Clinical Paper

Cleft Lip and Palate

3D Stereophotogrammetric assessment of pre- and postoperative volumetric changes in the cleft lip and palate nose


Abstract. In cleft lip and palate patients the shape of the nose invariably changes in three dimensions (3D) due to rhinoplasty surgery. The purpose of this study was to evaluate stereophotogrammetry as a 3D method to document volumetric changes of the nose in patients with a cleft lip (CL) or cleft lip and palate (CLP) after secondary open rhinoplasty. 12 patients with unilateral CL or CLP were enrolled in the study prospectively, 3D facial images were acquired using 3D stereophotogrammetry preoperatively and 3 months postoperatively. A 3D cephalometric analysis of the nose was performed and volumetric data were acquired. The reliability of the method was tested by performing an intra- and inter-observer analysis. Left, right and total nasal volumes and symmetry were compared. No statistically significant differences (p < 0.05) were found within and between observers for the measured volumes and symmetry. Postoperatively, the total volume of the nose increased significantly, especially the volume at the cleft side. No significant volume difference pre- and postoperatively was found for the non-cleft side. The symmetry of the nose improved significantly. 3D stereophotogrammetry is a sensitive, quick, non-invasive method for evaluating volumetric changes of the nose in patients with cleft lip or cleft lip and palate.

Keywords: stereophotogrammetry; cleft lip and palate; rhinoplasty; volumetric 3D measurements; reproducibility; surface registration; maxillofacial surgery; otorhinolaryngology; plastic and reconstructive surgery.

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The nose is known to be aberrant in appearance and function in patients with a cleft lip (CL) or a cleft lip and palate (CLP). Distortions of the nose can vary from almost invisible to catastrophic, mostly dependent on the severity and type of cleft. To correct the nasal deformity in CL or CLP patients is a challenge. In the Netherlands, for the last 25 years, a primary rhinoplasty correction has been performed at the time of primary lip closure in unilateral CL or CLP patients. This usually involves reducing the asymmetry by undermining and rotating the nose without altering bony tissue. Nevertheless, as the children grow older, the nasal shape remains deformed. There is usually an underprojection of the dome at the cleft side
side and surgery mainly focuses on correcting this asymmetry by increasing the projection (which enhances the volume of the nasal pyramid) on the cleft side.

Various studies have been undertaken to evaluate the result of different rhinoplastic procedures \cite{3,10,12,13,16,19,21,25}, but quantification of surgical changes remains difficult. Besides direct anthropometric measurements\cite{23}, two-dimensional (2D) photographs and radiographs are used to document and calculate the changes after surgery\cite{23}. Until now, studies comparing pre- and postoperative nasal changes in patients with clefts have been limited to these techniques\cite{15}. The human body however, is a three-dimensional (3D) entity and any change, whether from movement during facial expression or from surgery, occurs in three dimensions. Various 3D imaging techniques have been developed to overcome the shortcomings of conventional 2D imaging. These include 3D cephalometry\cite{26}, Moiré topography\cite{28}, 3D laser scanning\cite{6}, 3D optoelectronic digitizers\cite{8} and 3D stereophotogrammetry\cite{11,14,24}. The latter method has gained popularity over the last years as digital 3D data sets of the face can be acquired rapidly and non-invasively, while simultaneously being archived for future analysis\cite{2}. Recent studies have shown 3D cephalometric measurements acquired with a 3D stereophotogrammetrical camera setup to be valid and reproducible\cite{2,22}.

To the best of the authors’ knowledge, no stereophotogrammetry studies have been performed on the volumetric 3D changes of the nose after secondary rhinoplasty in CL and CLP patients. The purpose of this study was to evaluate the value of 3D stereophotogrammetry for volumetric documentation of the nose in CL and CLP patients who underwent secondary rhinoplastic surgery.

Materials and methods

The study sample comprised of CL and CLP patients from the Cleft Palate Craniofacial Unit of the Radboud University Nijmegen Medical Centre, Nijmegen, The Netherlands, operated on between June 2007 and December 2007. Inclusion criteria were: unilateral CL or unilateral CLP; age above 12 years; and signed informed consent. Exclusion criteria were: associated cranio-facial deformities; syndromes; and earlier secondary rhinoplastic surgery.

Operative procedure

All operative procedures were performed by one surgeon (PS). An open rhinoplasty (Rethi incision: rim incision traversing the columella) was performed in all patients. Depending on the deformity, the following nasal surgery components were employed: a septal deviation was corrected by remodelling the deviating septum and trimming the base. The lower lateral cartilages were reduced and sutured together in order to narrow the dome. A columellar strut was placed for nasal tip support. For this purpose part of the septal cartilage was used or cartilage was acquired from the auricular concha. Dome sutures, shield, tip or dorsal grafts were implemented if required. When correction of the nasal bone was mandatory a medial and lateral osteotomy including efracture and infracture was performed.

Pre- and postoperative 3D documentation

A 3D stereophotogrammetrical camera setup with an integrated software program modular system V 1.0 (3dMDface\textsuperscript{TM} System, 3dMD LLC, Atlanta, GA, USA) was used for pre- and postoperative 3D documentation of the nose. The technique used is based on cross-polarisation imaging, where a structured light is projected onto the face and the reflected light is captured using a camera system. This captures a 3D point cloud of the face, from which a surface model is generated. This data can be visualised and measured using a dedicated software program.

Fig. 1. 3D distance map of the pre- and postoperative soft tissue changes in patient 6. (a) Decrease (red) of volume on the non-cleft side; (b) patient 6 frontal view; (c) increase (green) in volume on the cleft side.
used to capture 3D photographs of the face. The 3D photographs were generated from six 2D photographs taken simultaneously (four grey-scale photographs and two full colour photographs). A polygon light pattern was projected onto the four grey-scale photographs. Based on this pattern and its deformed image, a 3D photograph was reconstructed. These 3D photographs were automatically saved as ‘three-dimensional surface binary’ files (.tsb file) and were visualized and analyzed using 3D editing software (3dMDpatient V3.0.1, 3dMDpatient™ Software Platform, 3dMD LLC). With this system it was possible to capture 180 degrees of the subject’s face, which concurred with an ear-to-eye 3D photograph. The 3D photographs were taken in natural head position and habitual occlusion. Patients were asked to relax their facial musculature, swallow and keep their molars in occlusion after swallowing. Patients were asked to relax their facial musculature, swallow and keep their molars in occlusion after swallowing.

### Table 1. Definitions of landmarks and planes used based on the 3D cephalometric soft-tissue analysis according to Swennen27.

<table>
<thead>
<tr>
<th>Landmark and planes</th>
<th>Landmark Abbreviation</th>
<th>Description</th>
<th>View</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alare (left)</td>
<td>al(l)</td>
<td>Left alare, most lateral point on the left alar contour.</td>
<td>Base view</td>
</tr>
<tr>
<td>Alare (right)</td>
<td>al(r)</td>
<td>Right alare, most lateral point on the right alar contour.</td>
<td>Base view</td>
</tr>
<tr>
<td>Cheilion (left)</td>
<td>ch(l)</td>
<td>Left cheilion, point located at the left labial commissure.</td>
<td>Frontal</td>
</tr>
<tr>
<td>Cheilion (right)</td>
<td>ch(r)</td>
<td>Right cheilion, point located at the right labial commissure.</td>
<td>Frontal</td>
</tr>
<tr>
<td>Cheilion (middle)</td>
<td>ch(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right cheilion and left cheilion.</td>
<td>Frontal</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>
<td>Frontal</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>
<td>Frontal</td>
</tr>
<tr>
<td>Exocanthion (left)</td>
<td>ex(l)</td>
<td>Left exocanthion, soft tissue point located at the outer commissure of the left eye fissure.</td>
<td>Frontal</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>
<td>Frontal</td>
</tr>
<tr>
<td>Exocanthion (middle)</td>
<td>ex(m)</td>
<td>Soft tissue point automatically computed as the midpoint of the right exocanthion and left exocanthion.</td>
<td>Frontal</td>
</tr>
<tr>
<td>Pupil reconstructed</td>
<td>p&quot;</td>
<td>Pupil reconstructed point, midpoint between the endocanthi and pupils, located on the level of the exocanthi.</td>
<td>Frontal</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>
<td>Lateral right</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plane</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Posterior nasal plane</td>
<td>A plane through landmarks ex(l), ex(r) and ch(m).</td>
</tr>
<tr>
<td>Lateral left nasal plane</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>A plane through landmarks en(r) and al(r) and perpendicular to the vertical plane.</td>
</tr>
<tr>
<td>Median plane</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>Upper nasal plane</td>
<td>A plane through landmark ex(m) and parallel to the horizontal plane.</td>
</tr>
<tr>
<td>Lower nasal plane</td>
<td>A plane through landmark sn and parallel to the horizontal plane.</td>
</tr>
<tr>
<td>Horizontal plane</td>
<td>The horizontal (x) 3D Reference Plane is automatically computed as a plane 6.6 degrees below the Cantion - Supraaurale 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>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>
</tbody>
</table>
side nasal volumes; the pre- and postoperative non-cleft side nasal volumes; the pre- and postoperative volumetric symmetry calculated by dividing the volume of the cleft side and the non-cleft side. A ratio of 1.00 means perfect symmetry.

Pre- and postoperative differences were analyzed using paired Student’s t-tests with a p-value of 0.05 indicating statistically significant differences. Paired Student’s t-tests were used to calculate the intra- and inter-observer reproducibility of the volumes for repeated measurements (mean difference) and to test for statistically significant differences. The measurement error was calculated as the standard deviation (SD) of the mean difference divided by \( \sqrt{2} \). Reliability coefficients between first and second measurement were calculated as Pearson correlation coefficients. Statistical data analysis was performed with the SPSS software program, version 16.0 (SPSS Inc., Chicago, USA).

**Results**

Eight male and four female patients aged 13–40 years (median, 18 years) met the inclusion criteria and had various deformities of the nose (Table 2). Two patients had an isolated CL and 10 had a CLP. There were 8 left- and 4 right-sided clefts. 12 secondary open rhinoplasty procedures were performed (Table 2). Interdomal sutures were used in all patients. In two patients no further surgical procedures were performed. In the remaining 10 patients, one or two of the following surgical procedures were used in order to achieve more symmetry and increase the volume of the tip on the cleft side: a columellar strut was used in seven patients (five using septal cartilage and two using auricular cartilage), three

![Image](image_url)

Fig. 2. 3D stereophotogrammetric photograph of the face. (a) Untextured 3D photograph with landmarks identified (red dots); (b) planes derived from the landmarks to outline the nasal area; (c) and (d) untextured cropped nose; (e) and (f) right and left halves of the untextured cropped nose.

<table>
<thead>
<tr>
<th>Patient</th>
<th>CL/CLP side</th>
<th>Deformity of the nose</th>
<th>Columellar strut</th>
<th>Alar graft</th>
<th>Tip graft</th>
<th>Nasal bone osteotomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Right</td>
<td>A, B, C, D</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Left</td>
<td>A, D</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Left</td>
<td>B, C, D</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Right</td>
<td>A, B, C, D</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Left</td>
<td>A, D</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>6</td>
<td>Left</td>
<td>A, B, C, D</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Right</td>
<td>A, B, C, D</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>8</td>
<td>Left</td>
<td>A, B, C, D</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>9</td>
<td>Left</td>
<td>A, B, C, D</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>10</td>
<td>Right</td>
<td>B, C, D</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
<td>Left*</td>
<td>A, B, C</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>12</td>
<td>Left</td>
<td>A, B, C, D</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

(A) Deviated columella; (B) depressed and deviated nasal tip; (C) wide nasal ala on the cleft side; (D) flat and v-shaped nostril.

* CL only.

† Nose septal cartilage.

‡ Auricular cartilage.

Table 2. Surgical characteristics for the 12 patients.
patients underwent an alar wing graft (two using auricular cartilage, one using septal cartilage), a tip graft was performed in one patient (using septal cartilage) and a transcutaneous nasal bone osteotomy was performed in two patients.

No statistically significant differences \( (p < 0.05) \) were found within and between observers for the measured volumes and symmetry (Table 3). The reliability coefficients for all volumes ranged from 0.96 to 1.00; duplicate measurement errors ranged from 55.68 to 147.40 mm.

The volumes of the total nose pre- and postoperatively were computed. A mean volume increase of 1228.36 mm\(^3\) was found (95% confidence interval (CI): 570.20–1886.52 mm\(^3\)). This increase was statistically significant \( (p = 0.002) \). The pre- and postoperative volumes of the cleft and non-cleft side of the nose are shown in Table 4. A mean pre- and postoperative volume difference of 966.29 mm\(^3\) was found for the cleft side, which was significant (95% CI: 437.43–1495.16 mm\(^3\); \( p = 0.002 \)). For the non-cleft side the mean pre- and postoperative volume difference was 262.07 mm\(^3\), which was not significant (95% CI: 47.40–571.54 mm\(^3\); \( p = 0.09 \)). Almost all patients had an augmentation of the nasal volume as a result of the operation as is shown by the increase of volume on the cleft side (Table 4). Patients four and nine showed a decrease in volume.

The results of the ratio cleft side to non-cleft side are given in Table 5. There was significant improvement of the symmetry (mean difference 0.03, 95% CI: 0.002–0.062; \( p = 0.03 \)).

### Discussion

To the best of the authors’ knowledge, this is the first study to evaluate volumetric changes after rhinoplasty using 3D stereophotogrammetry in patients with clefts. Various methods to assess cleft-related facial deformities have been described\(^1\). Traditionally studies comparing pre- and postoperative nasal changes in CL or CLP patients were limited to radiographs, anthropometry and 2D photogrammetry\(^1\).
As summarized in the introduction, various 3D imaging techniques have been developed to overcome the shortcomings of conventional 2D imaging.

During recent years, stereophotogrammetry has evolved. With the introduction of systems such as the 3dMDface™ System (3dMD LLC, Atlanta, USA), Di3D™ (Dimensional Imaging, Glasgow, UK) and 3D-Sensoren FaceSCAN™ (3D Shape GmbH, Erlangen, Germany), the applicability of 3D photographs in daily practice has become reality. 3D stereophotogrammetry is safe, non-invasive and able to capture superior quality ‘external surface’ photographs in less than 2 ms. These characteristics make it ideal to collect the 3D data of faces, even in children or babies. After processing the data, an accurate digital model of the patient’s face is created that can be used immediately in a clinical setting. Disadvantages of the system are the need for carefully controlled lighting conditions and the use of four to six high resolution cameras, making it a relatively non-portable system, while the cost of the setup can reach €50,000 or more.

The accuracy of these newly developed 3D imaging systems in recording facial morphologic features has recently been validated. Several recent studies have focused on determining the reproducibility of identifying landmarks by using various 3D modalities including 3D stereophotogrammetry. The results of these studies indicate the 3DMD system to be accurate and precise for facial purposes. Furthermore, the small error in placing landmarks does not lead to statistically significant different volumetric or symmetry measurements, as is seen in the intra- and inter-observer validation (Table 3).

Nevertheless, several sources of error can be identified using this system. Firstly, an error might occur when the 3D photographs are reconstructed. The 3D hardware and software has limitations in the reconstruction of, for example, the nostrils, because of the complex anatomy and the inability of the cameras to capture dark holes perfectly. As a consequence, the nostrils are the regions of error. This error is expected to be of minimal influence for this study since special attention was given to positioning the patient in a standardized manner while acquiring the pre- and the postoperative 3D photographs. An alternative to minimize this problem is using a Cone Beam CT (CBCT) 3D reconstruction of the nose, however, because of the radiation side effect, CBCT is not applicable for longitudinal follow up, whereas 3D photographs are harmless. Secondly, surface matching of the pre- and postoperative 3D photographs can result in minimal errors. Recently, the authors’ group published a paper about the error of matching 3D photographs onto skin surfaces derived from CBCT data.

The results of matching two different 3D photographs are even more reliable. In this way, a mean registration error of less than 0.6 mm is expected, which is clinically acceptable and valuable. A third possible error lies in the definition of the midline. In this study the midline is dictated by the median plane, which is based on the pupil reconstructed point. This landmark is indicated as the middle of the inter-endocanthal line. Identification of landmarks can be difficult and may lead to a small error. Since one and the same midline plane was used for the pre and postoperative 3D photographs the amount of volume increase as well as the symmetry ratio could not be affected.

For every patient the best operative technique was chosen by one experienced surgeon. The shape of the CL or CLP nose varied widely and as a consequence the surgical correction depended on the deformity of the nose and the wishes of the patient, making every rhinoplasty unique. Nevertheless, changes of the nasal region were obvious in all patients using the 3D photographs of the pre- and postoperative soft tissues (e.g. Fig. 1).

Since the main goal for surgery was to acquire more symmetry and tip projection, it was expected that the cleft side of the nose would increase in volume. In 10 out of 12 patients more volume was seen and measured on the cleft side. The results of the volumetric measurements were in accordance with the operative techniques performed. For example, alar wing volume increased in patients who acquired an alar wing graft. There was a decrease in volume of the complete nose in two patients. The decrease of volume in patient 4 was mostly caused by reduction of fibrous and connective tissue. Aside from this, there was no augmentation. In this patient the symmetry did not improve. In patient 9, both alar wings were mobilized and reinserted more medially in combination with a columellar strut and reduction of fibrous and connective tissue. This caused an overall reduction of volume and more symmetry. Patient 6 (Fig. 1) showed a decrease of volume on the non-cleft side that was attributed to the nasal osteotomy he underwent because of a deviation of the nasal bone to the non-cleft side. On the cleft side the volume increased partly because of a columellar strut and dome sutures. His nose became more symmetrical.

Although this study represents a small sample, significant statistical changes in the volume of the noses could be proved after 3 months of follow-up using 3D stereophotogrammetry. Student’s t-test was used for statistical analysis because of the small group with paired data. Using this test, the mean difference in the pre- and postoperative data could be analyzed taking into account the within-subject variability.

The main purpose of this study was to investigate the applicability of 3D stereophotogrammetry to measure short-term changes in nasal volumes after operation. In future studies changes over a longer period of time will be assessed as post-operative swelling might influence short-term results. In this way, it will be possible to compare different operative techniques in patients with a CL or CLP deformed nose.

In conclusion, 3D stereophotogrammetry is a sensitive, quick and non-invasive method for capturing and evaluating the changes of the nose after rhinoplasty in CL or CLP patients.

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Competing interests
None declared.

Ethical approval
Not required.

Financial interest in this study
None.

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