Volumetric changes of the nose and nasal airway 2 years after tooth-borne and bone-borne surgically assisted rapid maxillary expansion


This study aimed to assess the effects of bone-borne and tooth-borne surgically assisted rapid maxillary expansion on the volumes of the nose and nasal airway 2 yr after maxillary expansion. This prospective cohort study included 32 patients with transverse maxillary hypoplasia. Expansion was performed with a tooth-borne distractor (Hyrax) in 19 patients and with a bone-borne distractor [transpalatal distractor (TPD)] in the remaining 13. Cone beam computed tomography scans and three-dimensional (3D) photographs of the face were acquired before treatment and 22 ± 7 months later, and were used to evaluate the volumes of the nose and nasal airway. Nasal volume increased by 1.01 ± 1.6% in the Hyrax group and by 2.39 ± 2.4% in the TPD group. Nasal airway volume increased by 9.7 ± 5.6% in the Hyrax group and by 12.7% in the TPD group. Changes in the nasal volume and in the nasal airway volume between the pre- and post-treatment measurements were statistically significant, whereas differences between the treatment groups were not; 22 months after surgically assisted rapid maxillary expansion, the increases in the nasal volume and in the nasal airway volume were comparable between tooth-borne and bone-borne devices.

Surgically assisted rapid maxillary expansion (SARME) has long been used to correct transverse maxillary deficiency in adult patients. Although the procedure aims to expand the constricted maxilla to coordinate the upper and lower arches, the transversal enlargement of the maxillary apical base simultaneously alters the dimensions of the nose and the nasal cavity (1). The skeletal and dental effects of SARME with either tooth-borne or bone-borne expansion have been thoroughly described in the literature (2–9). However, traditional two-dimensional (2D) cephalograms provided limited information on the effects of expansion devices on the dimensions of the nose and the nasal airway. With the introduction of three-dimensional (3D) imaging modalities such as 3D stereophotogrammetry and cone beam computed tomography (CBCT), a more detailed and accurate evaluation of the changes in soft tissues and airway volumes became feasible (10). Compared with conventional radiography, CBCT allows more detailed visualization and quantification of the airway space (10, 11). Consequently, the past few years have seen an increasing number of publications using CBCT for upper airway analysis following maxillary expansion. These studies have mainly investigated the effects of each expansion device separately (1, 12, 13) or focused on the oropharyngeal airway (14). The effects of tooth-borne and bone-borne SARME on the volume of the nose and on the nasal airway volume have not yet been directly compared.

Therefore, the aim of the present study was to evaluate the long-term effects of bone-borne and tooth-borne SARME on the volume of the nose and on the nasal airway volume using 3D imaging software. The null hypothesis to be tested was that the choice of tooth-borne or bone-borne devices does not result in different volumetric changes of the nose and the nasal airway.

Material and methods

This study included 32 patients seeking orthodontic treatment at the Department of Orthodontics and Craniofacial Biology of the Radboud University Nijmegen Medical Centre, Nijmegen (the Netherlands). Inclusion criteria were skeletal maturity, skeletal transverse maxillary deficiency > 5 mm combined with another skeletal discrepancy that required orthognathic surgical intervention, and no developmental deformity. Exclusion criteria were the presence of developmental deformity, signs of fluid accumula-
tion in the maxillary sinuses on the CBCT images, and the absence of more than four teeth in the posterior maxillary arch. Nineteen patients underwent tooth-borne expansion and 13 underwent bone-borne expansion. The study protocol was approved by the Medical Ethics Committee of the Radboud University Nijmegen Medical Centre, Nijmegen, the Netherlands (no. 181/2005). All patients gave written informed consent.

**Surgical procedure**

The same surgical procedure was applied in all patients and has been described in detail in a previous study (9). Briefly, osteotomy at the level of Le Fort I, with additional midline osteotomy and pterygomaxillary disjunction, was performed under general anaesthesia. In 19 patients, a tooth-borne distractor (Hyrax; Dentaurum, Ispring, Germany) was cemented and fitted with orthodontic bands on the anchor teeth. In 13 patients, a bone-borne distractor [the transpalatal distractor (TPD); Surgi-Tec, Bruges, Belgium] was fixed to the palatal bone with two screws at the level of the second premolars (Fig. 1). The type of distractor used was chosen following agreement between the orthodontist and the surgeon; this decision was generally based on the periodontal condition of the anchor teeth and the degree of palatal constriction. All operations were performed by the same surgeon (M. de Koning). Following a 1-wk latency period, the appliances were activated at a rate of 1 mm/d. The expansion was continued until the palatal cusps of the maxillary teeth touched the buccal cusps of the lower dentition. When the desired expansion was achieved, the distraction device was blocked by inserting a blocking screw in one of the boreholes of the TPD and was left in place for a 3-month consolidation period. Orthodontic treatment using straight-wire fixed appliances was initiated 8–10 wk after the end of active distraction.

For each patient, CBCT scans and 3D photographs of the face were taken before treatment (T0) and after completion of the presurgical orthodontic treatment but before the second orthognathic intervention (T1; 22 ± 7 months later). The CBCT scans were acquired using the i-CAT® 3D Imaging System (Imaging Sciences International, Hatfield, PA, USA) with a field of view (FOV) of 22 × 16 cm and 0.4 mm voxel size. Data from the CBCT were exported in Digital Imaging and Communications in Medicine (DICOM) format. A 3D stereophotogrammetric camera, set up with an integrated software program modular system V 1.0 (3dMDface System, 3dMD LLC, Atlanta, GA, USA), was used to capture 3D photographs of the face. All photographs were taken with natural head position and relaxed facial musculature. For further analysis, each captured image was exported as a wavefront object file (.obj) and imported into Maxilim software version 2.2.2.1 (Medicim, Mechelen, Belgium).

**Nasal volume**

The volume of the nose was measured as previously described by van Loon et al. (15, 16). First of all, a surface-based matching procedure was performed for the pre- and post-treatment photographs (Fig. 2). This was followed by a modified 3D cephalometric analysis of the

---

Fig. 1. (A) Expansion with a tooth-borne appliance (Hyrax). (B) Expansion with a bone-borne appliance [transpalatal distractor (TPD)].

Fig. 2. (A) Pretreatment three-dimensional (3D) photograph (T0). (B) Post-treatment (i.e. after completion of presurgical orthodontic treatment but before the second orthognathic intervention) 3D photograph (T1). (C) Colour-coded distance map of superimposed pre- and post-treatment photographs. The green colour indicates that the post-treatment photograph is in front of the original photograph and the red colour indicates the reverse. Each colour gradation is 1 mm.
superimposed photographs to outline the region of the nose for volumetric measurements using the landmarks and planes as depicted in Table 1. This resulted in the matched 3D photographs on a Cartesian coordinate system with the regions of interest lined by various planes. These planes defined the borders of the volume of the nose and were used for further circumscription of the 3D photograph (Fig. 3). Finally, only the nasal regions remained and a virtual volume could be computed. The left and right nasal volumes of the pre- and postoperative 3D photographs were then measured in cubic centimetres (cm³). In addition to the volume, the greater alar cartilage width was obtained by measuring the distance between the right and left alar points. All measurements were performed by the same examiner (B. v.L.), who was blinded to the type of device and was not involved in treating the patient. The duplicate measurement error of this method has previously been described (15).

### Airway volume

The nasal airway volume was measured on the CBCT scan images using ITK-SNAP open-source software (http://www.itksnap.org). First of all, a square-shaped area of interest was defined to outline the nasal airway on the mid-sagittal slice. The upper anterior corner was defined by soft-tissue nasion, and the lower posterior border was defined by the posterior nasal spine (Fig. 4). All axial slices were checked to ensure that the airway was included in the selected area. The nasal airway was then manually segmented by tracing the soft tissue-air interface using the greater alar cartilage width as the base of the airway volume (Fig. 4).

### Table 1

**Definitions of landmarks and planes used based on the three-dimensional (3D) cephalometric soft-tissue analysis**

<table>
<thead>
<tr>
<th>Landmarks and planes</th>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Landmarks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alare (left)</td>
<td>al(l)</td>
<td>Left alare, most lateral point on the left alar contour</td>
</tr>
<tr>
<td>Alare (right)</td>
<td>al(r)</td>
<td>Right alare, most lateral point on the right alar contour</td>
</tr>
<tr>
<td>Cheilion (left)</td>
<td>ch(l)</td>
<td>Left cheilion, point located at the left labial commissure</td>
</tr>
<tr>
<td>Cheilion (right)</td>
<td>ch(r)</td>
<td>Right cheilion, point located at the right labial commissure</td>
</tr>
<tr>
<td>Cheilion (middle)</td>
<td>ch(m)</td>
<td>Soft-tissue point automatically computed as the midpoint between the right cheilion and the left cheilion</td>
</tr>
<tr>
<td>Endocanthion (left)</td>
<td>en(l)</td>
<td>Left endocanthion, soft-tissue point located at the inner commissure of the left eye fissure</td>
</tr>
<tr>
<td>Endocanthion (right)</td>
<td>en(r)</td>
<td>Right endocanthion, soft-tissue point located at the inner commissure of the right eye fissure</td>
</tr>
<tr>
<td>Exocanthion (left)</td>
<td>ex(l)</td>
<td>Left exocanthion, soft-tissue point located at the outer commisure of the left eye fissure</td>
</tr>
<tr>
<td>Exocanthion (right)</td>
<td>ex(r)</td>
<td>Right exocanthion, soft-tissue point located at the outer commissure of the right eye fissure</td>
</tr>
<tr>
<td>Exocanthion (middle)</td>
<td>ex(m)</td>
<td>Soft-tissue point automatically computed as the midpoint between the right exocanthion and the left exocanthion</td>
</tr>
<tr>
<td>Pupil reconstructed</td>
<td>p'</td>
<td>Pupil-reconstructed point, midpoint between the endocanthi and pupils, located on the level of the exocanthi</td>
</tr>
<tr>
<td>Subnasale</td>
<td>sn</td>
<td>Subnasale, midpoint on the nasolabial soft-tissue contour between the columella crest and the upper lip</td>
</tr>
<tr>
<td><strong>Planes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal plane</td>
<td></td>
<td>The horizontal (x) 3D reference plane is automatically computed as a plane 6.6° below the Cantion–Superaurale line, along the horizontal direction of the natural head position and through the pupil reconstructed point translated 77.2 mm more posteriorly</td>
</tr>
<tr>
<td>Vertical plane</td>
<td></td>
<td>The vertical (y) 3D reference plane is computed as a plane perpendicular to the horizontal (x) 3D reference plane and along the horizontal direction of the natural head position</td>
</tr>
<tr>
<td>Median plane</td>
<td></td>
<td>The median (z) 3D reference plane is computed through the pupil reconstructed point and as a plane perpendicular to the horizontal (x) and the vertical (y) 3D reference planes</td>
</tr>
<tr>
<td>Posterior nasal plane</td>
<td></td>
<td>A plane through landmarks ex(l), ex(r), and ch(m)</td>
</tr>
<tr>
<td>Upper nasal plane</td>
<td></td>
<td>A plane through landmark ex(m) and parallel to the horizontal plane</td>
</tr>
<tr>
<td>Lower nasal plane</td>
<td></td>
<td>A plane through landmark sn and parallel to the horizontal plane</td>
</tr>
<tr>
<td>Lateral left nasal plane</td>
<td></td>
<td>A plane through landmarks en(l) and al(l) and perpendicular to the vertical plane</td>
</tr>
<tr>
<td>Lateral right nasal plane</td>
<td></td>
<td>A plane through landmarks en(r) and al(r) and perpendicular to the vertical plane</td>
</tr>
</tbody>
</table>

**Fig. 3.** Untextured three-dimensional (3D) photographs. (A) Landmarks and planes outlining the nasal area on the superimposed pretreatment and post-treatment 3D photographs. (B) Cropped nasal area.
user-guided 3D active contour segmentation in ITK-SNAP (17). Once the segmentation was complete, the software automatically computed the volume of the nasal airway in cubic centimetres (Fig. 5). The most anterior coronal slice showing the entire palatal roots of the first molars was used to measure the distance between the palatal root apices at T0 and T1. All segmentations were performed by the same examiner (R.N.) who was blinded to the type of device and was not involved in treatment of the patients. Eleven randomly selected CBCT scans were segmented twice, with an intervening time period of 2 wk, to determine the intra-examiner reliability.

**Statistical analysis**

Statistical analysis was performed using the Statistical Package of the Social Sciences, 16.0 (SPSS; SPSS, Chicago, IL, USA). Descriptive statistics were calculated initially, to produce a rough outline of the results and box plots. Pre- and post-treatment measurements were compared using a paired \( t \)-test with significance set at \( P < 0.05 \). An independent \( t \)-test was used to compare the two groups (with significance at \( P < 0.05 \)). Pearson’s correlation coefficient test was used to assess the relationship between the volumetric soft-tissue changes in the nose and the nasal airway. The intra-observer reliability for repeated measurements was calculated using Pearson’s correlation coefficient and a paired-sample \( t \)-test for the first and second measurements.

**Results**

The tooth-borne expansion group comprised 19 patients (5 men and 14 women) with a mean age of 24.2 \( \pm \) 7.0 yr at the time of surgical intervention. The bone-borne group included 13 patients (6 men and 7 women) with a mean age of 31.9 \( \pm \) 10.0 yr. The average time between the T0 and T1 CBCT scans was 21.7 \( \pm \) 6.6 months for the Hyrax group and 22.6 \( \pm \) 6.9 months for the TPD group (not significantly different; \( P = 0.89 \)). The amount of expansion at the level of the palatal root apices of the first molars was 5.46 \( \pm \) 3.3 mm for the Hyrax group and 3.4 \( \pm \) 2.5 mm for the TPD group (not significantly different; \( P = 0.13 \)). The amount of dental expansion and its correlation to the skeletal changes have been described in detail in a previous study of the same patients (9).

**Soft tissue changes of the nose**

Intra-observer reproducibility of the nasal volume measurements was reported in a previous publication using the same protocol (15). Table 2 shows the nasal volume

---

*Fig. 4.* Square-shaped area of interest outlining the nasal airway on (A) the mid-sagittal slice. N’, soft-tissue nasion used to define the upper anterior corner; PNS, posterior nasal spine used to define the lower posterior border. (B) the square-shaped area of interest on a coronal slice.

*Fig. 5.* Segmented nasal airway measured using ITK-SNAP open-source software (http://www.itksnap.org). (A) Axial view, (B) Sagittal view, (C) Coronal view, (D) 3D view.
Table 2
Changes in the nasal volume (expressed in cm³) measured on the three-dimensional (3D) photographs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>Mean diff.</th>
<th>P-value*</th>
<th>95% CI of diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hyrax (n = 19)</td>
<td>TPD (n = 13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T0</td>
<td>35.78 (6.20)</td>
<td>39.36 (6.26)</td>
<td>-3.78</td>
<td>0.11</td>
</tr>
<tr>
<td>T1</td>
<td>36.14 (6.17)</td>
<td>40.59 (7.08)</td>
<td>-4.46</td>
<td>0.09</td>
</tr>
<tr>
<td>Difference (T1 - T0)</td>
<td>0.36 (0.53)</td>
<td>1.04 (1.13)</td>
<td>-0.67</td>
<td>0.07</td>
</tr>
<tr>
<td>Percentage change</td>
<td>1.08 (1.62)</td>
<td>2.39 (2.40)</td>
<td>-1.31</td>
<td>0.12</td>
</tr>
</tbody>
</table>

diff, difference; T0, before treatment; T1, after completion of presurgical orthodontic treatment but before the second orthognathic intervention; TPD, transpalatal distractor.

*Significance was calculated using an independent t-test with significance set at P < 0.05.

Table 3
Changes in the nasal airway volume (cm³) measured using cone beam computed tomography (CBCT)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean (SD)</th>
<th>Mean diff.</th>
<th>P-value*</th>
<th>95% CI of diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hyrax (n = 19)</td>
<td>TPD (n = 13)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T0</td>
<td>54.05 (12.83)</td>
<td>54.75 (17.04)</td>
<td>-0.70</td>
<td>0.9</td>
</tr>
<tr>
<td>T1</td>
<td>59.16 (13.80)</td>
<td>61.77 (16.01)</td>
<td>-2.60</td>
<td>0.64</td>
</tr>
<tr>
<td>Difference (T1 - T0)</td>
<td>5.11 (3.17)</td>
<td>7.01 (4.86)</td>
<td>-1.90</td>
<td>0.25</td>
</tr>
<tr>
<td>Percentage change</td>
<td>9.74 (5.60)</td>
<td>12.95 (12.70)</td>
<td>-3.20</td>
<td>0.35</td>
</tr>
</tbody>
</table>

diff, difference; T0, before treatment; T1, after completion of presurgical orthodontic treatment but before the second orthognathic intervention; TPD, transpalatal distractor.

*Significance was calculated using an independent t-test with significance set at P < 0.05.

measured on the 3D photographs for both groups at T0 and T1. Baseline data before treatment were comparable between the two treatment groups (P = 0.11). Following expansion, the nasal volume increased by 1.08 ± 1.62% in the Hyrax group and by 2.39 ± 2.4% in the TPD group. These changes were statistically significant between T0 and T1 (P = 0.008). The absolute and percentage increase in volume was slightly higher in the TPD group than in the Hyrax group; however, this difference was not statistically significant between the two groups (P = 0.12).

The alar width had increased in both groups between T0 and T1. The mean increase in alar width was 1.2 ± 0.9 mm for the Hyrax group and 1.4 ± 1.5 for the TPD group. There was no significant difference between the two treatment groups (P = 0.7).

Nasal airway changes

Intra-observer reproducibility was high between the repeated segmentations, with a correlation coefficient of 0.93 between the first and second segmentations (P < 0.001). There was no statistically significant difference between the first and second measurements (standard error of the mean = 1.55 cm³, P = 0.52).

Table 3 presents the changes in the nasal airway volume and the comparison between the two treatment groups. The airway volume increased by 9.74 ± 5.60% in the Hyrax group and by 12.95 ± 12.70% in the TPD group, each representing a statistically significant increase between T0 and T1 (P < 0.001). The difference between the two treatment groups was not statistically significant (P = 0.35). The absolute and percentage changes in airway volume were not correlated with the changes in the volume of the nose, as measured on the stereophotogrammetric images (P = 0.41, r = 0.15).

Discussion

The present study investigated the changes of the nose and nasal airway volumes following bone-borne and tooth-borne expansion about 2 yr after treatment. These volumetric changes were evaluated using CBCT scans and 3D photographs taken before treatment and at approximately 22 months post-SARME, at the end of presurgical orthodontics. The scans acquired at the end of the presurgical orthodontic stage were required for planning the second orthognathic intervention and did not subject the patients to additional X-ray exposure.

During the acquisition of CBCT scans, the temporomandibular joints are sometimes included in the limited FOV at the expense of including the entire nose. As a result of this technical limitation, the tip of the nose was cut off in many scans, which prevented us from evaluating the changes in the nose on the CBCT data. Changes in the nose were instead evaluated by means of 3D photographs acquired on the same day. Retrospectively, the mean age of the patients in the TPD group was higher than that of patients in the Hyrax group. As all patients included in the study were ske-
tally mature, this between-group age difference does not influence the airway changes described herein.

CBCT imaging has proven to be a valuable diagnostic tool for evaluating airway shape and dimensions (10, 18). Segmentation or post-processing of the DICOM images using third-party software is generally required to allow the 3D visualization and quantification of the airway volume (19). This airway segmentation can be performed either automatically or manually. Automatic segmentation by differentiating the densities between the airway and the surrounding soft tissue using a threshold value is significantly faster and is considered more practical (20); however, variations in the threshold value reportedly result in different volume measurements (20, 21). In the present study, segmentation of the airway was performed manually by tracing the soft tissue–air interface using user-guided 3D active contour segmentation in ITK-SNAP (17). Although it is more time consuming, manual segmentation offers the advantage of controlling the airway delineation slice by slice and has been shown to be more accurate (17, 22).

At 22 months postexpansion, a statistically significant increase in the nasal airway volume was observed in both groups (9.7% and 12.9% for tooth-borne and bone-borne expansion, respectively). These increases did not significantly differ between tooth-borne and bone-borne expansion, confirming the null hypothesis. Deeb et al. (1) similarly used CT data to evaluate changes in nasal volume following bone-borne expansion using the Dresden bone-borne distractor, and reported only a 5.1% increase of nasal airway volume as opposed to the 12.9% increase in the present study. This difference between results could be attributed to the method of airway volume quantification, as they estimated the volume based on three cross-sectional areas in the front, middle, and posterior parts of the nose.

The majority of previous studies have relied on acoustic rhinometry (AR) to evaluate the airway volume. Doruk et al. (23) found significant correlations between airway volume measurements using AR and CT. Compared with the present study, previous studies that used AR to evaluate airway volume tended to report a larger percentage increase in nasal airway volume. Babacan et al. (24) found a 14.09% increase in nasal airway volume, while Wriedt et al. (25) reported a 21.2% increase at 6 months following tooth-borne SARME. A long-term follow-up study by Seeberger et al. (26) reported 23.25% enhancement of the nasal volume at 63 months postexpansion.

The functional benefit of such an increase in volume has not been fully determined (27). Magnusson et al. (28) evaluated nasal cavity size, airway resistance, and the subjective sensation of nasal obstruction after SARME at 3 and 18 months postexpansion. They reported that a subjective improvement in nasal function was not apparent in the total sample and was only obvious in subjects with an initial nasal obstruction. Furthermore, they found no correlation between the objective increase in nasal cavity and the subjective sensation of improved nasal function.

Many studies have validated the accuracy of 3D stereophotogrammetry in capturing facial morphological features (29–31), and van Loon et al. proved its applicability for measuring postoperative changes in nasal volumes following rhinoplasty (15, 16). In the present study, changes in the nose volume following expansion were minimal and were not correlated with the increase in nasal airway volume. The posterior region or the nasal airway showed greater dimensional changes than the anterior or soft tissue part of the nose. Similar findings have been previously reported (32, 33), and were attributed to the nasal anatomy; because of the greater dimensions of the posterior region of the nasal cavity, the smallest amount of transverse expansion leads to a more pronounced change in the volume.

The increase in nasal base-width following SARME is an aesthetic concern for many clinicians. In the present study, the nasal width increase was limited to 1.2 and 1.4 mm in the Hyrax and TPD groups, respectively. These findings correspond to the results of previous studies. Berger et al. (34) reported a 2-mm increase in alar width, which was maintained at 1 yr following tooth-borne expansion. Similarly, Ramieri et al. (35) found a 1.4-mm increase in alar width 1 yr following bone-borne expansion. From an aesthetic point of view, it would be difficult to judge how this limited increase would be perceived by the patient. There is no established threshold in the literature to determine a layperson’s perception of minor variations in nasal width.

Acknowledgements – This work was supported by a grant from the Dutch Technology Foundation (STW 10315). R. Nada was funded by the Netherlands Fellowship Program PhD studies, Netherlands Ministry of Foreign Affairs, and Netherlands Organization for International Cooperation in Higher Education (Nuffic), grant number: NFP-PhD: CF 2916/2006.

Conflicts of interest – The authors report no conflicts of interest.

The authors had no role in the study design; collection, analysis, and interpretation of data; writing of the manuscript; or decision to submit the manuscript for publication.

References


