54-57].

1.5.2 The Nasal Cavity

1.5.2.1 Introduction

Nasal breathing is essential for the supply of moistened, filtered and warmed air to the lower respiratory tract. During the early stages of life, humans are obligate nasal breathers [58-60]. According to Mortola [61], the process of switching from nose- to mouth-breathing in infancy may be a behavioural response acquired gradually through a learning process. Further to this, it has been suggested that a mouth-breathing habit may be a learned practice that is not solely dependent on nasal obstruction [62]. In contrast, there are those that argue habitual mouth-breathing to be a result of nasal obstruction [17,23,63,64], and an extensive history of debate surrounds the controversy as to whether nasorespiratory function has an effect on the development of the dentofacial complex [65-69]. Patients with chronic mouth-breathing, secondary to nasal obstruction have been recognized as characteristically exhibiting facial traits which together have become universally labelled "long-face syndrome" and "adenoid facies". Typical features include: increase in lower facial height, lip apart posture, narrow alar base, self-report of mouth-breathing, narrow maxillary arch with a high palatal vault, and posterior cross-bite with possibly a Class II dental malocclusion [69]. These patients are candidates for RME therapy to

coordinate the widths of the maxillary teeth to the mandibular teeth.

Increase in nasal cavity dimensions as a result of RME has been reported in the literature since the early use of the approach [8,15,17,31,70-73]. The benefit of orthodontic treatment from a medical perspective was recognized formally in 1912 and 1913 in issues of The Laryngoscope, journal of The American Laryngological, Rhinological, and Otological Society [70]. Due to the anatomical proximity of the nasal cavity to the oral cavity, maxillary complex and teeth, it is not unexpected to see changes in the nasal cavity as a result of expansion of the maxillary palatal suture; however, any resulting change in nasal respiratory function is uncertain, and has been the focus of research for decades [17,23,62,66,69,74,75].

An involuntary conversion to oro-nasal breathing occurs once ventilation exceeds 40 to 45L/min. Airway resistance must be overcome for adequate oxygen needs to be fulfilled; when nasal resistance approaches 3.5 to 4cm H_2O/L/min, partial mouth-breathing also results [13]. Understandably there exists individual variation as to crossover threshold.

1.5.2.2 Anatomy and Physiology

The nasal passages are torturous labyrinths and because of their anatomy are easily vulnerable to obstruction; they extend anteriorly from the external nares through to the posterior nasopharynx (Figure 1-1).

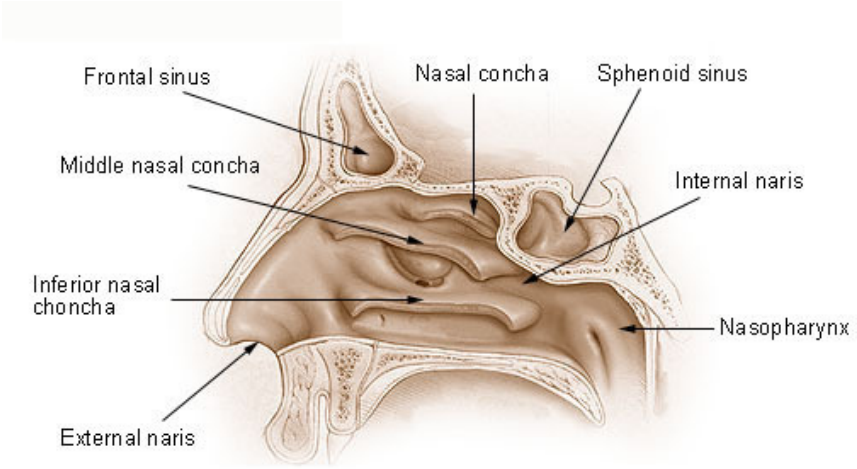

Figure 1-1: Nose and nasal cavity [76]

Obstruction can be defined as fixed (due to structural anatomical properties of the airway) or reversible (due to mucosal engorgement and swelling) [77]. Fixed blockages usually require surgical correction, and are not amenable to pharmacologic therapy. Fixed blockages may be due to: congenital (choanal stenosis) or acquired, abnormal anatomy (traumatic septal deviation, compensatory turbinate hypertrophy, post-rhinoplasty), a variation in normal anatomy (narrow nasal vault, congenitally

deviated septum), pathology (nasal polyps, tumours, hypertrophic adenoids), or foreign bodies. Reversible obstruction occurs commonly as a result of mucosal engorgement (also known as nasal congestion), and can be addressed pharmaceutically if it does not resolve spontaneously. Congestion can be due to physiologic processes (common stimuli include change in temperature/humidity or posture/body position, sleep, hormones, and the nasal cycle), or pathology (rhinitis, rhinosinusitis, sarcoidosis, inflammatory disorders, drug-induced) [58,77,78].

The nasal passage provides higher resistance, and accounts for about half the resistance of the entire respiratory system [58,79]. Within the nose, the nasal valve is believed to be the site of greatest resistance; at this location the velocity of nasal airflow is the fastest in the entire airway [59]. The nasal valve is defined by Cole [80-82] as a short resistor of a few millimeters in length; the area contains two sites of structural narrowing (anatomic and functional nasal valve). The former presents as the narrowed area of the vestibule and its structural integrity is stabilized by the surrounding cartilage and by inspiratory contraction of alar dilator muscles. The functional portion is located within the bony entrance to the cavum, and includes the erectile tissues of the inferior turbinates and the nasal septum. The anatomical valve is void of erectile mucosa.

The aforementioned nasal cycle was first described by Kayser in 1895 [83]. It is characterised by reciprocal decongestion and congestion of the nasal cavity lining between the left and right nostrils, with the total airflow kept constant [59,84]. The nasal cycle is a physiologic phenomenon; it was generally accepted to be exhibited in approximately 80 percent the population, yet recent studies suggest it may be less prevalent [84]. A standard cycle would behave such that the left and right sides of the nose have similar mean airflow, resistance, amplitude and volume changes, and opposite sides have identical periods but would be out of phase by 180 degrees [85]. It is believed to be under autonomic control [86], and most individuals are unaware of any changes in airflow or resistance [85]. It has been reported that there is however wide variation in airflow, patency and volume changes, with variable cycle lengths (ranging from 30 minutes to seven hours), with and without changes in the opposite nasal cavity [84]. The purpose of the cycle is not well understood; it is thought to assist in the humidification, filtration and mucociliary clearance in the congested phase [85], and to protect the nasal epithelium from constant extreme conditions. It can be modified or overwhelmed by exercise and topical decongestants, or anything that increases sympathetic tone [59].

1.5.2.3 Assessment

A myriad of differing methods exist to assess the nasal airway, and there is no recognized gold standard [87]; each has their strengths and limitations depending on what information is required. The different techniques range from radiographic evaluation to clinical assessments.

Radiographic techniques expose patients to excessive dosages of radiation; structural superimposition and positioning error limit validity of postero-anterior cephalographs, and traditional computed tomography (CT) has associated high cost. Along with magnetic resonance imaging (MRI), these techniques are used more frequently when pathological changes are suspected [88]. Cone-beam CT shows promise; equipment and analytic software is becoming increasingly available to orthodontists [3].

A physical examination with a speculum, and examination of the nasopharynx with a small mirror would be a primary inspection modality; further to this, a nasal endoscope can be used to examine the more difficult areas to visualize from an external approach, however it cannot provide dimensional estimates. Rhinostereometry provides a direct, accurate optical measure of nasal mucosal swelling; a surgical microscope with a ruled eyepiece attached is used to measure mucosal responsiveness

within a focused area [59] whilst the patient's head is held in a previously fitted frame. Peak nasal flow can be measured with an inspiratory flow meter; major disadvantages are possible alar collapse upon inspiration and that they are effort-dependent and assume normal ventilatory capacity of the lower airways. In addition, peak inspiratory flow meters have been found unreliable in detecting small changes in nasal patency and correlate poorly with changes in nasal resistance [89]. Rhinomanometry is a functional technique that provides a reading of airflow versus differential pressure, which can be helpful in assessing the patency over a limited region of the nasal cavity. It can identify the presence of an obstruction, however it cannot provide the site of the obstruction within the nasal passage [90].

1.5.3 Acoustic Rhinometry

1.5.3.1 Operation

Acoustic rhinometry (AR) provides an objective, reproducible [91], static measure of cross-sectional area as a function of distance into the nasal cavity, and in doing so calculates volume over a specified depth. The principle behind the procedure is based on the idea that changes in the acoustic impedance are proportionate to changes in cross-sectional area [92,93]. The acoustic

rhinometer emits an audible sound impulse into the nostril, which is processed upon its return by comparison to the original; the resultant size of the reflections are thought to provide information as to the area of the airway and with the knowledge of (i) the speed of the emitted sound pulse and (ii) the echo return time, distance from the nose tip can be calculated.

The sound pulse is generated by a discharge of electric current across two electrodes in the distal end of a wave tube [92]. The pulse travels within the wave tube, passes over a microphone at the proximal end, and then travels externally into the nostril of the subject via the nose tip. The resultant signal travels back past the microphone in the opposite direction, whereby the incident reflection is compared to the original pulse and the resultant information is digitized by a computer, which provides a graphic display of the cross-section versus distance curve (or rhinogram) (Figure 1-2) [81].

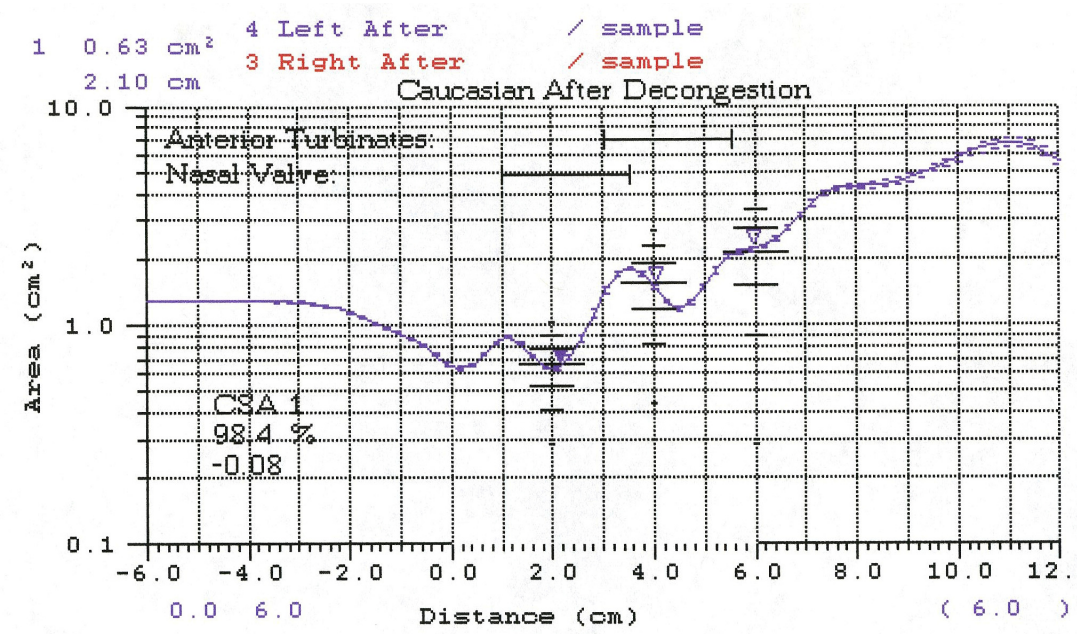

Figure 1-2: Rhinogram

1.5.3.2 Technique and Possible Sources of Error

The method of operation in obtaining a measurement is important from the aspects of accuracy and reproducibility, and European Rhinological Society standard operating procedures for acoustic rhinometry have been published [93,94]. In order to obtain an accurate reading, an adequate acoustic seal is necessary between the nose tip and the nostril, usually this is maintained with the use of a water-based lubricant gel. In addition, the operator must focus on achieving an optimal connection to the nostril; the nose tip must be passive so as not to distort or deform the nostril when applied during a measurement (Figure 1-3). The angle of the

wave tube should be as parallel as possible to the bridge of the nose (Figure 1-4).

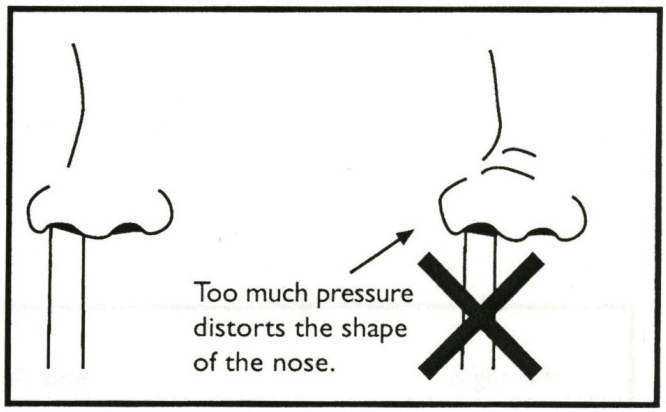

Figure 1-3: Acoustic rhinometer nose tip adaptation (from Eccovision® Quick Setup Guide, Hood Labs, Pembroke, MA, USA)

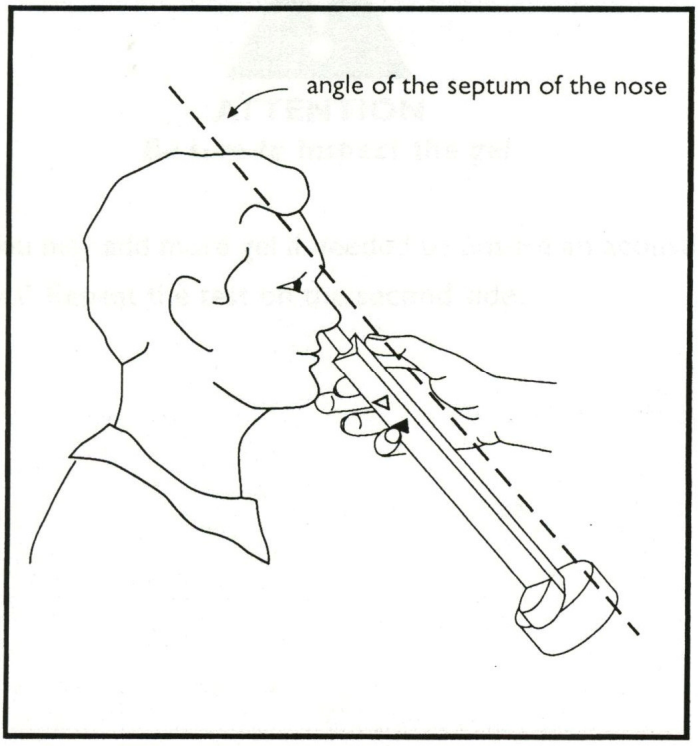

Figure 1-4: Technique for holding AR wavetube (from Eccovision® Quick Setup Guide, Hood Labs, Pembroke, MA, USA)

The patient must be able to pause their breath for a short time in order to avoid pressure changes in the nasal cavity as a response to airflow, and in addition avoid any simultaneous respiratory noise production such as swallowing or throat clearing [95]. To minimize error in measurements, patient acclimatization to a constant environment is essential. The procedure should be performed in a quiet room to eliminate the influence of external noise. Constant temperature and humidity is also an important consideration since sound velocity increases with increased temperature and humidity [96].

1.5.3.3 Applications of Acoustic Rhinometry

The use of AR in the nasal cavity was introduced by Hilberg in 1989 [92], and has demonstrated reasonable correlation with CT and MRI for the first six centimeters of the nasal cavity [92,97-104].

Acoustic rhinometry is useful to investigate anatomy and pathology of the upper airways [93,105]. The technique has been used to assess the results of nasal challenge [90], as well as the effects of medications [106,107], and physiological and environmental conditions [78,108] on the nasal passage. Diagnostic evaluation regarding nasal structure prior to nasal surgery [81], changes as a result of treatment

intervention [109-111] and research [112-115] are also areas where AR is currently being utilized.

1.5.3.4 Advantages

Advantages of AR [81]: 1) Its use is straightforward. The process is simple to explain to subjects. 2) It requires minimal cooperation to obtain a measure. Ideally the subject would hold their head in natural head position and pause their breath for a very short amount of time. 3) It is minimally invasive. It does not require intubation or attachments. It is not uncomfortable and does not cause the subject any discomfort, and because of this it is well-tolerated. 4) Results can be obtained rapidly and repeatedly. 5) The equipment is small, relatively affordable and accessible to medical and dental professionals. There is a component that can be used to assess pharyngeal space. 6) The results are immediately displayed graphically and numerically. The software allows a variety of parameter adjustments.

1.5.3.5 Acoustic Rhinometry and Rapid Maxillary Expansion

A limited number of publications are available investigating the use of AR to assess dimensional changes in nasal cavity as a result of RME therapy; of these, most are case series.

Two studies found significant increases in total volume measured by AR, and non-significant changes in total minimum cross-sectional area (MCA) after expansion [116,117]. Compadretti *et al* [116] evaluated nasal cavity change in children with reported mouth-breathing habits and constricted maxillary arches; only eight of fourteen children showed a change of breathing mode from oral to nasal. Wriedt *et al* [117] found these results in a series of cases treated with surgically-assisted RME.

Two further studies found significant increase in total nasal volume after expansion, without considering MCA [104,118], and Enoki *et al* [119] reported no significant difference in total MCA at the level of the nasal valve.

In contrast to the above, Baraldi *et al* [120] compared SARME treatment to a control group and found a significant increase of posterior MCA after treatment that approached values displayed by those in the control group, but a non-significant change in volume measures.

Four studies report a significant increase in nasal cavity dimensions demonstrated in expansion patients when compared to controls [121-124]. Bicakci *et al* [121] investigated MCA in subjects according to pre- or post-pubertal growth spurt, and suggest that changes are more stable if expansion is performed before this period. De Moura *et al*

[122] assessed the effects of RME on children with Down syndrome using AR and found total nasal volume and MCA significantly increased and is stable over a retention period in treatment subjects. Compadretti *et al* [123] in addition used rhinomanometry to evaluate nasal resistance and reported a significant decrease in resistance after RME, despite large individual variation of treatment response. Cappellette *et al* [124] used AR to prospectively compare the effects of RME on nasal cavity measures; they reported a significant increase in nearly all transverse areas and nasal volumes in the treatment group for separate left and right sides.

Two studies [119,125] estimated nasal airway resistance using AR, and found that nasal resistance significantly reduced as a result of RME.

Of the abovementioned articles, two trials present research parameters similar to our own, allowing for comparison. Bicakci *et al* [121] (2005) compared nasal MCA changes in 29 subjects treated with RME before or after the pubertal growth spurt versus 29 untreated control subjects. Treatment and control subjects were divided into two groups according to their skeletal maturity assessed using the cervical vertebral maturation method on lateral cephalograms taken initially before treatment (T_1). Early-treated subjects (Group I T, 16 patients (eight females, eight males; mean age 11 years eight months)) and early-control subjects (Group I C,

16 patients (eight females, eight males; mean age 12 years six months)) had not yet reached the pubertal peak in skeletal growth velocity and presented with cervical vertebral stage one to three. Late-treated subjects (Group II T, 13 patients (eight females, five males; mean age 14 years one month)) and late-control subjects (Group II C, 13 patients (eight females, five males; mean age 13 years four months) were at a stage during or after the pubertal peak in skeletal growth velocity with cervical stage four to six. Expansion was achieved with a bonded-type RME appliance with activation of a Hyrax screw twice per day until the desired expansion was achieved. AR data was obtained before treatment (T_1), after treatment (T_2) and after three months of retention period (T_3) to assess for nasal airway changes; measurements were taken after the application of a nasal decongestant. In comparing early- versus late-treatment groups, significant increases in values for MCA were seen in both groups between points T_1 and T_2 ($P<0.05$), but no significant differences were seen between the groups. For the late-treatment group, a significant reduction in MCA was found between points T_2 and T_3, this was not the case for the early-treatment group. In comparing overall changes (from T_1 to T_3), both the early- and late-treatment groups had significantly greater increase in MCA values compared to the controls, but no

statistically significant differences were seen between the treatment groups. Compadretti *et al* [123] (2006) examined 27 children (13 male, 14 female, mean age 9.5±2.1 years) undergoing RME and evaluated them by acoustic rhinometry, rhinomanometry, postero-anterior cephalograms (select patients), audiometry and tympanometry. Expansion was accomplished with a Hyrax-type expansion device, with an activation frequency of two quarter-turns per day until the desired expansion was achieved, after which the appliance was kept as a retainer for three months. An untreated control group consisted of 24 patients (16 male, eight female, mean age 10.2±1.5years). Great variability in results was reported, however AR results revealed a significant increase in total minimum cross-sectional areas (TMCA) and total nasal volume (TNV) after expansion in basal and decongested conditions. Significant differences were reported in increases in TMCA and TNV in basal and decongested conditions between the treated and control groups.

1.6 Conclusion

Nasal obstruction is a common presentation with a multifactorial aetiology. Conclusive evidence on the nasal airway and its response to RME would assist orthodontists in their treatment

decisions, giving consideration beyond purely dentoalveolar components.

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Chapter 2. Systematic Review

Rapid Palatal Expansion Effects on Nasal Airway Dimensions as Measured by Acoustic Rhinometry: A Systematic Review

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2.1 Abstract

Objective: To evaluate available information on the effects of rapid maxillary expansion on nasal airway minimal cross-sectional area and volume, as measured by acoustic rhinometry.

Materials and Methods: An electronic database search was conducted. Based on abstracts/titles, articles were initially selected; then full articles were retrieved and were further sorted according to secondary, more stringent criteria. References from selected articles were hand-searched for potential missed publications. Clinical trials using acoustic rhinometry on subjects undergoing rapid maxillary expansion therapy were included. Syndromic or medically compromised patients and absence of an untreated control group were reasons for exclusion. Selected studies thereafter were evaluated methodologically.

Results: Only four articles reached final selection, and their overall

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methodology scores were low, limiting the applicability of results. After rapid maxillary expansion, three of four studies found statistically significant increases in minimal cross-sectional area, and two of three studies reported statistically significant increases in nasal cavity volume as compared with control groups. It appears that any increase is less stable if a traditional technique is used on patients who have passed their peak growth spurt.

Conclusions: Although some increases in nasal dimensions have been reported, the changes in nasal volume were small and should not be presented to patients as a clinically significant indication for therapeutic maxillary expansion. (Angle Orthod. 2009;79:1000–1007.)

Key Words: Systematic review; Rapid maxillary expansion; Acoustic rhinometry; Nasal airway dimensions

2.2 Introduction

During rapid maxillary expansion (RME), the greatest changes occur in the maxillary dentition, especially in the transverse dimension. Although some immediate changes in vertical and transverse dimensions have been reported, no long-term changes have been found.[1–3] In addition, on a long-term basis, the transverse skeletal

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maxillary increase ranges from approximately 25% of the total appliance adjustment in prepubertal adolescents to a not significant change in postpubertal adolescents when traditional RME was evaluated.[2,3] However, the RME effect on the nasal cavity and respiratory function has been disputed.[4,5]

Differing methods of measurement of nasal airway dimensions and function have been proposed and utilized; each technique has its strengths and limitations.[6] Radiographic techniques expose patients to excessive dosages of radiation; patient positioning error and structural superimposition limit posteroanterior cephalograph validity, and traditional computed tomography has associated high cost.[6] Cone-beam computed tomography shows promising possibilities, and equipment is becoming increasingly available to orthodontists.[6] Nasal endoscopy provides exceptional visualization of the area of interest, but it cannot provide dimensional estimates.[6] Rhinostereometry is a direct optical technique that is performed to measure nasal mucosal swelling with the use of a surgical microscope. This method poses practical clinical limitations[7] such as the requirement for an individual tooth splint per subject, as well as provides only limited information of specific structures and not of the larger part of the nasal airway. Rhinomanometry can help identify

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whether an obstruction to nasal airflow is absent or present, however it cannot localize the level and sites of obstruction. Finally, acoustic rhinometry (AR)[6–10] determines minimum cross-sectional area (MCA) as a function of distance in the nasal airways by emitting a sound impulse and then processing the resultant reflection and comparing it with the original; the size of the reflections may reflect changes in airway size, and the return time may provide the distance between the changes.

Thus, AR has the advantage of providing objective area and volume measurements, along with ease of use and minimal invasiveness. AR has been validated for evaluation of nasal cavity dimensions compared with other techniques.[6,8–10] It has demonstrated reasonable correlation with both computed tomography and magnetic resonance imaging for the anterior six centimeters of the nasal cavity.[8,10–12]

Multiple studies have used AR for assessment of changes to airway dimensions after RME intervention. The purpose of this systematic review is to evaluate the effects of RME on nasal airway dimension measured by AR, while addressing the quality of evidence and the methodology of those reports. Knowledge of scientific evidence on the nasal airway would facilitate orthodontists' decisions as to

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whether RME could be a treatment alternative that not only produces dentoalveolar changes, but also has implications in the nasal complex. This information would also be important for otolaryngologists.

2.3 Materials and Methods

An electronic database search was conducted in several databases. The computerized search was accomplished with the assistance of a senior Health Sciences Librarian. Databases searched, along with terms used as keywords/subject headings within each database are listed in Table 2-1. No language limitation was set.

In selecting articles from the search results, initial inclusion criteria applied to the title/abstract were as follows:

- Use of a rapid palatal/maxillary expansion device
- Use of an instrument to measure nasal area/volume

Independent article selection was accomplished by two researchers. If the abstract was judged to contain insufficient information for a decision of inclusion or exclusion, the full article was obtained and reviewed before a final decision was made.

Full articles from the abstract/titles previously selected were

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Table 2-1: Search results from databases

Database	Search Strategy	Results	Abstracts Obtained	Articles Selected for the Systematic Review	% of Total Selected Articles (3) Found by Database
Old MEDLINE (1950-1965)	exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air$.mp, nas$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	0	0	0	0
MEDLINE + In-Process & Other Non-Indexed Citations (1950 to August week 2 2008)	exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air$.mp, nas$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	188	32	3	75
Pubmed (up to August 18, 2008)	palatal expansion technique, palatal expansion, maxillary expansion, rapid palatal expansion, rapid maxillary expansion, air*, nas* 1 OR 2 OR 3 OR 4 OR 5, 6 OR 7, 8 AND 9	221	35	4	100
EMBASE (1988 to week 33 of 2008)	exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air$.mp, nas$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	153	9	1	25
All EBM Reviews - Cochrane DSR, ACP Journal Club, DARE, and CCTR (up to August 18, 2008)	exp palatal expansion technique, palatal expansion.mp, maxillary expansion.mp, rapid palatal expansion.mp, rapid maxillary expansion.mp, air$.mp, nas$.mp 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	14	3	1	25
Lilacs (up to August 18, 2008)	palatal expansion technique, maxillary expansion, nas$, air$ 1 OR 2, AND 3 OR 4	29	0	0	0
Scopus (up to August 18, 2008)	palatal expansion technique, palatal expansion, maxillary expansion, rapid palatal expansion, rapid maxillary expansion, air*, nas* 1 OR 2 OR 3 OR 4 OR 5, 6 OR 7, 8 AND 9	284	33	3	75
Thomson's ISI Web of Science (from 1900-1914 up to August 18, 2008)	palatal expansion technique, palatal expansion, maxillary expansion, rapid palatal expansion, rapid maxillary expansion, air*, nas* 1 OR 2 OR 3 OR 4 OR 5, 7 OR 8, 6 AND 9	156	22	3	75
Hand-search			0	0	0

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retrieved. Retrieved articles were ultimately selected if they also satisfied the following secondary inclusion criteria:

• Human clinical trials with a non-treated control group (no case reports or series of cases)

• Non-syndromic nor medically compromised subjects

• Use of AR as a method to measure nasal airway differences (minimal cross sections and volume evaluated)

Any discrepancies in inclusion of articles between researchers were addressed through discussion and consensus. Reference lists from selected articles were hand-searched for additional publications that may not have appeared in the electronic database searches.

Articles that satisfied the final inclusion criteria were evaluated using the methodologic criteria listed in Table 2-2. Methodologic scores are summarized in Table 2-3. A meta-analysis was planned if the quality of information retrieved warranted a meaningful statistical combination.

2.4 Results

The details for each search, as well as the number of abstracts retrieved from each database, are listed in Table 2-1, but only four articles [13–16] met all inclusion criteria. Attempts to retrieve two

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Table 2-2: Methodological score for clinical trials (Maximum number of ✓s = 15, modified from Lagravere *et al*, 2005 [2])

I. Study Design (7 ✓)

A. Objective – objective clearly formulated (✓)

B. Sample size – considered adequate (✓)

C. Sample size – estimated before collection of data (✓)

D. Selection criteria – clearly described (✓)

E. Baseline characteristics – similar baseline characteristics (✓)

F. Timing – prospective (✓)

G. Randomization – stated (✓)

II. Study Measurements (3✓)

H. Measurement method – appropriate to the objective (✓)

I. Blind measurement – blinding (✓)

J. Reliability ─ adequate level of agreement (✓)

III. Statistical Analysis (5✓)

K. Dropouts – dropouts included in data analysis (✓)

L. Statistical analysis – appropriate for data (✓)

M. Confounders – confounders included in analysis (✓)

N. Statistical significance level – P value stated (✓)

O. Confidence intervals provided (✓)

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abstracts/articles of possible use from the handsearch of the reference lists were unsuccessful. One publication of interest from the Lilacs search was also unobtainable.

Methodologic assessment of finally selected publications resulted in scores approximating 50% of the possible total maximum; score summaries can be seen in Table 2-3. Table 2-4 provides a study summary of the main methodologic characteristics and obtained results from the publications included in the final selection. Table 2-5 provides the list of excluded articles and the reasons for their exclusion. Common reasons for exclusion were case series, or the fact that the study did not use AR for nasal airway status assessment.

2.5 Discussion

The principle of AR is based on the reflection of sound waves inside the nasal cavity. Its use is very diverse in the field of rhinology and has been validated with results showing reasonable correlation to computed tomography (CT) and magnetic resonance imaging (MRI) for the first six centimeters of the nasal cavity.[8,10–12] These latter imaging techniques provide useful information with respect to local and surrounding structural anatomy, but they are costly and time-

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Table 2-3: Methodological score of selected articles

Articles	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total (/15)
Bicakci et al [13]	✓	/	✗	/	✗	✓	✗	✓	✗	✗	✗	✓	✓	✓	✓	8
Compadretti et al [14]	✓	/	✗	/	✗	✓	✗	✓	✗	✗	✗	✓	✓	✓	✗	7
Baraldi et al [15]	✓	/	✗	✓	✗	✓	✗	✓	✗	✗	✗	✓	✓	/	✗	7
Cappellette Jr et al [16]	✓	/	✗	✓	✗	✓	✗	✓	✗	✗	✗	✓	✓	✓	✗	7.5

✓fulfilled satisfactorily the methodological criteria (1 check point)
/ fulfilled partially the methodological criteria (0.5 check point)
✗did not fulfill the methodological criteria (0 check point)

Table 2-4: Description of studies included in final selection

Author (Year)	Size	Age	Male	Female	Treatment/ Appliance	Evaluation Method [measurement (units)]	Mean measurement differences using AR				Estimated mean percent increase using AR			
							Cross-sectional area		Volume		Cross-sectional area		Volume	
Bicakci et al (2005) [13]	58	11-8	8	8	bonded RME	acoustic rhinometry [MCA (mm^2)]	0.34*		N/A		16.92		N/A	
		12-6	8	8	control		0.08				Information unavailable			
		14-1	5	8	bonded RME		0.19*				8.76			
		13-4	5	8	control		0.02				Information unavailable			
Compadretti et al (2006) [14]	51	9.5±2.1	13	14	Hyrax	rhinomanometry, acoustic rhinometry [TMCA (cm^2) & TNV (cm^3)] & cephalometry	**Basal**	**Decon-gested**	**Basal**	**Decon-gested**	Information unavailable			
							0.15*	0.17*	0.65*	1.44*				
		10.2±1.5	16	8	control		0.03	0.01	0.06	0.03				
Baraldi et al (2007) [15]	23	25.15±6.93	4	9	SARME/ Haas or Hyrax	acoustic rhinometry [MCA (cm^2) & Volume] & frontal cephalograms	**MCA1**	**MCA2**	**Vol1**	**Vol2**	**MCA1**	**MCA2**	**Vol1**	**Vol2**
							0.02	0.32	0.18	1.16	1.94	25.81	4.97	8.61
		26.10±4.68	4	6	control		*1.17*	*1.61*	*4.05*	*15.19*	N/A			
Cappellette Jr et al (2008) [16]	50	4-14 (range)	27	23	modified Biederman	acoustic rhinometry (posttreatment - pretreatment)	**MCA1**		**MCA2**		**VOL1**		**VOL2**	
							L	**R**	**L**	**R**	**L**	**R**	**L**	**R**
								*	*	*	*	*		*
	20	4-11 (range)	11	9	control									*

* Statistically significant

Italics = Control group measures taken only once thus absolute measures are given as opposed to changes.

consuming to interpret. AR is a non-invasive, relatively inexpensive technique that requires minimal time and patient cooperation. The equipment requires very little space to operate, making it suitable in a clinical situation. Geometry of the nasal cavity is provided in two dimensions on the AR output. The cross-sectional area, as a function of distance from the nostril into the nasal cavity visually, displays the location and size of the MCAs. The resultant reflected waves are shown over a large depth, but the machine is programmed to measure over a certain distance anteroposteriorly. Standardizations of operation have been recommended,[17,18] and adherence to these recommendations should produce highly accurate and repeatable measures.

Because of the influence of the nasal cycle on the nasal mucosa, it has been recommended that topical decongestants be given when AR is used to assess the nasal cavity.[19] Decongestants reduce the possibility of the confounding effect of differing levels of congestion on the nasal mucosa, thus allowing measure of an individual's nasal anatomy as opposed to their variable physiologic or pathologic states. Inflammatory conditions, exercise, head posture, emotional and hormonal states, and medications can influence the nasal mucosa. This has clinical implications, in that it is

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important to assess all individuals in their most decongested state so results can be compared over time or after intervention.

Because each of the selected investigations differed in approach, it was difficult to directly compare the results. Methodologic assessment resulted in all studies scoring similarly. Measurement reliability was not discussed, nor was blinding or randomization. These limitations weaken the overall strength of the results in that biases may have been introduced.

The presence of a malocclusion requiring RME was similar between all studies. However, in the study by Baraldi *et al*,[15] patients who required surgically assisted rapid maxillary expansion (SARME) included non-growing adults, whereas Cappellette *et al*[16] investigated an adolescent subject group who presented with a mouth-breathing habit. Bicakci *et al*[13] required that adolescent subjects have no history of nasal disease, whereas Baraldi *et al*[15] required no use of medications for nasal obstruction and a negative history of labial/palatal fissures or presence of craniofacial anomalies or chronic systemic disease. These are important factors when baseline differences between subjects are considered. Compadretti *et al*[14] assessed children and adolescents with varying histories of ENT surgery, tonsillitis, snoring/sleep apnea, mouth

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breathing posture, allergies, and septal deformity or hypertrophy of inferior turbinates. Statistical analysis showed that these variables, along with gender and unilateral or bilateral crossbites, did not influence measurements or response to treatment.

An investigation by Babacan *et al*[20] compared subjects with differing levels of maturity. Investigators evaluated RME in an adolescent subject group and SARME therapy in an adult subject group and showed a significant increase in nasal volume measured using AR but no differences between groups.

Changes in breathing pattern were discussed by Compadretti *et al*,[14] who reported that 42.8% of patients switched from an oral to a nasal breathing mode after RME, which was consistent with findings from other studies.[4,21,22] This may have occurred as the result of increased flow capacity of the nasal cavity caused by an increase in MCA after RME.

Because of the anatomic proximity of the nasal cavity to the oral cavity, maxillary complex, and teeth, changes in the nasal cavity as a result of expansion of the maxillary palatal suture are not unexpected. It is important to note that although theoretically changes in the nasal cavity can occur with changes in maxillary arch width, a multitude of factors exist that can influence nasal

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airway geometry and resultant patient perception of airflow. Our results did report trends (some statistically significant) of an increase in MCA after RME.

Bicakci *et al*[13] compared nasal airway changes in 29 subjects treated with RME either before or after the pubertal growth spurt versus 29 untreated control subjects. Treatment and control subjects were divided into two groups according to their skeletal maturity, which was assessed using the cervical vertebral maturation method on lateral cephalograms taken before treatment. Early-treated subjects and early-control subjects had not yet reached the pubertal peak in skeletal growth velocity and presented with a cervical vertebral stage from one to three. Late-treated subjects and late-control subjects were at a stage during or after the pubertal peak in skeletal growth velocity with cervical stage from four to six. The study reported a significant increase in MCA in subjects before and after their pubertal growth spurt compared with untreated controls, but no significant difference in MCA change was noted between treatment groups until after the retention phase, when a significant decrease in MCA was reported in the group assessed to be past their skeletal growth spurt. This could possibly be explained by the increasing rigidity of the facial

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skeleton with age.[23,24] Compadretti *et al*[14] reported rhinometric results of a significant increase in total MCA and total nasal volume (NV) in both basal and decongested conditions between control and treatment groups (see Table 2-4). Baraldi *et al*[15] did not observe significant increases in MCA or NV after SARME, but a not significant increase in posterior MCA was observed post SARME.

Of interest is a patient-reported improvement in airflow through the nose after RME therapy. With normal anatomy, inspired air passes at high velocities anteriorly up to the nasal valve area, after which velocity drops substantially because of increased volume in the nasal cavity. Airflow deviates from laminar to turbulent once inside the nasal cavity, thereby promoting the resultant cleaning and conditioning of inspired air. Air through the nose has been thought of as passing through a series of pipes of varying cross-sections, but nasal anatomy is complex, resulting in limitations of this postulation. Although a physically compressible medium, air is said to be incompressible at velocities below 0.3 Mach—a condition that is largely satisfied by the current situation.[25] Air traveling through the nasal passage can be accurately modeled by Bernoulli's equation,[26] with consideration of flow across the nasal valve region as a result of pressure differences, with constant density and

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negligible viscosity. Bernoulli's principle, which was developed from the momentum equations with assumptions of conservation, states that for a fluid, an increase in speed of the fluid occurs simultaneously with a decrease in pressure. Flow in the nose is analogous to a subsonic diffuser; therefore, from the continuity equation, the volumetric flow rate must be maintained, which leads to slower air velocity. The nasal valve was defined by Cole[27] as a short resistor of a few millimetres in length with a base at the floor of the nose, the lateral walls as the ala, and a bony caval entrance anterior to the inferior turbinate and within a few millimetres of the bony pyriform aperture. Because the nasal valve is contributed to in part by the lateral walls of the nasal cavity, widening of these walls by RME may result in an increase in the nasal valve (increasing MCA), thereby decreasing resistance to nasal airflow. In laminar flow, Ohm's law states that resistance equals the change in pressure divided by volumetric flow rate ($R=\Delta P/Q$), and in conditions of turbulent flow, the formula changes to the square of the volumetric flow rate ($R=\Delta P/Q^2$). When theory is applied to clinical findings, it can be seen that as a result of RME, both nasal volume and MCA increase, thereby decreasing resistance to airflow and allowing increased movement of air through the nasal passage with

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decreased nasal respiratory effort.

Recent reports that used CT images to quantify nasal change after RME have been published. A study by Palaisa *et al*[28] used conventional tomography to evaluate nasal cavity changes after RME treatment in 19 subjects aged 8 to 15 years at three time points (before, immediately after, and 3 months after RME therapy). Investigators found overall that the area and volume increased significantly in each region of the nasal cavity measured (anterior, middle, or posterior) between time points, with the exception of the right middle from before to after RME, and reported an overall increase in volume of 10.7% from before to after RME. They did not detect any relapse in measurements during a three month retention phase after expansion. However, it may have been useful to extend this interval to ensure adequate time for any changes. Investigators also concluded that no significant correlations were found between the amount of expansion and the increase in nasal cavity area or volume for any region of the nasal cavity.

In summary, each of these four studies reported changes consistent with an increased MCA and/or NV, but none of the changes is likely to be considered clinically significant. The finally selected articles included no report of percent increase in MCA or volume (an

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estimate was calculated where possible in Table 2-4); these data may be an important practical consideration for clinicians in distinguishing between clinical and statistical significance. In addition, although it is probable that RME has an effect on the nasal airway, clinical and patient-perceived improvements are yet to be reliably established. Quality of life effects of RME beyond the orthodontic advantages have been reported,[4,21,29,30] including change from a mouth-breathing dependence to a nasal respiratory pattern, as well as improved overall health and sleep. Most reports, however, have described investigations of limited quality, such as from case series. Individuals who present with maxillary transverse constriction and reduced nasal respiration should be considered possible candidates for treatment with expansion therapy. Treatment of this type is minimally invasive and can address a dental disharmony requiring correction. One must consider conceivably greater effects in those individuals who have nasal constrictions in the areas most affected by RME as opposed to those with causes for reduced airflow in other areas of the nasal airway passage (e.g. enlarged tonsils and/or adenoids). Long-term randomized controlled trials are needed to facilitate further evaluation of the effects of RME on the nasal airway, as well as

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investigation using patient perception and feedback as to their nasal airway status before and after RME.

2.6 Conclusions

- RME should not be encouraged as a treatment option for individuals with reduced MCA without an orthodontic indication. In cases with an orthodontic treatment need, nasal cavity changes are expected; however, their clinical significance is questionable.
- Variability has been noted; therefore, for a given individual patient, the change may be significant.
- Given the current limited quality of evidence, it is encouraged that future studies overcome the identified limitations in an effort to support related conclusions with stronger methodologic quality.

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Table 2-5. Articles not selected from the initial abstract selection list and reason for exclusion

Reason for Exclusion	Article
No control group	Babacan [1]
Syndromic subjects	de Moura [2] Pirelli [3]
Did not use AR	Bascifiti [4] Dogru [5] Hartgerink [6] Loreille [7] Timms [8] Warren [9] Wollens [10]
Summary of treated cases, did not use AR	Gray [11]
Case series, did not use AR	Berretin-Felix [12] Cistulli [13] De Mol Van Otterloo [14] Garrett [15] Hershey [16] Malkoc [17] Palaisa [18] Pirelli [19] Timms [20] Timms [21] Wertz [22] White [23]
Case series	Ceroni Compadretti [24] Doruk [25] Doruk [26] Enoki [27] Kunkel [28] Picchi [29] Piccini [30] Wriedt [31]
Discussion paper	Bonk [32] Brogan [33] Timms [34]

AR=acoustic rhinometry

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Chapter 3. Effect of Rapid Maxillary Expansion on Nasal Airway Dimensions measured by Acoustic Rhinometry

3.1 Introduction

Rapid maxillary expansion (RME) is a conventional method of orthodontic treatment used to address skeletal transverse deficiencies of the maxillary dentoalveolar process. Bone-borne expansion appliances have been recently introduced; these appliances apply lateral forces directly to the maxillary bones from their attachment to the palatal cortical plate thereby avoiding many limitations and negative side-effects associated with traditional appliances [1-4]. Expansion procedures have been employed for over a century, and pioneers of RME therapy had the foresight to discuss theoretical implications of expansion treatment on the nasal cavity [5-12], yet still the effect of RME on nasal airway is commonly discussed using anecdotal evidence based on speculative observations or series of cases (rather than empiric evidence).

Due to the proximity of the nasal cavity to the maxillary dentition and the reported lateral separation of the maxillary bones as a result of expansion treatment, it is conceivable that changes in the nasal passage would occur with any changes that occur in the palate. Whether or not these changes result in clinically significant alteration in the nasal passage such that function is altered has been a topic of debate [10,13-18].

The nasal cavity acts to filter, humidify and warm inspired air, this is protective to the lower airways and to the overall health of the individual [19]. The nasal passage is irregular in shape and has the potential to provide high resistance to airflow as a result of obstructive circumstances; fixed blockages are structural and usually treated surgically, whereas reversible obstruction is usually responsive in nature and commonly involves mucosal inflammation [20].

Many techniques are available to measure the nasal cavity, each has an ideal application and unique assessment capability depending on what information is required. Acoustic rhinometry (AR) was introduced by Hilberg in 1989 [21] for use in the nasal airway. Acoustic rhinometry measures nasal cross-sectional area and volume; the method is non-invasive, requires minimal patient cooperation and has shown reasonable correlation with CT and MRI for the first six centimeters of the nasal cavity [21-29].

A limited number of randomized controlled investigations have examined the response of the nasal airway in response to RME with the use of acoustic rhinometry [30]. The results reported are considerably varied making it difficult for orthodontists to make an evidence-based decision as to whether RME would be indicated and warranted in patients with nasal obstruction. This study is

focused on investigating whether any changes in minimal cross-sectional area and nasal cavity volume exist after RME using two types of expansion appliances (tooth-borne vs. bone anchored) comparing results with an untreated control group, and in addition assessing any subjective changes as a result of expansion of the maxillae.

3.2 Materials and Methods

This study was conducted under the approval of the Health Research Ethics Board, University of Alberta (Appendix A).

3.2.1 Accuracy

Measurement apparatus accuracy was tested by measuring and comparing the MCA of an artificial airway to its known dimension. The nasal airway of an acrylic reproduction (Subject 10) was used (Figure 3-1). The apparatus was a replica built using rapid prototyping, initially used and reported in a separate study [31]. Ten successive measures of MCA were performed with the Eccovision® 4.50 acoustic rhinometer (Hood Laboratories, Pembroke, MA, USA), and the total average was then compared statistically to the documented area.

Figure 3-1: Artificial airway apparatus (Subject 10)

3.2.2 Repeatability

Intra-examiner reliability was assessed by measuring MCA and volume in ten adult volunteers under decongested conditions (i.e. after application of topical decongestant 0.1% w/v xylometazoline hydrochloride nasal solution). For each individual, measures were taken five times over one hour (i.e. every 12 minutes) with an acoustic rhinometer.

3.2.3 Study Subjects

Subjects were recruited from the Graduate Orthodontic Clinic patient pool. Eligible subjects met the following inclusion criteria:

males aged between 12 -15 years, females aged between 11 – 14 years, diagnosed need for maxillary expansion treatment, full permanent dentition erupted (with the exception of third molars), and absence of syndromic characteristics or systematic diseases.

3.2.4 Design and Procedure

The time interval for eligible patient recruitment was 18 months. Treatment was initiated immediately after recruitment and informed consent. All subjects provided a signed consent form (Appendix B) in which they were informed that they would be placed in any one of three groups (see below). Once recruited, the subject was assigned a code for blinding purposes. Orthodontic clinical records were taken for each candidate, following an accepted standard of care for diagnosis.

Subjects were randomly appointed to one of three groups: one group did not start treatment for six months and served as an untreated control group, the second group was treated with maxillary expansion using a tooth-borne (Hyrax) appliance, and the third group was treated with an osseous-integrated implant/onplant bone-anchored maxillary expansion apparatus. Randomization was achieved by means of a generated randomization table.

Treatment for subjects serving as control group was delayed for six months. The delay was considered to not have negative consequences regarding overall treatment outcome; after the six month period, the subjects were able to start treatment depending on their need. Acoustic rhinometric measures were obtained from control subjects at baseline (T0) and six months thereafter (T2).

Of the intervention groups, one was treated with the use of a tooth-borne RME expansion appliance (Figure 3-2). Appliance retention was provided by four orthodontic bands cemented to left and right maxillary first molars and premolars.

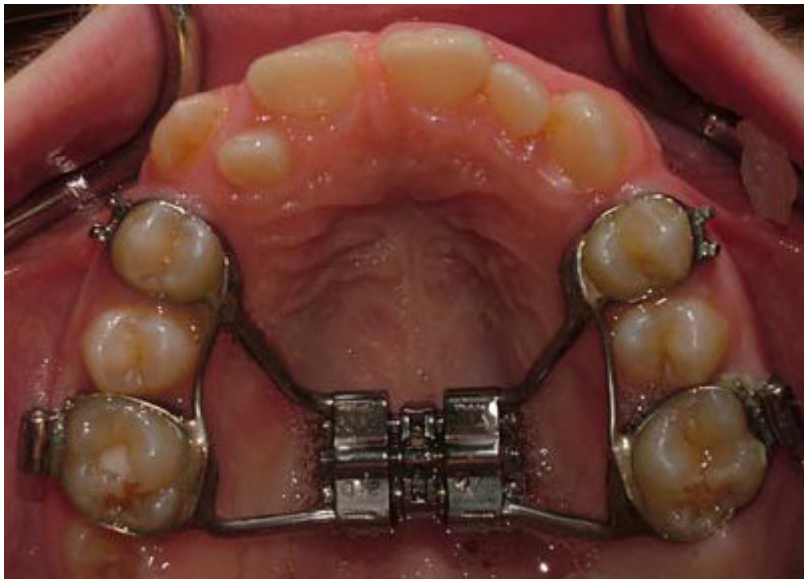


Figure 3-2: Tooth-borne expansion appliance (courtesy of Manuel Lagravere)

This appliance was activated by one turn of a Hyrax screw twice daily (0.25 mm per turn, 0.5 mm daily) until appropriate expansion

was achieved. After completion of the active expansion treatment, the screw was passivated with a ligature tie and retained for approximately 5.5 months. Acoustic rhinometric measures were obtained from tooth-borne appliance subjects at baseline (T0), after active expansion (T1) and after six months (T2).

The second intervention group was treated with the use of an implant-anchored expansion appliance (Figures 3-3 and 3-4). The appliance consisted of a Hyrax midline screw joined to the palate via an osseointegrated implant on one side and miniscrew on the other, as described by Harzer [32]. The osseous-integrated palatal implant and onplant were inserted, and a Hyrax screw was initially activated after four days. The treatment of this group involved appliance activation every second day (0.125mm/day) until appropriate expansion was achieved. After completion of active expansion, the appliance screw was passivated with a ligature tie and the appliance was retained for approximately four months. The osseous-integrated palatal implant was maintained after appliance removal for use in the second phase of treatment. Acoustic rhinometric measures were obtained from bone-borne appliance subjects at baseline (T0), after active expansion (T1) and after six months (T2).

Figure 3-3: Palatal aspect of bone-borne appliance (Dresden Distractor design [33])

Figure 3-4: Occlusal aspect of bone-borne appliance (Dresden Distractor design [32])

At each session, nasal airway dimensions were measured three times for each nostril with an acoustic rhinometer (see below). The average MCA and volume were used, and sum of the average measures for both sides of the nose were calculated. Measurements were obtained before and minimum ten minutes

after use of a decongestant nasal spray (0.1% w/v xylometazoline hydrochloride nasal solution). (For the purpose of this study, decongested values were used to eliminate any potential influence of nasal mucosal swelling.) Technique for use of the acoustic rhinometer followed manufacturer's instructions (Eccovision® Operator Manual, Hood Labs, Pembroke, MA, USA).

Subjective evaluation of nasal obstruction and respiratory health status were obtained at each airway assessment in order to gain insight into whether any association exists between subjective and objective findings. The Nasal Obstruction Symptom Evaluation (NOSE) Instrument was used, modified from The NOSE Scale© 2003, the American Academy of Otolaryngology-Head and Neck Surgery Foundation [34]. The instrument consists of five questions requiring patients to consider different aspects of their existing nasal symptoms and score on a scale from zero to four (Appendix C).

3.2.5 Measurement

An acoustic rhinometer (Figure 3-5) was used in order to measure nasal cavity dimensions (Eccovision® 4.50, Hood Laboratories, Pembroke, MA, USA). Measures were performed by the same blinded operator before and after palatal expansion, and before full-fixed appliance therapy for the intervention groups; for control

subjects measures were taken at baseline and six months afterwards. Acoustic rhinometry measures were obtained according to manufacturer's instructions (Eccovision® Operator Manual, Hood Labs, Pembroke, MA, USA), and according to standard operating procedures recommended in the literature [35,36].

Figure 3-5: Eccovision® 4.50 acoustic rhinometer

Protocol:

1. The subject was seated in an upright position and acclimatized to conditions with constant temperature (21°C) and humidity. The nose was cleared.
2. The subject was instructed regarding procedure, what they would experience, and what was required of them for cooperation (i.e. pause in breathing while data was

being obtained, and with respect to gel used to create acoustic seal around nosepiece, and decongestant).

3. The unit was calibrated, sealant gel applied to the nosepiece and the nosepiece was held at an angle parallel to the bridge of the nose, in order to produce minimal distortion of the nostril.
4. The subject was instructed to pause breathing once the start button was pressed, and measures were taken three times for each nostril (i.e. right, left, right, left, right, left). The patient was walked through administration of nasal decongestant (0.1% w/v xylometazoline hydrochloride nasal solution), one application per nostril (50µg of xylometazoline hydrochloride).

   Technique:

   1. Clear the nose.

   2. Lean forward slightly and insert the nozzle into nostril (Figure 3-6, recommended to angle bottle slightly more horizontally).

   3. Compress bottle firmly and deeply inhale simultaneously.

   4. Repeat for the other nostril.

Figure 3-6: Technique for application of decongestant

NB: It was expected that in patients with sensitive nasal passages, some local discomfort could be experienced when applying the nasal spray. Other side effects, such as palpitations, nausea and headache, are very rare. If the patient's maturity level was deemed inadequate for self-administration, assistance was provided by the researcher obtaining the measure.

5. Subjective survey was completed, allowing for approximately ten minutes to lapse for decongested readings to be obtained, in the same order as prior to decongestant application.

3.2.6 Statistical Methods

Descriptive statistics were completed on all data gathered. To assess accuracy of the machine itself, the average measure of the

total MCA for Subject 10 was compared to the known value by means of an independent T-test. Reliability analysis was conducted using intra-class correlation coefficient of decongested MCA and volume. The research question was concerned with whether MCA and volume change over time, regardless of type of expansion therapy, in addition to subjective reports of nasal function. Due to the short interval between treatment timepoints T0 and T1, changes in nasal cavity dimensions were presumed negligible for subjects in the control group; to avoid unwarranted subject radiation, measures from records taken at T0 were repeated for T1 for control subjects. Multivariate analysis of variance (MANOVA) was used to assess differences in mean MCA and volume between groups at each timepoint, as well as to evaluate whether any differences in change in MCA and volume exist between groups between timepoints i) T1 and T0, and ii) T2 and T0. Correlation between overall change in total MCA and volume with overall change in subjective score was assessed. Statistical analysis was performed using SPSS software version 16.0.

3.3 Results

3.3.1 Accuracy

Accuracy of the acoustic rhinometer was assessed by comparing the average measured total MCA (0.637 ± 0.036 cm^2) to the known value (0.623 cm^2) for Subject 10. T-test results show a non significant difference [t(9)=1.243, p=0.245] between obtained and true values, indicating high measurement accuracy for the device. Table 3-1 shows obtained left and right measures, as well as the total MCA.

Table 3-1: Obtained left and right MCA measures for Subject 10

Right MCA	Left MCA	Total MCA
0.31	0.31	0.62
0.25	0.35	0.60
0.32	0.34	0.66
0.32	0.34	0.66
0.35	0.35	0.70
0.28	0.33	0.61
0.33	0.34	0.67
0.3	0.35	0.65
0.27	0.33	0.60
0.30	0.30	0.60

3.3.2 Reliability

Intra-rater reliability was assessed using intra-class correlation coefficients (ICC) calculated from repeated measures of MCA and volume. The ICC and its corresponding 95% confidence interval for absolute agreement of volume and MCA measures are shown in

Table 3-2, indicating high reliability of the operator and technique. Data obtained is shown in Tables 3-3 through 3-6, along with mean values and standard deviation per subject.

Table 3-2: ICC

	ICC	95% CI
R volume	0.985	(0.964, 0.996)
L volume	0.963	(0.907, 0.989)
R MCA	0.965	(0.913, 0.990)
L MCA	0.982	(0.957, 0.995)

Table 3-3: Right MCA reliability measures along with mean and standard deviation per subject

Subject	RMCA#1	RMCA#2	RMCA#3	RMCA#4	RMCA#5	Mean	SD
1	0.61	0.75	0.64	0.79	0.62	0.682	0.082
2	0.61	0.67	0.48	0.60	0.56	0.584	0.070
3	0.54	0.48	0.49	0.53	0.53	0.514	0.027
4	0.43	0.44	0.33	0.43	0.27	0.380	0.076
5	0.37	0.38	0.36	0.41	0.36	0.376	0.021
6	0.57	0.56	0.53	0.55	0.54	0.550	0.016
7	0.59	0.63	0.66	0.56	0.59	0.606	0.039
8	0.43	0.40	0.43	0.45	0.44	0.430	0.019
9	0.39	0.40	0.44	0.51	0.45	0.438	0.048
10	0.68	0.72	0.70	0.64	0.71	0.690	0.032

Table 3-4: Left MCA reliability measures along with mean and standard deviation per subject

Subject	LMCA#1	LMCA#2	LMCA#3	LMCA#4	LMCA#5	Mean	SD
1	0.19	0.15	0.19	0.22	0.23	0.196	0.031
2	0.70	0.59	0.61	0.68	0.50	0.616	0.080
3	0.68	0.64	0.73	0.65	0.50	0.640	0.086
4	0.58	0.55	0.49	0.50	0.56	0.536	0.039
5	0.37	0.33	0.35	0.33	0.34	0.344	0.017
6	0.63	0.65	0.64	0.73	0.67	0.664	0.040
7	0.44	0.52	0.60	0.48	0.46	0.500	0.063
8	0.44	0.38	0.40	0.33	0.33	0.376	0.047
9	0.60	0.60	0.62	0.62	0.61	0.610	0.010
10	0.73	0.71	0.72	0.72	0.75	0.726	0.015

Table 3-5: Right volume reliability measures along with mean and standard deviation per subject

Subject	RV#1	RV#2	RV#3	RV#4	RV#5	Mean	SD
1	8.07	8.69	7.87	7.25	6.97	7.770	0.681
2	11.62	9.36	9.65	11.39	10.90	10.584	1.024
3	6.38	5.90	5.98	5.85	6.59	6.140	0.327
4	4.73	5.03	4.35	5.32	4.25	4.736	0.451
5	4.37	4.38	4.51	4.59	4.44	4.458	0.093
6	9.08	8.95	8.04	8.40	8.87	8.668	0.435
7	10.73	9.55	9.44	9.38	8.72	9.564	0.728
8	6.23	6.72	6.44	6.66	6.64	6.538	0.202
9	6.68	6.90	6.95	7.44	7.15	7.024	0.286
10	8.75	9.89	9.81	9.48	10.95	9.776	0.796

Table 3-6: Left volume reliability measures along with mean and standard deviation per subject

Subject	LV#1	LV#2	LV#3	LV#4	LV#5	Mean	SD
1	3.47	2.91	3.61	3.75	4.14	3.576	0.448
2	12.69	10.31	10.05	11.28	8.23	10.512	1.643
3	8.84	8.75	9.41	9.12	6.67	8.558	1.087
4	6.19	6.72	6.44	6.56	6.88	6.558	0.264
5	5.43	5.24	5.46	5.44	5.41	5.396	0.089
6	7.98	7.49	7.90	8.80	9.91	8.416	0.961
7	6.55	6.85	7.84	6.37	6.66	6.854	0.578
8	6.85	6.87	6.32	5.39	5.22	6.130	0.787
9	8.64	8.55	8.21	8.24	8.39	8.406	0.188
10	7.23	9.04	9.37	10.78	10.11	9.306	1.342

3.3.3 Expansion Study

A total of thirty subjects were recruited to the study; their gender and age distribution are shown in Table 3-7.

Table 3-7: Gender and age distribution

Treatment	Gender	Frequency	Mean Age	Age Std Deviation
Tooth-borne	Male	5	14.35	1.57
	Female	4	14.19	0.80
	Total	9	14.28	1.21
Bone-borne	Male	4	15.33	1.82
	Female	6	12.75	1.23
	Total	10	13.78	1.93
Control	Male	5	13.03	1.30
	Female	6	13.71	1.45
	Total	11	13.40	1.36

Boxplots (Figure 3-7 and 3-8) show central tendency and dispersion of the data at each timepoint for each group, both for total MCA and volume.

Figure 3-7: Boxplot for total MCA

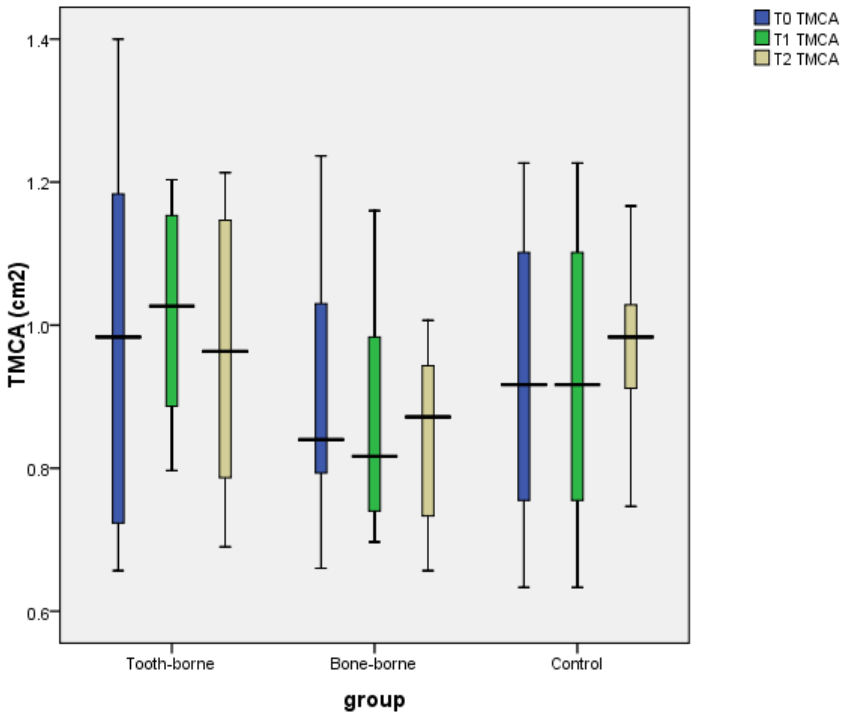
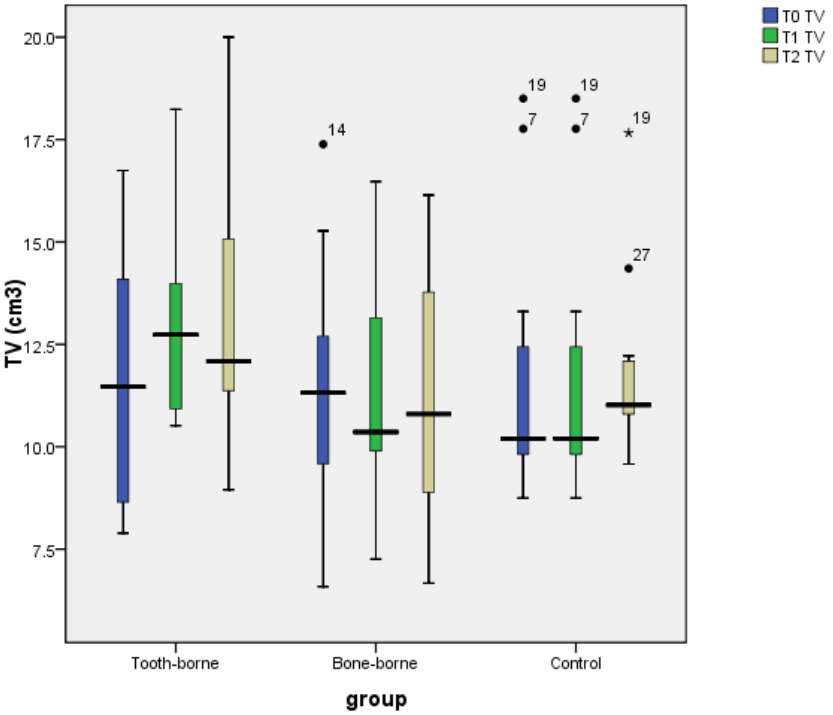


Figure 3-8: Boxplot for total volume



To confirm initial homogeneity between groups, a MANOVA was conducted with dependent variables total MCA and volume and between group factor of treatment; results indicate non significant initial difference between groups at T0 [F(4,52)=0.329, p=0.857]. Similarly, MANOVA revealed non significant difference between groups at T1 [F(4,52)=0.797, p=0.533] and T2 [F(4,52)=1.861, p=0.131] for total MCA and volume.

Multivariate analyses of variance were conducted with dependent variables total MCA and volume differences between timepoints

(i.e. T2-T0 and T1-T0), and between group factor of treatment to assess whether changes in total MCA and volume between timepoints were significant between groups. Results indicate non significant difference between groups for changes in total MCA and volume between timepoints [$F(4,52)=1.584$, $p=0.192$ and $F(4,52)=1.395$, $p=0.249$ respectively]. MANOVA results were confirmed by Kruskal-Wallis non-parametric assessment.

Repeated measures MANOVA was used to assess whether MCA and volume changed over time, regardless of type of expansion therapy, and revealed non significant differences in total MCA and volume between the treatment groups, between times of measurement and due to any interaction between group and time (Appendix D, Table A); this is also presented in profile plots (Appendix D, Figures A and B). In addition, a low effect size was seen as a result of treatment method, time or their interaction. Results were confirmed with Friedman non-parametric methods. Table 3-8 presents mean and standard deviations for MCA and volume per group at each timepoint.

Table 3-8: Mean and SD for each study group at each timepoint

Measure	Timepoint	Group					
		Tooth-borne		Bone-borne		Control	
		Mean	SD	Mean	SD	Mean	SD
MCA (cm^2)	T0	0.996	0.262	0.905	0.185	0.928	0.199
	T1	1.012	0.152	0.872	0.163	0.928	0.199
	T2	0.957	0.196	0.840	0.131	0.967	0.130
Volume (cm^3)	T0	11.832	3.360	11.330	3.385	11.828	3.343
	T1	13.160	2.816	11.161	2.813	11.828	3.343
	T2	13.129	3.407	11.351	3.235	11.913	2.310

A repeated measures analysis of variance was conducted to assess if there was a difference between participants in the expansion groups and the control group in the amount of change (if any) in their total and individual question scores on The NOSE Scale© survey of subjective measure of nasal obstruction. Non significant effects were found for the main effects of group and time, and for the interaction between group and time (Appendix D, Table B).

Spearman's rank non-parametric correlation analysis between total symptom score change and total MCA change (rho= -0.121), as well as between total symptom score change and total volume change (rho= 0.046) revealed non-significant results (p=0.524 and p=0.809, respectively).

3.4 Discussion

The purpose of this study was to assess nasal MCA and volume changes as a result of application of two distinctly different RME appliances and to compare any difference to an untreated control group. Consideration was also given to subjective assessment of nasal symptoms throughout the process.

Outliers exist and should be noted (Figure 3-8) however, there was no evident reason to exclude them from the data set. Subjects #19, 7, 14, and 27 displayed higher total nasal volumes. Of these, three were assigned to the control group, and #7 warrants discussion as the subject's total volume value appeared to drop at timepoint T2. This is difficult to explain, perhaps the individual was experiencing excessive soft tissue swelling of the nasal mucosa at timepoint T2 which was less responsive to decongestant (although subjective report at that time did not show any difference in perceived obstruction compared to prior timepoints, and respiratory health history did not report significant findings); another reason may be due to error. Interestingly, all four outlier subjects fell within the upper quartile of subject age; although there has been evidence lacking to associate increased volume with age, unconfirmed reports suggest increase in MCA with increased body surface area [35].

Descriptive statistics revealed individual variation in subjects' MCA and volume. The majority of subjects displayed minimal percent change overall from T0 to T2, while a small number of individuals' measures either substantially increased or decreased, which is difficult to rationalize. In these few individuals, the subjective report did not correspond with their nasal airway status at the time the measures were taken.

Evaluation of survey responses in this investigation did not show any changes in subjective sensation of nasal airway function due to therapy or time, and lack correlation with both overall change in total MCA and volume. This is in agreement with other studies [37-42]. Wheeler and Corey [20] and Schumacher [43] state that symptom scores often inconsistently correspond to other objective measures.

Our results are in contrast to previous studies applying similar research parameters [44-46] in which significant increase in nasal dimensions were reported. Bicakci *et al* [44] investigated total MCA in subjects according to developmental stage (pre- or post-pubertal growth spurt). They reported significant increase in MCA after RME compared to matched control subjects after expansion, and in addition suggest that changes are more stable if expansion is performed before the pubertal growth spurt. Their measures were obtained before and after RME and after three months retention.

Although they reported mean ages of the subjects included, they did not provide maximum and minimum age range or inclusion criteria for age, and control group subjects were not specified as having transverse maxillary constriction. Compadretti *et al* [45] used rhinomanometry to evaluate nasal resistance as well as AR to evaluate total MCA and volume changes after RME, and reported a significant decrease in resistance and increase in MCA and volumes compared to control subjects after expansion therapy, despite large individual variation of treatment response. They compared measures before expansion and at 12 month follow-up, and their treatment subjects ranged in age from 5 to 13 years whereas control subjects ranged between 8 and 12 years. Cappellette *et al* [46] used AR to prospectively compare the effects of RME on nasal cavity measures; they reported a significant increase in nearly all transverse areas and nasal volumes in the treatment group for separate left and right sides. However, the age range of subjects was between 4 to 14 years, their measures compared exclusively before and immediately after expansion, and control subjects did not present with maxillary constriction. As a consequence, differences in results between the present study and those aforementioned may be related to differences in criteria in patient inclusion (particularly age), subject ethnicity, and/or type

and dosage of topical decongestant (medication type was provided in two articles (oxymetazoline), however dosage was not reported).

There must be consideration as to how much nasal volume or MCA increase is clinically significant. Expansion appliances direct force to separate the maxillae close to the nasal floor, where the area of highest resistance (the nasal valve) is situated. Theoretically, if the maxillae are separated bodily, the walls of the nasal cavity also separate, with a greater amount of bony separation inferiorly. Our results show that expansion does not statistically change the dimensions in the nasal passage for air flow. Other studies report significant differences in nasal cavity dimensions, however the actual magnitude of the measured changes may have questionable biologic significance. Whether the amount of area and volume gained in other studies has an effect on patients' quality of life needs to be assessed, however from our study it appears that RME does not significantly change nasal function symptoms. While the measurements obtained may reveal anatomic relationships, they are not indicative of an individual's physiologic breathing pattern, and if nasal obstruction exists, a cause should be established prior to treatment.

3.5 Conclusion

Considering nasal airway minimal cross-sectional area and volume after rapid maxillary expansion, no significant changes were found in subjects treated with tooth- or bone-anchored appliances compared to control subjects over three timepoints. Similarly, no significant difference was found in subjective reports, and no correlation was measured between nasal airway dimensional change and subject symptoms. Table 3-9 relates initial hypotheses to resultant findings.

Table 3-9: Summary of H_o and resultant findings

H_o	Findings
There is no difference in mean minimum cross-sectional area and volume between groups at each timepoint.	Lack of evidence to reject H_o – Non significant difference in MCA and volume was found between groups at all timepoints
There is no difference between groups in change in minimum cross-sectional area and volume between timepoints T0 and T1.	Lack of evidence to reject H_o – Non significant difference in change in MCA and volume was found between groups for time span T0 to T1
There is no difference between groups in change in minimum cross-sectional area and volume between timepoints T0 and T2.	Lack of evidence to reject H_o – Non significant difference in change in MCA and volume was found between groups for time span T0 to T2
There is no subjective change in nasal symptoms due to RME.	Lack of evidence to reject H_o – Non significant difference found between groups in the amount of change in their total and individual question scores on The NOSE Scale©
Mean minimum cross-sectional area and volume are the same at all time points.	Lack of evidence to reject H_o – Non significant difference in MCA and volume found between timepoints
Mean minimum cross-sectional area and volume are the same for each treatment group.	Lack of evidence to reject H_o – Non significant difference in MCA and volume found between groups
Differences in minimum cross-sectional area and volume between treatment groups are the same at all time points.	Lack of evidence to reject H_o – Non significant result for interaction between group and time on dependent variables MCA and volume

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Chapter 4. General Discussion and Recommendations

4.1 General Discussion

This experimental investigation was conducted in order to gain insight into nasal dimensional changes and their anatomical response to RME intervention. This study is unique in that two types of expansion appliances were used, one being a traditional standard and the other being newly developed and not yet in widespread use. The results of this research are in contrast to many published works with similar focus [1-11].

Design method of a randomized clinical trial was used in order to minimize any bias and confounding factors, and controlling as many sources of variation as possible. In this study, random allocation of subjects to treatment groups was followed, thus it is possible to infer causation of the results found. Inferences to population cannot be made as subjects were not randomly selected from the "general" population, they were selected based on inclusion criteria from a very unique setting, that being the graduate orthodontic clinic at the University of Alberta.

In this repeated measures experiment, interpretation of the data is complicated in that there are two sources of variability, both within-subjects and between- subject groups. Within a subject, the observations may differ because they were taken at different times, while if the mean value was calculated for each subject (or group

of subjects), these means theoretically would also differ. Individual patient variation in response was present in this study; this may be due to physiologic (e.g. hormonal fluctuations), or environmental influence (e.g. seasonal changes).

Due to the influence of the nasal cycle on nasal mucosa, it has been recommended that topical decongestants be utilized when using AR to assess the nasal cavity [12]. Xylometazoline hydrochloride was used to reduce any confounding effect of differing levels of congestion of the nasal mucosa, thus allowing measures of the subject's nasal anatomy as opposed to their variable physiologic or pathologic states. It is of interest to note in severely congested individuals, the area of greatest constriction on the rhinogram usually corresponds to the second MCA, and after application of topical decongestant it moves anteriorly to the bony isthmus, as the second MCA corresponds approximately to the anterior end of the middle turbinate and anterior third of the inferior turbinate where highly erectile tissue is located [13,14].

Acoustic rhinometry is highly recommended for objective assessment of nasal obstruction as it provides a representation of nasal cavity geometry [15]. Limitations have been reported, however should be of minimal consideration for the purpose of this study. Unlike CT which provides a three dimensional view, the AR

rhinogram does not provide the specifics relating to shape of the areas inside the airway. This may be of more significant consequence when measuring air flow through the nasal passage as shape of the airway greatly influences the ebbs and flows of air. A second disadvantage of AR is that the algorithms used assume negligible sound loss; this may be a consideration behind narrow constrictions and in the regions of the sinus ostia, however this does not reduce the ability to measure changes in nasal cavity dimensions [16-18].

Subjective assessment of nasal function has been shown to poorly correlate with concomitant objective measures [19-24]. Schumacher [15] suggests using subjective scoring of changes in obstructive symptoms only when recent rapid changes have been encountered, due to the limitations of a person's memory to recall gradual change and the possibility of a large interval of time over which changes may occur. He also draws mention to the fact that surveys do not consider individuals with asymptomatic nasal obstruction, or those individuals who complain of nasal obstruction but who have normal nasal airflow. Sensation of nasal patency can be modified, for example, via cold receptors in the nose; menthol is thought to activate these cold receptors, leaving a feeling of improved nasal air flow, and application of topical anaesthesia to

nasal mucosa blocks these receptors resulting in a sensation of increased obstruction [25].

Orthodontic clinicians should assess patients for nasal obstruction, and if suspected refer to a medical specialist before orthodontic intervention for examination and treatment of their underlying medical condition [26,27]. The findings from this study suggest negligible effects on nasal cavity dimension as a result of RME, therefore maxillary expansion cannot be considered a treatment option to address nasal obstruction. This research is the initial component to a final study which will include a larger sample size, the results of which will be managed as in this pilot project.

4.2 Recommendations

An interesting focus for future research would be to compare nasal volume and area measures between acoustic rhinometry and cone-beam computed tomography; the latter diagnostic tool is promising to be in widespread use in orthodontics and software is available which claims to provide accurate depiction of the upper airway within the scan. In addition, unsupported accounts are made within the scope of orthodontics both anecdotally and from industry-supported research regarding nasal airway changes from the use of different appliances; use of acoustic rhinometry to assess

dimensional changes could prove or disprove these claims. The acoustic rhinometer used in this study has an attachment that can measure pharyngeal geometry; assessment of airway changes after orthognathic surgery could be considered. Of course it is of interest to compare these results to those of the final study sample size; it is anticipated that overall results will not differ from the results of this initial component.

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Appendix

Appendix A: Ethics Approval

Health Research Ethics Board

213 Heritage Medical Research Centre
University of Alberta, Edmonton, Alberta T6G 2S2
p.780.492.9724 (Biomedical Panel)
p.780.492.0302 (Health Panel)
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ETHICS APPROVAL FORM

Date: January 2008

Name(s) of Principal Investigator(s): Dr. Paul Major

Department: Dentistry

Title: **Analysis of dentofacial changes and nasal airway function with a tooth borne and an osseointegrated implant/onplant - anchored maxillary expansion appliance**

The Health Research Ethics Board (Biomedical Panel) has reviewed the file on this project, for which all documentation is currently up to date. The research has been found to be acceptable within the limitations of human experimentation.

Specific Comments: This is the annual re-approval and is valid for one year. Next year, a few weeks prior to its expiration, a Progress Report will be sent to you for completion. If no major issues are identified, your approval will be renewed for another year.

For studies where investigators must obtain informed consent, signed copies of the consent form must be retained, as should all study related documents, so as to be available to the HREB on request. They should be kept for the duration of the project and for at least seven years following its completion. In the case of clinical trials approved under Division 5 of the Food and Drug Regulations of Health Canada, study records must be retained for 25 years.

S.K.M. Kimber, MD, FRCPC
Chair, Health Research Ethics Board
Biomedical Panel

Issue: #0678

UNIVERSITY OF ALBERTA

Capital Health
Edmonton and area

CARITAS HEALTH GROUP

Appendix B: Subject Information Letter and Consent Form

Analysis of Dentofacial Changes and Nasal Function with a Tooth Borne and an Osseous-integrated Inplant/Onplant Anchored Maxillary Expansion Appliance

Principal Investigator:

- Dr. Paul Major

Co-Investigators:

- Dr. Manuel Lagravere
- Dr. Jillian Gordon
- Dr. Doug Dederich

Background:

You have been asked to take part in this study because you have a crossbite in the back teeth requiring orthodontics. There are two treatment options for your condition. The first treatment includes the placement of an expansion appliance that attaches to the upper back teeth. The second treatment includes a similar expander which is attached to two inplant/onplants placed on each side of the palate.

Purpose:

You are being asked to participate in a research study which will evaluate how efficient the expansion appliance using onplants is compared to the traditional one which uses teeth as anchors.

Procedures:

Your complete orthodontic treatment will be provided by Dr. Lagravere in the Orthodontic Graduate Clinic at the University of Alberta. In addition to the standard procedures necessary to treat your type of bite problem, a series of dental impressions and radiographs will be made. Measurement of how well you breathe through the nose will also be made. Depending on the expansion treatment you are randomly selected for, a dental

implant/onplant may be inserted on each side of your palate.

The implant/onplants will be placed with local freezing and the discomfort you are likely to experience is similar to having a tooth removed. A second minor surgery will be required to remove the implant/onplants when the orthodontic treatment is completed. These two appointments will take approximately 45 minutes each. Once the correct upper jaw width has been achieved, typical full braces will be placed on the upper and lower teeth to complete bite correction and tooth alignment. To help track jaw and tooth position changes five additional three-dimensional x-ray, panoramic and lateral cephalometric x-rays will be taken.

The rate of airflow while breathing through the nose and dimensions of the inside of the nose will be measured three times. You will be asked to blow through the nose into a special mask that fits over the nose. A device that uses sound waves to measure the sized of the inside of the nose will be placed close to the nostril and a recording is made. You will not feel any discomfort.

Possible Benefits:

Participation in this study will not alter the quality of your treatment. Information gained from this study will help us compare the effects of a bone-anchored upper jaw expander to a traditional tooth anchored upper jaw expander and will help us treat other patients with your condition with the best appliance.

Possible Risks:

The risks associated with the implant/onplant surgery are similar to those expected with tooth removal and may include minor risk of infection or bleeding. The onplants are constructed from titanium and stainless steel and will not cause an allergic reaction.

The x-rays taken for this study generate a total amount of radiation equal

to approximately 20% of annual dose expected in normal living.

Confidentiality:

Personal records related to this study will be kept strictly confidential. Only the researchers involved in this study and the Health Research Ethics Board will have access to your records. Any reports published as a result of this study will not identify you by name.

Voluntary Participation:

You are free to withdraw from the research study at any time, and your continuing orthodontic care will not be compromised in any way.

Reimbursement of Expenses:

You will be provided with parking coupons for each visit.

Contact Names and Telephone Numbers:

If you have any concerns regarding your rights as a study participant, you may contact Dr. Kline, Director of Graduate Studies and Research, Department of Dentistry, at 492-3312.

Please contact any of the individuals identified below if you have any questions or concerns:

Dr. Lagravere
PhD Resident
Orthodontic Graduate Program
University of Alberta
492-1335
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Dr. Major
Professor and Director
Orthodontic Graduate Program
University of Alberta
492-4469
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Consent Form

Analysis of Dentofacial Changes and Nasal Function with a Tooth Borne and an Osseous-integrated Inplant/Onplant Anchored Maxillary Expansion Appliance

Investigators: Dr. Paul Major, Dr. Manuel Lagravere, Dr. Jillian Gordon, Dr. Doug Dederich

Please circle the answer:

Do you understand that you have been asked to be in a research study?
Yes No

Have you read and received a copy of the attached information sheet?
Yes No

Do you understand the benefits and risks involved in taking part of this research study?
Yes No

Have you had the opportunity to ask questions and discuss the research study?
Yes No

Do you understand that you are free to refuse to participate or withdraw from the research study at any time? This will not affect the results of your orthodontic treatment.
Yes No

Has the issue about confidentiality been explained to you? Do you understand who will have access to your records?
Yes No

This research study was explain to me by: _____

I agree to take part of the research study.

_____	_____	_____
Patient's signature	Date	Witness
_____		_____
Printed name		Printed Name

I agree for my child to take part in this research study.

_____	_____	_____
Parent's Signature	Date	Witness
_____		_____
Printed name		Printed name

I believe the persons signing this form understand what is involved in this study and voluntarily agrees to participate.

_____	_____
Signature of Investigator or Designee	Date

Appendix C: NOSE Instrument

Name:_____ Date:_____

Nasal Obstruction Symptom Evaluation (NOSE) Instrument

To the patient: Please help us to better understand the impact of nasal obstruction on your quality of life by completing the following survey. Thank you!

Over the past month, how much of a problem were the following conditions for you? (Please circle the most correct response.)

	Not a problem	Very mild problem	Moderate problem	Fairly bad problem	Severe problem
Nasal congestion or stuffiness	0	1	2	3	4
Nasal blockage or obstruction	0	1	2	3	4
Trouble breathing through my nose	0	1	2	3	4
Trouble sleeping	0	1	2	3	4
Unable to get enough air through my nose during exercise or exertion	0	1	2	3	4

Respiratory Health History

Have you had/been diagnosed with any of the following:

Nasal septal deviation	Yes	No
Allergies	Yes	No
Respiratory Infections	Yes	No
Nasal turbinate hypertrophy	Yes	No
Previous surgeries including:		
Endoscopic sinus surgery	Yes	No
Tonsillectomy	Yes	No
Adeniodectomy	Yes	No
Chronic medical conditions including:		
Asthma	Yes	No
Cystic fibrosis	Yes	No
Sleep apnea	Yes	No
Gastroesophageal reflux	Yes	No
Do you smoke?	Yes	No
Do you snore during sleep?	Yes	No

Please list any medications being used:

_____

_____

_____

Appendix D: Chapter 3 Supplemental Tables and Figures

Table A: Repeated measures MANOVA results for total MCA and volume

Effect		
Time	Group	Time*Group Interaction
F(4,24)=1.278, p=0.306	F(4,52)=0.580, p=0.678	F(8,48)=1.169, p=0.337

Table B: Repeated measures ANOVA results for overall and individual questions on The NOSE Scale© survey

	Effect		
	Time	Group	Time*Group Interaction
Total (/20)	F(2,54)=0.887, p=0.418	F(2,27)=1.704, p=0.201	F(4,54)=0.362, p=0.834
Nasal congestion or stuffiness (/4)	F(2,54)=2.407, p=0.100	F(2,27)=0.418, p=0.663	F(4,54)=1.009, p=0.411
Nasal blockage or obstruction (/4)	F(2,54)=2.148, p=0.127	F(2,27)=2.218, p=0.128	F(4,54)=0.790, p=0.537
Trouble breathing through my nose (/4)	F(2,54)=2.062, p=0.137	F(2,27)=0.710, p=0.501	F(4,54)=0.346, p=0.846
Trouble sleeping (/4)	F(2,54)=0.140, p=0.870	F(2,27)=1.565, p=0.228	F(4,54)=0.320, p=0.863
Unable to get enough air through my nose during exercise or exertion (/4)	F(2,54)=0.133, p=0.876	F(2,27)=1.052, p=0.363	F(4,54)=1.393, p=0.249

Figure A: Profile plot of mean total minimum cross-sectional area

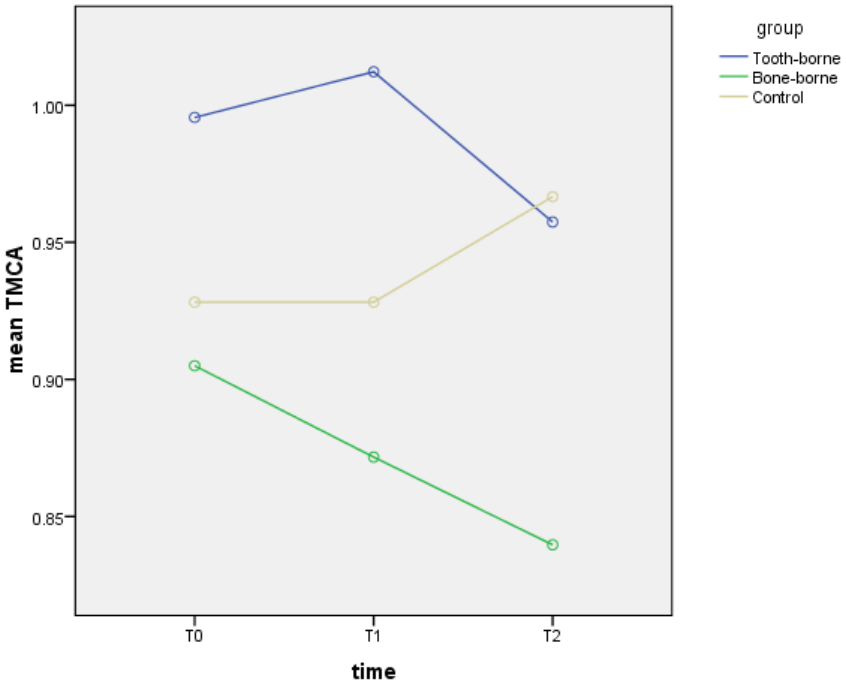

Figure B: Profile plot of mean total volume