Three-dimensional computed tomographic analysis of changes to the external features of the nose after surgically assisted rapid maxillary expansion and orthodontic treatment: A prospective longitudinal study

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Introduction: The aim of this prospective, longitudinal study was to evaluate changes to the external shape and form of the nose after surgically assisted rapid maxillary expansion and orthodontic treatment. The changes were registered using a 3-dimensional computer tomography technique, based on superimposition on the anterior base of the skull. Methods: The subjects comprised 35 patients (mean age, 19.7 years; range, 16.1–43.9 years). Low-dose, helical computerized tomography images were taken at treatment start and after orthodontic treatment, about 18 months postsurgery. The 3-dimensional models were registered and superimposed on the anterior cranial base. Results: There were in general significant widening and overall anterior and inferior displacement of the nasal soft tissues. The changes varied in size and direction. No correlation was found between the initial and final widths of the nose, or between the initial and final widths of the nostrils. Conclusions: After surgically assisted rapid maxillary expansion, the most obvious changes to the external features of the nose were at the most lateral alar bases. The difference in lateral displacement profoundly influenced the perception of a more rounded nose. Patients with narrow and constrained nostrils can benefit from these changes. The 3-dimensional superimposition applied in this study is a reliable method, circumventing projection and measurement errors. (Am J Orthod Dentofacial Orthop 2013;144:404-13)

Transverse maxillary hypoplasia is associated primarily with functional impairments, such as posterior crossbite, dental crowding, reduced nasal respiratory function, or anteroposterior skeletal anomalies, and less with facial esthetics.\textsuperscript{1–5} A widely recognized treatment modality for this condition is correction of the underlying skeletal anomalies by surgically assisted rapid maxillary expansion (SARME).\textsuperscript{6–8}

Although the skeletal and dental effects of SARME have been evaluated in several clinical and radiographic studies, little is known about its effect on the shape and form of the nose.\textsuperscript{9–11} The soft-tissue changes can be quite obvious, and most clinicians have observed patients in whom SARME has been associated with pronounced changes to the nose. In some patients, this might be regarded as an untoward side effect; in others, it could improve facial esthetics.

Soft-tissue changes after corrective orthognathic surgery have been described in a number of studies.\textsuperscript{12–15} Consistent findings after maxillary advancement and maxillary impaction are labial changes and widening of the nose.\textsuperscript{16} Most surgeons are aware of these phenomena and use different techniques to reduce these effects.\textsuperscript{17,18}
The size and shape of the nostrils and the width of the alar base are considered to play important roles in respiration. It is suggested that the site responsible for sensing airflow and stuffiness is in the nasal vestibule. Guenther et al associated modifications in the shape of the external nares with changed airway patency. This finding was supported by Cole, who found significant associations between minor alterations in this region and improvement or deterioration in respiratory function. Moreover, Magnusson et al concluded that even small changes to the soft tissues in the most anterior part of a narrow nose can be critical to the subject’s perception of nasal obstruction.

However, with reference to SARME, little is known about associated soft-tissue changes and the effects on facial esthetics and respiration. SARME is often followed by second-stage surgery that can have a further impact on the soft tissues and respiration. Thus, it is essential to identify soft-tissue changes associated with SARME to predict or prevent these effects.

Previous studies on SARME and its effects on soft tissues have been limited by the methods available at the time for quantifying soft-tissue changes. Ngan et al and Filho et al used traditional 2-dimensional (2D) lateral cephalograms. When applied to assess changes in the soft-tissue profile, 2D cephalometrics have major disadvantages. It is difficult to quantify soft-tissue alterations adequately from a frontal perspective. Berger et al used serial frontal photographs to measure soft-tissue changes, and Ramieri et al used laser scanning and 3-dimensional (3D) morphometry. In the 3D analysis, the superimposition method is crucial. The major disadvantage of these methods is the potential error associated with uncertain superimposition, which is related to approximations or averaged data.

Recently, there have been impressive advances in computed tomography and imaging techniques, offering new, precise, and accurate approaches to superimposition.

The purpose of this prospective study was to evaluate changes to the external features of the nose after SARME and orthodontic treatment, using a 3D imaging technique and registration based on superimposition on the anterior cranial base.

MATERIAL AND METHODS

Our prospective sample comprised patients scheduled to undergo SARME. The inclusion criterion for SARME was a real transverse discrepancy according to Jacobs et al. The magnitude of the skeletal discrepancy (>5 mm) was primarily assessed clinically and on study models in Class I relationships. Transverse assessments were also done on computed tomography models. This sample was previously evaluated by Magnusson et al with reference to skeletal changes after SARME. The same orthodontic, surgical, and radiographic procedures were applied in both studies.

According to power and size calculations, a priori, the minimum sample size was set at 34 patients, \( \alpha = 0.05 \), and power of 80%. To ensure that the sample size met these requirements, 40 patients were recruited consecutively at the Department of Orthodontics, Institute for Postgraduate Dental Education, Jönköping, Sweden, and at the Department of Dentofacial Orthopaedics, Maxillofacial Unit, University Hospital, in Linköping, Sweden. Participation in the study was voluntary: 3 patients declined to participate, and 2 patients were excluded because their computed tomography records were incomplete. The sample thus comprised 35 patients (14 male, 21 female). The mean age at treatment start was 19.7 years (range, 16.1–43.9 years).

The study was approved by the ethics committee of the Faculty of Health Sciences, Linköping University, in Sweden (reference: M746-04).

The presurgical orthodontic preparation included the following. The maxillary expansion appliance comprised a tooth-borne device activated by means of a conventional hyrax expander (hyrax II; Dentaurum, Ispringen, Germany) with a soldered framework and orthodontic bands (Fig 1). The degree of expansion was calculated for each patient, including a general bilateral overexpansion of half a molar-cusp width. The patients were instructed to activate the jackscrew 1 turn (approximately 0.225–0.250 mm) twice a day after a postoperative latency period of 5 days. Postoperative control was scheduled for 12 days postsurgery and included a periapical radiograph to ensure clinically symmetrical interdental separation and a medial diastema. In patients with a “bad separation”—ie, intra-alveolar separation and risk for periodontal injuries—prophylactic treatment was initiated. At that time, the amount of additional expansion was calculated.

Surgical treatment was undertaken by 2 experienced senior oral and maxillofacial surgeons (P.N. and another) at the Department of Oral and Maxillofacial Surgery, Institute for Postgraduate Dental Education, Jönköping, Sweden, and at the Department of Dentofacial Orthopaedics, Maxillofacial Unit, University Hospital, Linköping, Sweden, with a technique similar to that described by Glassman et al.

The surgery was carried out under general anesthesia and nasotracheal intubation. The mucoperiosteal incision in the maxillary vestibule extended from the
right to the left second premolar. Osteotomies were performed on the maxillary lateral walls, from the piriform aperture to the pterygoid plates. The pterygomaxillary sutures were kept intact. The linings of the floor and lateral walls of the nasal passage were reflected. A vertical osteotomy at the anterior nasal spine and the median palatal suture was carried out to ensure separation of the maxillary halves. The hyrax expander was activated by 12 turns to verify the success of the osteotomy and to ensure visible symmetrical separation; it was then deactivated by the same amount.

Depending on their physical condition, the patients were discharged from the hospital on the same day or the day after surgery.

The postsurgical orthodontic procedures included the following. After a mean active expansion period of 15 days (range, 11-17 days), the appliance was used as a passive retainer for 90 days. At that time, the hyrax expander was replaced by a modified transpalatal arch, and fixed appliance treatment began.

On completion of the active treatment phase, the transpalatal arch was removed, and fixed appliance treatment continued with stiff rectangular archwires to adjust the transverse width and to control and correct the buccal root torque of the molars.

All transverse discrepancies were corrected by the end of treatment (mean, 18 months postoperatively), and the orthodontic treatment period was then concluded. At this point, 26 patients were referred for second-stage orthognathic surgery. In the remaining 9 patients, the fixed appliance was debonded, and a Hawley plate was provided as a retainer.

The computed tomography examinations were undertaken at the Center for Medical Image Science and Visualization at University Hospital, Linköping, Sweden, and at the Department of Radiology, Ryhov County Hospital, Jönköping, Sweden, 1 week before surgery and at the end of the active orthodontic treatment phase (mean, 18 months postoperatively).

A helical computed tomography machine (Somatome Sensation 64 CT-scanner; Siemens Medical Solutions, Erlangen, Germany) with a low-dose protocol (CARE dose 4D; Siemens Medical Solutions) was used at 120 kV and 55 mA. The rotation time was 1 second, and the pitch factor was 0.9, with a collimation of 0.6 mm. The increment was 0.3 mm. According to the manufacturer, the isotopic resolution or voxel size was 0.33 mm. The patient’s head was positioned so that the Frankfort horizontal plane was vertical.

The scanned area comprised the anterior cranial base to the mandibular base. After examination, the images were processed at a radiologic workstation (Sectra Imtec AB, Linköping, Sweden) with aslice thickness of 0.75 mm and slice increments of 0.3 mm in Kernel H 60s sharp FR, to allow further segmentation and registration.

The data were processed to visualize and measure soft-tissue changes caused by SARME, using a modified version of a technique described by Cervidanes et al. This process involves image segmentation, registration, and visualization (Fig 2).

The image registration and superimposition of the preoperative and postoperative 3D models were done before segmentation with a volumetric registration method: specifically, normalized mutual information, based on the anterior cranial base. The cranial fossae and the ethmoid bone surfaces are regarded as stable areas, with growth completed before puberty. Once the preoperative and postoperative volumes are registered, they share the same coordinate system, which compensates for any discrepancies between before and after volumes, and diminishes the risks of projection and measurement errors.

Segmentation is the process of outlining the shape of a structure—in this case, anterior cranial base, and the outer surfaces of the nasal and midface soft tissues. The segmentation was performed semiautomatically in AMIRA (Mercury Computer System, Berlin, Germany) by an author (H.K.). In the semiautomatic segmentation technique, the region of interest is outlined with mouse clicks in the cross-sections of a data set, and algorithms (simple thresholding and region growing) are applied, so that the path that best fits the edge of the image is shown. With simple thresholding, it is possible to select a range of gray values (in Hounsfield units, HU). In this study, the lower threshold in bony structures was set to 300 HU, and values above this level were automatically selected. The threshold value was interactively

Fig 1. Skeletal maxillary transverse discrepancy exceeding 5 mm. Tooth-borne maxillary expansion appliance, activated by a conventional hyrax expander (Hyrax II; Dentaurum, Ispringen, Germany).
adjusted to achieve better contours. Semiautomatic tools in AMIRA were effectively used to accelerate the process.

A landmark-based, nonrigid mapping technique, thin-plate spline, was used to determine the corresponding soft-tissue points between the presurgery and postsurgery 3D models. This was done by a pipeline procedure according to the method of Kim et al.

Di2Mesh software (Institute for Surgical Technology & Biomechanics, University of Bern, Bern, Switzerland) is a graphical user interface-based application allowing the user to compute surface-to-surface distances in any specified direction and visualize them with a color map.

Fifteen validated landmarks were used for the measurements (Fig 3). The landmarks were identified and digitized by the first author (A.M.). The nonrigid transformation model, thin-plate spline deformation, and closest-point matching were used to show displacements. The software (Di2Mesh) computed the closest-point relationship between the presurgical and postsurgical landmarks in a 3D Euclidean space coordinate system.

The displacement vectors were normalized with the Frankfort horizontal plane coordinate system according to the method of Xia et al. The transversal plane is defined by right and left porion, and the averaged coordinates of right and left orbitale. The frontal plane is perpendicular to the transversal plane, through right and left porion. The sagittal plane is perpendicular to the transversal and frontal planes, through nasion. This means that the zero point of the Frankfort horizontal plane will be the center of left and right porion. As shown in Figure 4, lateral displacement on the x-axis, superior displacement on the y-axis, and anterior displacement on the z-axis were recorded as positive values.

The transverse displacements of corresponding landmarks on the x-axis were also summarized. The Euclidean distances—ie, the shortest distances between 2 landmarks—were measured to evaluate the height and width of the nose and nostrils (Fig 5).

Ten computed tomography volumes were randomly selected. The anatomic landmarks were located and digitized in each 3D model. The same observer (A.M.) repeated the procedure 4 weeks later, and the

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**Fig 2.** Helical computed tomography images were taken for each patient before and after treatment. Visualization and segmentation involve creation of a 3D model and delineation of the anatomic structures of interest. The 3D models were superimposed on the anterior cranial base by means of a volumetric registration method. A graphical user interface-based application (Di2Mesh) was used for 3D analysis and measurements.
displacements of the landmarks were calculated. The error of the measurements was calculated by intraclass correlation coefficient (ICC) for single measurements; this is an expression of intraobserver reliability. An ICC above 0.75 indicates excellent reliability. The ICC values were between 0.851 and 0.992. Landmarks 1, 6, and 7 in the midline showed the weakest ICC values.

**Statistical analysis**

Statistical analyses were undertaken using the Statistical Package for the Social Sciences III (version 20.0; SPSS, Chicago, Ill). The distribution of data was tested with the 1-sample Kolmogorov-Smirnov test. The results showed normal distribution of the data, but because of the sample size, nonparametric tests were also warranted. Median values and percentiles were used to describe the changes and distributions. The Wilcoxon signed rank nonparametric test was used to evaluate pretreatment and posttreatment differences. The level of significance was set at $P < 0.05$. The Spearman rho was applied to assess the correlations between the changes at the nose.

**RESULTS**

There were in general significant widening and overall anterior and inferior displacement at the nose.

For the x-axis (lateral displacement, left and right), all landmarks at the alar wings showed lateral displacement (Table I). The displacements on the left and right sides were symmetrical and most obvious at the lateral alar bases (Fig 3; landmarks 14 and 15). The amount of displacement of the lateral alar bases decreased gradually toward pronasale and toward the facial insertion of the nostrils.

The most pronounced lateral change to the nostrils was at the utmost lateral point of the inner contour of the nostrils, which decreased in the anterior and inferior directions of the x-axis.

For the y-axis (superior and inferior displacement), most landmarks showed moderate inferior displacement (Table I). The most significant displacements, albeit minor, were found at pronasale and subnasale (Fig 3; landmarks 1 and 7). The amounts of displacement at pronasale and subnasale decreased gradually in the posterior and lateral directions on the y-axis.

For the z-axis (anterior and posterior displacement), the most significant and obvious displacement occurred...
anteriorly (Table I), particularly at landmarks near the facial insertion (Fig 3; landmarks 4, 5, 10, 11, 14, and 15). This anterior displacement was, however, not evident at subnasale (Fig 3; landmark 7), which showed a contrasting, posterior displacement.

The Euclidean distance (the shortest distance between 2 landmarks) was analyzed and calculated for height and width of the nose and nostrils (Fig 5; Table II). Nose height, measured between pronasale and subnasale (Fig 5, A), remained unchanged, but a significant and evident widening was apparent at the alar wings and alar base (Fig 5, A; nose width I, nose width III). The nose width at the facial insertion persisted unchanged (Fig 5, A; nose width II). A significant widening of the nostrils was obvious at the lateral alar wings (Fig 5, B; nostril width I) but not at the lowest point (Fig 5, B; nostril width II). The nostril length remained unchanged. No correlation was found between the initial and final widths of the nose, or between the initial and final widths of the nostrils.

**Table I. Median displacements and changes at the nose measured at 15 landmarks (in mm) (Fig 3)**

<table>
<thead>
<tr>
<th>Landmark</th>
<th>X-axis</th>
<th>Y-axis</th>
<th>Z-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median change</td>
<td>p&lt;sub&gt;10&lt;/sub&gt;</td>
<td>p&lt;sub&gt;90&lt;/sub&gt;</td>
</tr>
<tr>
<td>1</td>
<td>0.11</td>
<td>-0.64</td>
<td>0.86</td>
</tr>
<tr>
<td>2</td>
<td>1.10</td>
<td>0.06</td>
<td>1.89</td>
</tr>
<tr>
<td>3</td>
<td>0.70</td>
<td>-0.13</td>
<td>1.91</td>
</tr>
<tr>
<td>4</td>
<td>0.59</td>
<td>-0.62</td>
<td>2.16</td>
</tr>
<tr>
<td>5</td>
<td>0.58</td>
<td>-1.22</td>
<td>1.85</td>
</tr>
<tr>
<td>6</td>
<td>0.10</td>
<td>-0.54</td>
<td>1.38</td>
</tr>
<tr>
<td>7</td>
<td>0.09</td>
<td>-1.22</td>
<td>1.20</td>
</tr>
<tr>
<td>8</td>
<td>0.42</td>
<td>-0.47</td>
<td>1.67</td>
</tr>
<tr>
<td>9</td>
<td>-0.10</td>
<td>-1.44</td>
<td>1.00</td>
</tr>
<tr>
<td>10</td>
<td>0.35</td>
<td>-1.32</td>
<td>2.26</td>
</tr>
<tr>
<td>11</td>
<td>0.29</td>
<td>-1.04</td>
<td>1.87</td>
</tr>
<tr>
<td>12</td>
<td>0.81</td>
<td>-0.42</td>
<td>2.40</td>
</tr>
<tr>
<td>13</td>
<td>0.67</td>
<td>-0.33</td>
<td>1.76</td>
</tr>
<tr>
<td>14</td>
<td>1.47</td>
<td>0.30</td>
<td>2.90</td>
</tr>
<tr>
<td>15</td>
<td>1.41</td>
<td>0.46</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Displacements were recorded as positive values laterally in the x-axis, superiorly in the y-axis, and anteriorly in the z-axis.

p<sub>10</sub>, 10th percentile; p<sub>90</sub>, 90th percentile; NS, nonsignificant.

*P < 0.05; **P < 0.01; ***P < 0.001.

The table above illustrates median displacements and changes at the nose measured at 15 landmarks (in mm) (Fig 3). Anterior displacement was evident at landmarks near the facial insertion (landmarks 4, 5, 10, 11, 14, and 15). The anterior displacement at subnasale (landmark 7) showed a contrasting, posterior displacement.
DISCUSSION

The results show that after SARME there is a true 3D change in the nose: not only widening of the nose, but also anterior and inferior displacement of the whole nasomaxillary complex. The displacements vary in size and direction, and the complexity of the changes is difficult to assess without a valid and reliable method.

The computed tomography models and the refined 3D methodology used in this study, with volumetric registration based on the anterior cranial base, offer precise and accurate superimpositions, which are essential for quantifying and determining spatial displacements. The vectors were normalized with the Frankfort horizontal plane coordinate system, which is essential for quantifying and determining spatial displacements. The soft-tissue changes not only are thus related to the anterior displacement of the underlying skeletal structures. However, Lagravère et al 44 found no evidence for either anterior or inferior skeletal displacement after SARME. To resolve such contradictory findings, further studies are warranted, applying appropriate modern measuring techniques to document maxillary displacement after SARME and correlations with soft-tissue changes.

Because candidates for SARME are patients with transverse skeletal discrepancies, it would be logical to expect most changes to occur in a transverse direction. The results showed lateral displacements, but these were accompanied by anterior and inferior displacements. A possible and rational explanation is the occurrence of corresponding displacements in the soft and hard tissues. According to Chung et al 43 and Bretos et al, 41 the anterior displacement in our study could be related to the anterior displacement of the underlying skeletal structures. However, Lagravère et al 44 found no evidence for either anterior or inferior skeletal displacement after SARME. To resolve such contradictory findings, further studies are warranted, applying appropriate modern measuring techniques to document maxillary displacement after SARME and correlations with soft-tissue changes.

The soft-tissue changes not only are thus related to the extent or direction of the skeletal displacements, but also are more likely multifactorial consequences of different elements, such as the surgical technique, the amount of soft tissues, the facial type, or a gain or loss in weight. It is nevertheless important for the clinician to be aware of soft-tissue changes associated with SARME. Ideally, it should be possible to predict the treatment outcome to prevent unwanted side effects.

On the x-axis, the most significant displacements were found at the lateral parts of the nose, primarily at the alar base (Fig 3; landmarks 14 and 15), secondarily at the lateral alar wings (Fig 3; landmarks 2 and 3), and less significantly, at the insertions of the alar wings (Fig 3; landmarks 4 and 5). No significant lateral changes were found in the midsagittal plane.

The difference in lateral displacements between the lateral landmarks played an essential role in the perception of a more rounded shape and an increased size of the nose. This, combined with more circular swelling after SARME will subside within a few weeks, but residual swelling will persist. 41 To prevent this source of error, the soft-tissue registration was done at the end of treatment, at a mean of 18 months postoperatively.

The most obvious amount of widening was found at the most lateral alar base (Fig 5, A; nose width III), a mean of 2.88 mm, representing a mean increase of 9% of the initial width. Berger et al 25 reported an increase in the nasal base width of up to 2 mm, and Ramieri et al 27 found a mean widening of 1.4 mm. The widening in our study was more pronounced than the values in previous studies. This discrepancy cannot be readily explained but might be attributable to such factors as variations in surgical techniques or differences in the accuracy and reliability of the measuring methods applied in the studies.

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### Table II. Median changes between landmarks without orientation in space (in mm) (Fig 5)

<table>
<thead>
<tr>
<th>Landmark</th>
<th>Median change</th>
<th>P&lt;0.10</th>
<th>P&lt;0.01</th>
<th>Wilcoxon test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nose height</td>
<td>0.18</td>
<td>-1.38</td>
<td>2.15</td>
<td>NS</td>
</tr>
<tr>
<td>Nose width I</td>
<td>1.66</td>
<td>0.27</td>
<td>3.13</td>
<td>*</td>
</tr>
<tr>
<td>Nose width II</td>
<td>1.01</td>
<td>-0.65</td>
<td>2.72</td>
<td>NS</td>
</tr>
<tr>
<td>Nose width III</td>
<td>3.09</td>
<td>1.56</td>
<td>4.70</td>
<td></td>
</tr>
<tr>
<td>Nostril height</td>
<td>-0.47</td>
<td>-1.12</td>
<td>0.83</td>
<td>NS</td>
</tr>
<tr>
<td>Nostril width I</td>
<td>1.47</td>
<td>-0.08</td>
<td>3.19</td>
<td></td>
</tr>
<tr>
<td>Nostril width II</td>
<td>0.68</td>
<td>-1.51</td>
<td>2.29</td>
<td>NS</td>
</tr>
</tbody>
</table>

*P < 0.01; **P < 0.001.
nostrils, made the nostrils more visible in the frontal view and gave a sense of an increased nasolabial angle, even though an overall anterior and inferior displacement of the nasomaxillary complex was evident. This outcome might be attributable to the surgical technique used. The osteotomies were performed on the maxillary lateral walls, from the piriform aperture to the pterygoid plates, including detachment of the mucosa and soft tissue on the nasal floor and lateral walls. The detachment of soft tissues at the insertion of the alar wings (Fig 3; landmarks 4 and 5) might explain why this displacement was much less pronounced than that in the attached soft tissues at the lateral alar bases (Fig 3; landmarks 14 and 15).

Whether this widening and the overall anterior and inferior displacement of the nose are beneficial to the patient is a clinical judgment. The main purpose of the surgical techniques available for controlling the width of the nose is to diminish the width at the anterior insertions of the alar wings and nostrils. These techniques do not take into account the widening at the attached lateral alar base.\(^ {15} \) Such a procedure should be used with caution after SARME when there is a risk of an unesthetic accentuated rounding of the anterior nose.

The most statistically significant changes were found in the anterior direction (z-axis). The changes were in most cases quite minor, but the uniformity in direction and the significance nevertheless demonstrate anterior movement of the nose. The magnitude of the anterior displacements varied but, in accordance with the lateral displacement on the x-axis, was most obvious at the most lateral alar base (Fig 3; landmarks 14 and 15).

The displacements on the y-axis were less significant, small, and varied in direction and can perhaps be related to factors other than the effects of SARME. The most significant displacements on the y-axis were found at subnasale and pronasale. We found no correlation between the initial and final nostril widths, or between the initial and final nose widths. This lack of correlation highlights the complexity of all affected components. There is, however, a clear tendency toward overall lateral, anterior, and inferior displacement of the nose; the clinician should take these into account in treatment planning.

Some measurements were of particular note. The height of the nose measured from subnasale to pronasale as well as the length of the nostrils remained unchanged. These findings indicate increased nostril area associated with widening of the nostrils. The change in nostril shape from a narrow slit to a more ovoid or circular form postoperatively was obvious and significant. In this context, it is of interest that narrow nostrils are associated with nasal obstruction,\(^ {46} \) and widening is associated with a subjective perception of improved nasal function.\(^ {4} \) Consequently, patients with narrow and constrained nostrils benefit from the soft-tissue changes.

These data consisted of measurements of displacements at specific digitized landmarks at the nose. The Di2Mesh software application can, without landmarks, also analyze any specified displacement and visualize the displacements using a color map. The color visualization of the displacements in this software showed major changes in the paranasal region. These changes were not analyzed because of the lack of reliable and valid landmarks in this area, but they will have an indirect impact on the appearance of the nose and the midface. Furthermore, at the time of registration, uncertain lip posture precluded evaluation of changes to the upper lip.

With respect to radiation exposure, it is important that ethical aspects are addressed, not only in the context of clinical studies, but also in routine practice. Radiation exposure should always follow the “as low as reasonably achievable” principle.\(^ {47} \) In this study, the assessed risk of radiation exposure was weighed against achieving the required information: a 3D assessment of changes to the external shape and form of the nose. The sample comprised nongrowing patients scheduled to undergo SARME; additional 2D images would have increased their radiation dose but provided only limited or partial diagnostic information.

To secure a high diagnostic advantage in treatment planning, a low-dose helical computed tomography machine was used, with a low-dose protocol. Cone-beam computed tomography scans would have been an acceptable alternative but were not available at the time. The submission to the board of ethics for approval of the study included a discussion of radiation exposure.

**CONCLUSIONS**

There were in general significant widening and overall anterior and inferior displacement of all nasomaxillary soft tissues.

The changes were most obvious laterally and anteriorly on the x-axis and y-axis.

There was variety in the size of the displacements that rounded the shape of the nose in the frontal view.

There was significant widening of the nostrils and an increase in nostril area. Patients with narrow and constrained nostrils can benefit from the soft-tissue changes.

There were no correlations between the initial and final widths of the nostrils, or the initial and final widths of the nose.

It is questionable whether an alar cinch suture will prevent widening at the alar base.
ACKNOWLEDGMENTS

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