Assessment of facial asymmetry before and after the surgical repair of cleft lip in UCLP cases

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Abstract

This study was carried to assess facial asymmetries of unilateral cleft lip and palate (UCLP) before and after primary lip repair. The 3D facial images of 30 UCLP cases (mean age 3.7±0.8 months old), were captured 1-2 days before surgery, and 4 months after surgery using stereophotogrammetry. Generic mesh, a mathematical facial mask that consists of thousands of points (vertices) was conformed on the 3D images. Average preoperative and postoperative conformed facial meshes were obtained and mirrored by reflecting on lateral plane. Facial asymmetry was assessed by measuring the distances between the corresponding vertices of the superimposed facial meshes. The asymmetries were further examined in three directions, horizontal, vertical and antero-posterior. Preoperatively, the philtrum and bridge of the nose were deviated towards the non-cleft side. The maximum vertical asymmetry was at the upper lip. The greatest anteroposterior asymmetries were at the alar base and the paranasal area. The overall facial asymmetry was markedly improved after surgery, residual anteroposterior asymmetry was noted at the alar base, upper lip and cheek on the cleft slide. In conclusion, dense correspondence analysis provided an insight into the anatomical reasons of the residual dysmorphology following the surgical repair of cleft lip for future surgical consideratioons.

Introduction

The UCLP is the most common craniofacial deformity. The surgical repair of the lip and nose is usually performed at early months of life. The ultimate goals of the primary surgery are to improve facial aesthetic and function. However, facial appearance is not always completely restored, and residual facial asymmetry has been noted stigma following the surgical repair of UCLP.[1,2]

Objective assessment of the residual facial asymmetry is crucial to guide the primary surgical repair of cleft lip and palate. The vast majority of the studies on cleft dceformities focused on the evaluation of of postoperative asymmetry [3-8] and in few studies the facial asymmetry was evaluated before and after.[9-11] In most of these the analysis of facial morphology was based on a set of few landmarks which limited the evaluation of the 3D captured images. One of the common methods of evaluating facial asymmetry is the mirror image technique in which the reflected 3D model of the face is superimposed on its original one. This allowed a robust comparison between the right and left sides of the face. Facial asymmetry is then calculated by measuring the minimum linear distances between the surfaces of the original 3D model and its mirror image, and the disparities between the two images are usually displayed using colour map. The main drawback of this method is that the distances between the nearest points of the two superimposed surfaces are measured irrespective of their anatomical correspondence, which underestimates the measurement of the asymmetry. Furthermore, the points of the superimposed surfaces may not be anatomically related, i.e., the pronasale of one 3D image may not be directly related to the pronasale of its mirror image.

The application of facial surface mesh, which consists of thousands of mathematical points "vertices", provides a solution for this problem.[12] A generic mesh, which has a facial mask like appearance can be conformed to take the individual shapes of the 3D facial images, and dense correspondences can be established between the vertices of a group of facial images.[13] The conformed mesh provides a comprehensive analysis of the spatial differences in facial morphology.[14]

The assessment of facial asymmetry in UCLP cases before and after primary lip surgery using dense correspondence analysis has not been considered before.

Aim of the study:

To present a new approach for the evaluation of the total and regional facial asymmetries of UCLP cases before and after primary lip repair.

Material and methods

Ethical approval (15/SW/0095) has been obtained from the REC and R&D committees. The sample consisted of 3D facial images of 30 non-syndromic UCLP cases of Caucasian origins. For each infant the 3D facial images were captured 1-2 days before primary surgery and about 4 months postoperatively, before any palatal surgery (figure 1). The mean age of the infants at the capture of the 3D facial image before surgery was 3.7±0.8 months and was 8.4± 1.8 months after surgery. All the cases undergone a Modified Millard cheiloplasty and a McComb primary rhinoplasty which were carried by the same surgeon. A professional photographer captured the images using the same imaging system 3dMDface System (3dMD Inc., Atlanta, GA, USA). This stereophotogrammetric system consists of two pods; each contains 3 stereo pairs cameras that capture the face in 3D from ear to ear. The infants were seated on a raised infant seat which was 1.5 meter away from the capturing system; the images were captured while the infants were at rest and looking slightly above the midpoint of the camera pods for clear capturing of the nose. The capture time was 1.5 millie seconds; this short acquisition time was essential to avoid image distortion due to involuntary movement of the head during image capture. A 3D model of the face was constructed by processing the stereo pair of images using a designed software for this purpose. The developed 3D facial model was saved in “obj” file format.

Assessment of facial asymmetry

Facial asymmetry was analysed by the application of generic mesh (figure 2 (a, b)); this is a mathematical facial mask which consists of (7190) indexed points “vertices”. The vertices are mathematically represented and symmetrically distributed. The generic facial mesh was conformed to resemble the 3D characteristics of facial morphology (figure 2 (c, d, e)). The conformation process allows the generic mesh to perfectly adapt “conform” on the 3D geometric morphology of the face maintaining the generic mathematical information, through the indexed vertices, for analysis. For each case, a presurgical and postsurgical conformed meshes were created. Procrustes Analysis (PA) was applied to obtain an average preoperative mesh and an average postoperative mesh which were used in the analysis. PA is mathematical translation, rotation and superimposition of the images based on the correspondence between the images The average meshes were mirrored by reflecting the original model on a lateral reference plane. The lateral reference plan is an arbitrary plane, it acts as a mathematical mirror which generates a reflection “mirror copy” of the 3D image of the face to assess asymmetry.

The original 3D conformed mesh and its mirror image which were superimposed using PA. Facial asymmetry was assessed by measuring the distances between corresponding vertices.

In perfect symmetry, the distances between the original image and its mirror copy would be zero.

The asymmetry was displayed in colours ranged from dark blue to red. The colour coded map represents the average distances between the corresponding vertices of the superimposed 3D facial meshes. On a scale from zero to 5, the colours gradually changed from blue, sky blue, yellow, to orange and red as the distances between the corresponding surfaces of the original and mirror images increased

The details of the asymmetry were examined in relation to each of the three directions: horizontal, vertical and anteroposterior. The red represented the asymmetry towards the right side (X direction), in an upward (Y) direction or toward the observer in the Z direction. While asymmetry towards the left side (X) direction, downward (Y) direction or away from the observer (Z) direction was highlighted in blue colour. The green colour indicated minimal asymmetry. The colour outside the central nasolabial region is irrelevant to the study, it is due to the imperfect conformation of the generic mesh at the boundaries of the face.

To assess the errors of the methods, the same operator repeated the measurement process twice, on month apart, on a randomly selected 15 cases. The date were analysed using student-t test at $p<0.05$.

Results

There were no statistically significant differences between the repeated conformation process (p-value >0.05). The mean absolute differences between corresponding vertices of the repeated preoperative conformed meshes were 0.390 mm, 0.330 mm and 0.333 mm in X, Y, and Z directions respectively. For the postoperative conformed meshes, the mean absolute differences were 0.317 mm for X direction, 0.274 mm for Y direction and 0.286 for Z direction.

Figure 3 displays the total facial asymmetry before surgery. The nasolabial area was the most asymmetrical region of the face; the maximum asymmetry (dark red) was at the philtrum, columella, and the vermillion border of the upper lip (>5 mm), less asymmetry was noted at the tip of the nose. The asymmetry decreased laterally toward the nostrils.

Figure 4, 5 and 6 represent the presurgical asymmetry in the horizontal, vertical and the antero-posterior directions respectively. The maximum asymmetry was noted at the philtrum and the bridge of the nose towards the non-cleft side (left), this was slightly less at the alar regions (figure 4). The maximum vertical asymmetry (figure 5) was at the upper lip, while the nose did not show vertical asymmetry (less than 1mm). The greatest anteroposterior asymmetries were at the alar base, upper lip and paranasal area (figure 6). The bridge of the nose and columella did not display anteroposterior asymmetry.

Figure 7 shows the average asymmetry postoperatively. The asymmetry was markedly improved after surgery, but residual asymmetries were identified at the tip of the nose and nasal cartilages. Figure 8, 9 and 10 showed the directions of the asymmetry postoperatively mediolaterally (X direction), vertical (Y direction) and anteroposterior (Z direction) respectively. In figure 8, the philtrum and the cupid bow were deviated toward the cleft side, while the nose deviated toward the non-cleft side. The vertical asymmetries after surgery (figure 9) were minimal. The anteroposterior asymmetry (figure 10) was identified at the alar base, upper lip and the cheek of the cleft side in comparison to the non-cleft left side.

In summary, surgery has improved the asymmetry associated with cleft lip. However, residual asymmetries (anteroposterior deficiency) were noted at the alar base, upper lip and cheek on the cleft slide.

Discussion

This is the first study which applied dense correspondence analysis for the evaluation of facial asymmetry of UCLP; it provided detailed information on facial morphology using the conformation mesh algorithm, and demonstrated, for the first time, the direction of facial asymmetry in relation to the three main cartesian directions, before and after primary lip surgery of UCLP. Furthermore, it eliminated the non-anatomic correspondence of the superimposed images associated with iterative closest point (ICP) that underestimates facial asymmetry.[15] The application of PA for the registration (superimposition) of the original and mirror images provided an actual and realistic method for measuring facial asymmetry between the anatomically corresponding surfaces.

Previous studies[9,10] reported that the maximum preoperative asymmetry was at the nose and the upper lip. The studies they were based on the analysis of a set of landmarks applied landmarks that could not provide the details of the morphological characteristics of the nasolabial region between these landmarks.

Analysing the asymmetry into 3 separate directions provided an unprecedented insight into the nature of the residual asymmetry at each anatomical region. We illustrated that the nose and the philtrum deviated toward the non-cleft side before surgery, this is due to the distorted balance of the muscular associated with the cleft lip as a result of the loss of the caudal-anterior attachment of perioral and perinasal muscles with the nasal septum that pulls the nose and the philtrum in that direction.[16] It is interesting to note the vertical shortening at the upper lip and the corner of the mouth on the cleft side, this is sceondary to the aberrant insertion of the orbicularis oris muscles in the nostril and the piriform aperture. The upper lip, nares and paranasal area showed asymmetry in the backwards direction of the affected side that can be attributed to the unopposed pulling forces by the zygomaticus muscles and the lack of bony support of the hypoplastic maxilla on the cleft side.

It has been reported that the main residual asymmetry was at the landmarks of the nose,[10] on other study the residual asymmetry was mainly around the landmarks of the upper lip.[9] This contradicting findings are due to the limited facial analysis of the previous studies; residual dysmorphology was measured at a single points which underestimthe asymmetry and provide a sparse repsresntation of the face. None of the previous studies provided details regarding the direction of the residual asymmetry which we believe is essential to exactly identify the muscular component responsible of this dysmorphology.

According to the results of this study the primary lip repair has addressed the asymmetry in the vertical and to some extent in the anteroposterior directions. The detected deficiency in the anteroposterior prominence of the cleft side could be due to two main reasons; the genetically programmed growth deficiency or the inadequate dissection and elevation of the lateral nasal superiors muscles up to the zygomatic prominence and the inerior orbital rim on the cleft side. The combined effect can not be excluded, the deficency of facial growth on the cleft side is thought to be due to intrinsic primary defect. Modified Millard cheiloplasty improved the vertical shortening of the upper lip. However, asymmetry at the mouth corners was detected. This vertical deficiency could be attributed to the incomplete mobilization of the superiorly and laterally dysoriented bundels of the orbicularis oris muscle. A dequate moblisation is necessary to minimise this vertical shortness, it is also important to consider the skin incision at the inner surface of nostril on the lateral side of the cleft to allow the adequate lengthening of the lip and the roration of the superiorly attachd nasolabila muscles.

Horizontally, there was clear lateral displacement of the lateral alar base of the cleft side. This is partially due to incomplete mobilisation and crosses over stitching of the lateral nasal aliqeaue nasaii muscle. The muscle has a superior and inferior bundles attached to the greater cartilage of the nsoe and the upper lip respectively. These should be mobilised through a wide dissesction and crossed over to be sutured to the corresponding fibres of the muscles on the non-cleft side to miminize the lateral dsicplacement of the surgically repaired cleft side.

In summary, the results of this study provides the surgeon with an unprecedented opportunity to understand the nature of the 3D deformity of cleft lip and also provides quantitative demonstration on the improvement of facial asymmetry in x,y,z directions. The methods highlight the areas of residual asymmetry following the surgical repair of cleft lip which may require some surgical modifications.

Conclusion

Dense correspondence analysis statified facial asymmetry before and after the surgical repair of cleft lip in UCLP cases in three directions which disclosed the anatomical of this dysmophology. Despite the marked improvement in the overall asymmetry following the surgical repair of cleft lip, residual mediolateral and anteroposterior asymmetries were identified. Residual vertical asymmetry was negligible. Surgical fine tuning could improve residual dysmophology and facial asymmetry.

Legends of the figures:

Figure 1: 3D facial image of cleft infant (a) before primary lip surgery, (b) four months after the surgery.

Figure 2: Generic mesh conformation: generic mesh: (a) surface model, (b) mesh model. (c) Conformation of generic mesh on 3D facial model of cleft patient. The conformed mesh: (d) surface model, (e) mesh model.

Figure 3 The average distances between the corresponding points of the original conformed meshes and their mirror images preoperatively, the dark blue colour indicates zero distance.

Figure 4: Average preoperative mediolateral asymmetry in "X" direction. The dark blue colour represents deviation towards the right side (non-cleft side) > 5 mm. The red colour represents deviation toward the left side (cleft side) > 5 mm. The green colour represents no deviation (symmetry).

Figure 5: Average preoperative vertical asymmetry in "Y" direction showing the vertical shortening of the upper lip as the most characteristic feature of the cleft deformities.

Figure 5: Average preoperative antero-posterior asymmetry asymmetry in "Z "direction. The red colour demonstrates the asymmetry in forward direction. The blue colour displays the asymmetry in backward direction. The green colour represents symmetrical in antero-posterior direction.

Figure 7: Average postoperative combined asymmetry postoperatively. The red colour represents asymmetry in upward direction. The blue colour represents asymmetry in downward direction. The green colour represents symmetrical in vertical direction.

Figure 6: Average postoperative medio-lateral asymmetry in the "x" direction. The blue colour represents deviation towards the right side (non-cleft side). The red colour represents deviation toward the left side (cleft side). The green colour represents no deviation (symmetry).

Figure 7: Average postoperative vertical asymmetry in “Y” direction. The yellowish colour represents asymmetry in upward direction. The bluish colour represents asymmetry in downward direction.

Figure 8: Average postoperative asymmetry in the antero-posterior “Z” direction. The colour bar adjusted that the dark red colour represents asymmetry > 2 mm in forward direction. The blue colour represents asymmetry > 2 mm in backward direction. The green colour represents symmetrical in antero-posterior direction. There is clear antero-posterior deficiency at the cleft side.

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