

Volumetric analysis of cleft lip deformity using 3D stereophotogrammetry



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PURPOSE: To quantify and compare pre-operative and post-operative volumetric adjustments of the upper lip tissues in patients with cleft lip.

METHODS: The authors performed an anthropometric study and a quantitative analysis of the differences based on three-dimensional morphology of the nasolabial area. Twenty facial images using the three-dimensional stereophotogrammetry were taken from ten selected subjects on two separate occasions, sitting in natural head position.

Facial landmarks were marked and measurements recorded, in order to calculate the volumetric adjustments in the soft tissues of the upper lip, comparing the preoperative and postoperative results. Student test and p-Value were performed for statistical analysis.

RESULTS: The analysis of the 3D images showed variability with the pre- and postoperative volumes of the nasolabial area with: an increase of upper lip volume all patients; a complete view of the severity in the preoperative; and an improvement of the appearance in the postoperative. The amount of increase of the upper lip volume was established about 29,7%. For all measurements, the variability between pre- and post-operative was significant ($p < 0.01$).

CONCLUSION: The 3D stereophotogrammetry technique allows a detailed preoperative evaluation and an accurate assessment of the surgical outcomes. The study provides a value of volumetric variation of the upper lip in individuals with cleft lip.

KEY WORDS: Cleft lip, Nasolabial area, 3D Morphological Analysis, 3D Stereophotogrammetry, Upper lip volume

Introduction

Optimization of care to correct the cleft lip deformity is hampered by lack of objective measures to quantify pre-operative severity and postoperative outcome¹.

Individuals with unilateral (UCLP) cleft lip have usually their primary repair at three months of age. Several methods illustrate facial evaluation, such as anthropometry or two-dimensional photogrammetry, but most of them are prevented because children do not cooperate easily.

The use of three-dimensional (3D) stereo-photogrammetry in cranio-facial anthropometric studies brings many advantages to surgical procedures: high accuracy and precision, quick acquisition, non-invasiveness, the ability to rotate and view a 3D scan from all angles, the ability to track 3D changes pre- and postoperatively, 3D video-analysis and improved surgeon and patient satisfaction².

The purpose of this study was to quantify and compare pre-operative and post-operative volumetric adjustments of the upper lip tissues in patients with cleft lip, analyzing differences based on three-dimensional morphology of the nasolabial area. The null hypothesis was that there is no difference between preoperative and postoperative volumes of the upper lip.

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Materials and Methods

PATIENTS

The study recruited 10 pediatric patients (7 males and 3 females) aged three months, presenting with unilateral cleft lip.

Our anthropometric study and quantitative analysis of the nasolabial area was done in 2 steps: 1-day preoperative and 1-month postoperative.

The study was performed at the Craniofacial Centre of the Bambino Gesù Children Hospital (Rome, Italy). The design received approval by local Ethics Committee and it followed the Declaration of Helsinki. Parents of all infants received an information sheet and signed a consent form.

The sample enrolled was homogeneous for age, surgical technique (Millard repair) performed by the same surgeon, timing.

Facial images of the children using the three-dimensional stereophotogrammetry were taken in natural head position in their mother's arms.

3D IMAGING AND DATA PROCESSING

The day before the primary repair, three-dimensional facial images were taken of each child in a rest position.

Each parent held the child in his own arms and set in front of the camera. One operator behind the camera used bright or musical objects in order to get the attention of the infant. Every child had three pictures captured, in frontal and lateral position. One operator chose the best 3D acquisition, in terms of facial expression and quality of the captures.

The 3-D facial photographs were acquired with the 3dMDtrio system (3dMD, Atlanta, USA) that is capable of considerably fast captures. The acquired images were loaded to 3dMDVultus software (3dMD, Atlanta, USA) and then to Geomagic Wrap (3D Systems, Inc).

The follow-up visits have been set up after a month, when the 3-D facial photographs were repeated for each child. A 3D analysis was performed in order to outline the upper lip region for the volumetric measurements.

Measurements have been carried out while drawing perimeter points of the upper-lip area and highlighting anatomical relations between soft tissues and underlying hard tissue, then values obtained before and after the primary repair were measured.

Two observers (SE and CE) established a frontal plane passing through 3D anthropometric points right cheilion, left cheilion and nasion (Fig. 1); landmarks in Table I were used to outline the upper lip region. (Fig. 2, Table I) These landmarks and planes defined the borders of the volume of the interested region and were used for circumscription of the 3D photograph. Finally,

TABLE I - Landmarks used, based on the 3D cephalometric soft-tissue analysis according to Swennen ⁽²¹⁾.

| Landmark Name | | |
|------------------------|------------------------------|----------------------|
| Subnasale | Right Columella | Right Subalare |
| Righth Alar Curvature | Left Columella | Left Subalare |
| Left Alar Curvature | Middle Right Columella | Labial Superious |
| Right Subnasale | Midle Left Columella | Right Crista Philtri |
| Left Subalare | Insertion of Columella Right | Left Crista Philtri |
| Right Rostri (Lateral) | Insertion of Columella Left | Right Cheilion |
| Left Nostril (Lateral) | Subnasale | Left Cheilion |

TABLE II- Volumetric data in preoperative and postoperative captures (mm³)

| Cases | Preop. 1st measure | Preop. 2nd measure | Preop. Mean | Postop. 1st measure | Postop. 2nd measure | Postop. Mean | Difference |
|----------|-----------------------|-----------------------|----------------|------------------------|------------------------|-----------------|------------|
| 1. A.A. | 2478 | 1682 | 2080.0 | 3757 | 1484 | 2620.5 | 540.5 |
| 2. D.M. | 3887 | 2519 | 3203.0 | 3863 | 3405 | 3634.0 | 431.0 |
| 3. I.G. | 1830 | 1474 | 1652.0 | 3680 | 2153 | 2916.5 | 1264.5 |
| 4. L.F. | 1567 | 950 | 1258.5 | 2106 | 974 | 1540.0 | 281.5 |
| 5. M.B. | 2184 | 878 | 1531.0 | 1750 | 1607 | 1678.5 | 147.5 |
| 6. M.E. | 1480 | 883 | 1181.5 | 1826 | 878 | 1352.0 | 170.5 |
| 7. M.S. | 1693 | 765 | 1229.0 | 2874 | 892 | 1883.0 | 654.0 |
| 8. R.M. | 1285 | 546 | 915.5 | 2205 | 967 | 1586.0 | 670.5 |
| 9. R.G. | 1648 | 1351 | 1499.5 | 2846 | 1122 | 1984.0 | 484.5 |
| 10. S.M. | 2112 | 1526 | 1819.0 | 2719 | 1356 | 2037.5 | 218.5 |
| DS | 749.0090045 | 579.9333678 | 645.4855967 | 796.326315 | 784.9591355 | 719.9366947 | 74.5 |
| Average | 2016.4 | 1257.4 | 1636.9 | 2762.6 | 1483.8 | 2123.2 | 486.3 |
| p-Value | | | | << 0.01 | | | |

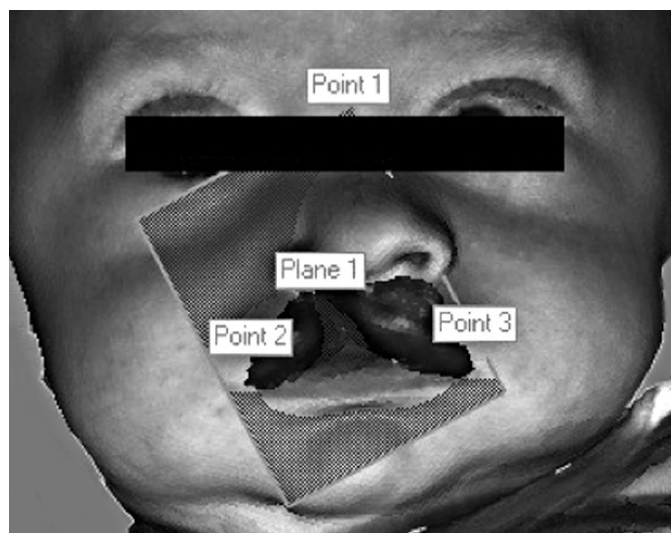


Fig. 1: Frontal plane passing through right cheilion, left cheilion and nasion, with a selection of upper lip area, in a preoperative capture.

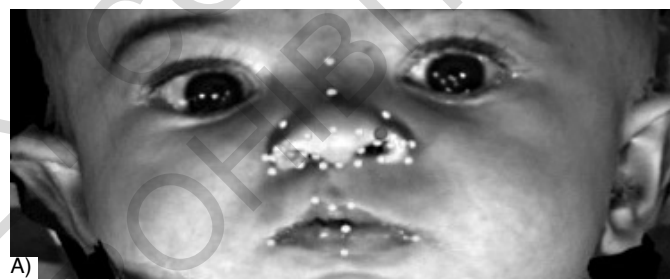


Fig. 2: Landmarks based on the 3D cephalometric soft-tissue analysis (Legend in Table I). Pre- and postoperative.

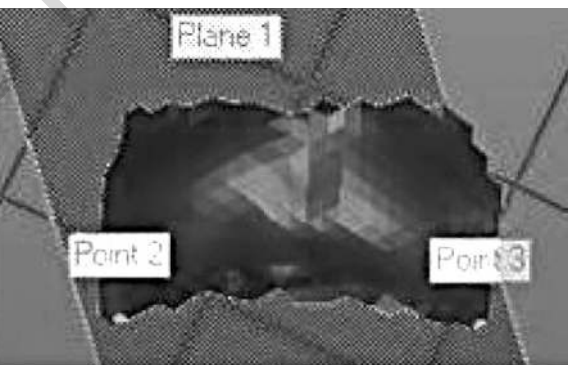
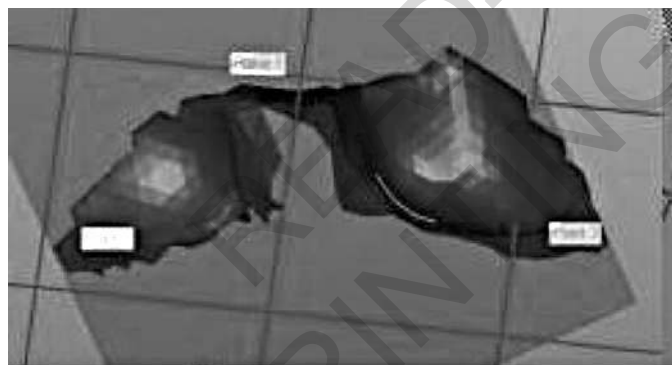


Fig. 3: Upper lip in unilateral cleft lip. Pre- and postoperative area.

only the upper lip was left and a virtual volume could be computed and measured in mm^3 (Fig. 3).

In order to determine intra- and inter-observer reliability, two observers (SE and CE) independently performed all measurements.

The measurements of the surfaces obtained were then saved as Excel® spread sheets (Microsoft Inc, Florida, USA), in order to compare preoperative and postoperative surface values.

STATISTICAL ANALYSIS

We aimed to quantify the pre- and post-operative volumes of the upper lip and to verify if eventual differences were significant. The null hypothesis was that there is no difference between preoperative and postoperative volumes. One-tailed *t*-student test were performed. A *p*-Value lower than 0.01 was considered significant. The software program used was Excel.

Results

10 patients (out of 10 recruited) completed the study, with production of a total of 20 3D-images. All patients underwent the same surgical procedure performed by the same surgeon. None complication was observed in the postoperative period.

The patients' age was 3 months at first photographic step and 4 months at second step. All patients had their entire face area captured with 3D stereophotogrammetry the day before of the primary repair and again one month after the surgery (Fig. 2).

A month after the repair of the nasolabial soft tissues, the upper lip was definitely reshaped.

The 3D viewers rotated around and zoom to point can be set to a specific part of a mesh, highlighting a complete view of the severity in the preoperative and an improvement of the appearance in the postoperative.

The volume of the upper lip was twice compared in the pre- and the post-operative (Fig. 3).

3D images showed a significant increase of upper-lip volume in all patients ($p < 0.01$). Volumetric data are presented in Table 2, which exhibit an increase in volume by an average of 486,3 mm³. The amount of this increase was established about 29,7%.

Discussion

There is a lack of imaging studies of infants because of the difficulties in capturing facial area, but the rapid imaging of the 3D stereophotogrammetry imaging allows the evaluation of alert and uncooperative babies². With this technique is easier to obtain accurate anthropometric measurements, because this system is not affected by camera rotation, unlike in two-dimensional photograph analysis, so surgical outcomes are valued with objective criteria.

3D stereophotogrammetry is considered a reproducible safe process used in different medical study (i.e. rhinoplasty³, orthognathic surgery⁴, craniosynostosis⁵, breast⁶).

Lübberts et al. evaluate the precision and the accuracy of the 3dMD photogrammetric system in craniomaxillofacial application. They tested it for measuring angle, distance, and system re-registration on mannequin head measurements. The results showed that the system was reliable and had a mean global error of 0.2 mm⁷. They found neither the position of the head nor that of the camera influenced the measurements. They recommended its use over manual anthropometry and 2D imaging. Moreover, the capturing of the image was no doubt faster than routine 2D photography; the image capture was instantaneous (1.5 milliseconds), and a single image was needed for complete facial assessment⁷.

Naini et al. showed good agreement between craniofacial measurements using the 3dMDface system com-

pared with manual anthropometry. For all measurements, except chin height and labial fissure width, there was a greater variability with the manual method compared to 3D assessment. Overall, there was a significantly greater variability in manual compared with 3D assessments ($p < 0.02$)⁸. So, they conclude that quantitative methods of measurement are important in craniofacial research and the three-dimensional imaging has the potential for accurate facial measurement and permits the clinician to take measurements in the absence of the patient once the image has been captured and virtually stored⁸. It may also provide an invaluable interactive tool for discussion with patients when communicating existing problems and exhibiting more accurate outcomes^{9,10}. The imaging technology may be used to observe the behavior of the soft tissues more accurately compared to hand tracing and 2D photographic predictions⁸⁻¹¹.

Stereophotogrammetry has been reported as being superior between optics-based systems for creating a 3D surface image, owing to instantaneous image capture, making it ideal for clinical use, particularly with children^{7,8,12}. In addition, the set-up is relatively simple, with a short calibration process, and it produces a more complete and accurate 3D image, which can be manipulated to view all planes. It also permits the accurate location of various landmarks. Furthermore, and perhaps most importantly, many of the stereophotogrammetric systems allow the subject to be orientated in a natural head position, with their eyes open¹³.

Overall, the system was found to be accurate within 0.4 mm and was advocated for recording cleft deformities and measuring changes following surgery¹⁴. Aldridge et al. looked at the precision, error and repeatability associated with anthropometric landmark coordinate data collected from 3D images acquired with the 3dMDface system. The sample consisted of small children with Down syndrome or craniosynostosis. The results showed the system to be highly repeatable and precise with sub-millimeter error only¹⁵.

Three-dimensional imaging in cleft care provides a modern platform for recording the morphology of the facial complex. The applications of this technology in the case of cleft lip and palate, are constantly developing. To this day, even though three-dimensional stereophotogrammetric technique has been already employed for years, none study used the same method to evaluate the volumetric changes pre and post-repair of cleft lip and palate.

Concerning with cleft lip and palate, the 3D stereo-photogrammetry has been applied with other techniques measuring standard linear distance between facial landmarks. Krimmel et al. attempted to measure the cleft of the lip in unoperated patients using plaster casts, in order to compare anthropometric landmarks obtained with normal values: in this study, the highest degree of deformity was seen in the horizontal dimensions of the nose. They assert three-dimensional photogrammetry overco-

mes several limitations of direct anthropometry and has proven to be reliable and can be applied more readily to potentially uncooperative patients¹⁶. Ayoub et al. studied postoperative three-dimensional images of unilateral cleft lip subjects, with a similar anthropometric measurement technique, with the aim of calculating the cleft-side and noncleft-side curvature lengths following surgical operation: they calculated differences in nasal width, philtrum width, columella length and Cupid's bow width. In conclusion they suggest that the incomplete approximation of the muscle fibers during surgical repair contribute to the residual deformities of the nasolabial complex¹⁷. Oh et al. examined asymmetries in unilateral cleft lip patients and correlated data obtained by three-dimensional anthropometric analysis with those obtained using visual analog scale score from ten surgeons, finally suggesting that the degree of asymmetry measured as VAS is correlated significantly with three-dimensional measurements¹⁸. In a related study, Allazawi et al. attempted a three-dimensional anthropometric analysis of nasolabial asymmetry in UCLP subjects before and one year after primary lip repair, providing that, in the second capture, cleft side elements of nasolabial area were still smaller than those of the no-cleft side, but upper-lip asymmetry was improved and the congenitally elongated alar wing of the cleft side had the same width as the no-cleft side¹⁹.

We used the 3D stereophotogrammetry technique for a comparative study in the preoperative and 1 month after the surgical repair of the cleft lip. The null hypothesis was that there is no difference between preoperative and postoperative volumes of the upper lip. Therefore, we aimed to quantify the pre- and post-operative volumes, and to numerically establish if there were changes after the surgery.

The method we used allowed a noninvasive capture of the face and facilitated the 3D objective assessment of the face following cleft repair. The purpose was to verify if the surgical technique used would result in a variation soft tissues volumes and to quantify it. The results suggested a possibility to calculate the increase of the upper lip volume in all cases.

Limit of the study is the placement of the points. In order to determine intra- and inter-observer reliability, two observers independently performed all measurements. However, the literature shows the 3D measurements to have less variation in comparison to manual measurements. We believe that the volumetric increase is linked to the Millard's cheiloplasty technique also, which contribute the increase in size the soft tissues of nasolabial area through the restoration of the anatomical continuity of orbicularis oris muscle. Besides the soft tissue positions, the dimensions of the subject to the month next will not be stable with many variables influencing the soft-tissue dimensions. Despite this possible influencing factor, one study found the landmark variance, over time, to be as low as 0.6 mm²⁰.

In conclusion, according to Naini⁸, we believe this technology has no doubt proved to be an exceptional tool to add to the cleft care armamentarium.

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