The Impact of Facial Expression on Facial Appearance of the Surgically Managed Unilateral Cleft Lip and Palate Patients (UCLP)

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Abstract

Aim: To evaluate the impact of facial expression on the asymmetry of surgically managed UCLP cases**. Materials and methods**: The study was carried out on 13 four year old children. Facial images were captured at rest and at maximum smile using stereophotogrammetry. A generic mesh, which is a mathematical facial mask consisting of a fixed number of indexed vertices, was utilised for the assessment of facial asymmetry. This was quantified by measuring the disparity between the left and right sides of the face after superimposing the original 3D images on their mirror copies. **Results:** Residual asymmetries at rest were identified at the vermillion of the upper lip and at the nares with a deviation of the philtrum towards the scar tissue. Vertical and anteroposterior asymmetries were identified on the cleft side. At maximum smile the asymmetry increased noticeably at the vermillion of the upper lip and at the alar base . In the mediolateral direction, the philtrum deviated towards the cleft side with a significant increase of the asymmetry scores. **Discussion:** Asymmetry of the upper lip has significantly increased at maximum smile as a result of the upward forces of all perioral lifting muscles which affect the lip directly. **Conclusions:** The innovation of this study is the measurement of facial asymmetry for the objective outcome measure of the surgical repair of UCLP. The philtrum was the main site of residual asymmetry which indicates the need for refining the primary repair of the cleft lip. Further corrective surgery may be required.

Key words:

3D; face; cleft; imaging; asymmetry; smile; scar.

Introduction

The aim of surgical correction of cleft lip is to restore facial aesthetics and function. Despite improvements in surgical techniques, patients are still left with the cleft stigma which impacts on their social interaction and self-esteem, 13, 37 particularly in early childhood. 1 The assessment of facial asymmetry is an important measure of the outcome of the surgical repair of cleft lip. In most cleft centres, facial asymmetry is assessed clinically during routine examination. This subjective assessment lacks reproducibility, and its validity is questionable. 28, 32 Two dimensional (2D) photographs are used routinely to record facial morphology and for the objective analysis of residual asymmetry following cleft repair. The posing errors and the magnification of the face associated with 2D photography impact on its reliability in the assessment of facial morphology and evaluation of facial deformities .3, 4, 14 Over the last 10 years stereophotogrammetry has been used to capture the 3D facial morphology for the anlaysis of cleft lip before and after surgery. 17 The application of 3D imaging in the evaluation of facial asymmetry overcomes the limitations of 2D imaging. In particular, stereophotogrammetry offers safety, speedy acquisition and accuracy in recording facial morphology, therefore, it is an excellent method for capturing the facial morphology of patients with cleft, especially children.

Several studies have explored the residual asymmetry in the nasolabial regions following the surgical repair of cleft lip and palate. 7, 8, 12, 20, 25, 31 These studies quantified the residual asymmetry at rest; however, the impact of facial expressions on the residual facial asymmetry has not been fully investigated. The expression of a smile plays a vital role in daily communications and the lips are a focus of attention during social interactions. 36 Evaluation of residual deformity at rest and during facial expressions has important clinical implications in the evaluation of the outcome of primary cleft repair and in determining the need for revision surgery. 36 Studies on the impact of expression on the assessment of facial asymmetry are limited. 6, 16 Previous studies were based on the analysis of a limited set of facial landmarks that do not fully describe the complexity of facial morphology. In an attempt to address this limitation, the concept of the generic facial mesh was introduced and has been applied for the analysis of facial morphology. 23 The generic facial mesh is a mathematical face mask that consists of thousands of points known as quasi-landmarks. 10 This mesh is adapted "warped" on the face in a process known as "conformation" to capture the 3D details of the facial morphology. 9 The conformed facial mesh therefore provides the most complete description of the face and comprehensive analysis of facial characteristics due to the standard number and the 3D orientation of the quasi-landmarks of the mesh . 5, 11 This method has been proven successful in orthognathic surgery for the evaluation of facial asymmetry at rest and at maximum facial expressions. 2

Aim of the study

The aim of this study was to evaluate the impact of maximum smile on the residual facial asymmetry of surgically managed unilateral cleft lip and palate cases (UCLP).

Material and method

Ethical approval was obtained from the REC and R&D committees (15/SW/0095). Thirteen surgically managed UCLP cases at the age of 4 years participated in this study. All the participants were of Caucasian origin, diagnosed with a non-syndromic UCLP and were treated by the same surgeon according to the same surgical protocol: a Modified Millard cheiloplasty and McComb primary rhinoplasty. The lip repair was performed when the infants were around three months old. Two 3D facial images were captured for each child four years after the primary surgical repair of cleft lip; one at rest and one at maximum smile (Figure 1).

The images were captured using the stereophotogrammetric device; the 3dMDface System (3dMD Inc., Atlanta, GA, USA). During image capturing, the patients were seated on a raised chair approximately 1.5 metres from the capturing system, and they were asked to look slightly above the midpoint of the camera pods to obtain a clear picture of the nose. Three stereo pair cameras and a flashing system were synchronised to simultaneously capture the face from ear to ear within 1.5 ms. To maximise the reproducibility of maximum smile, the children were instructed to keep the teeth in occlusion, utter the word 'cheese' while stretching the lips as widely as possible and showing the front teeth. The children practised this pose, which was repeated during image capturing according to the protocol developed by our team. 15, 18 The stereo pair of images were processed to build a 3D facial model for each case which was saved in obj file format for the analysis.

Assessment of facial asymmetry

A generic mesh was utilised for the assessment of the residual facial asymmetry (Figure 2). This mesh consisted of 7,145 vertices which were symmetrically distributed and were indexed to be mathematically identified. The mesh was conformed on each 3D image to record the 3D morphology of the face. The generic mesh represented the children's faces (Figure 3) by a fixed number of indexed vertices (dense mathematical landmarks). The models of the right sided cleft were mathemtically reflected to ensure that all the clefts were on the left side of the 3D facial models. Two conformation meshes were developed for each case; one at rest and one at maximum smile. Each mesh was mathematically reflected on an arbitrary plane to create its mirror image. Partial Procrustes analysis was applied to align the original and mirror meshes. The facial asymmetry score was calculated by measuring the mean corresponding distance between the vertices of the original and mirror meshes. In a perfect symmetrical face, the asymmetry score will be zero. The distances between the original image and its mirror copy quantified the facial asymmetry which was displayed in colour maps. In addition to assessing the global facial asymmetry, we further stratified the asymmetry in three directions; mediolateral, vertical and anteroposterior. Asymmetry scores of specific anatomical regions including the nose and the upper lip regions were calculated. A Wilcoxson signed-ranked test was applied to assess the significance of changes in asymmetry scores for the whole face, nose and upper lip at rest and at maximum smile in X, Y and Z directions.

Errors of the method

The conformation process of the generic mesh on the 3D facial models was repeated for ten randomly selected cases to identify the errors of the method. The differences were statistically analysed using Student's *t*-test at a significant level of 0.05.

Results

There were no statistically significant differences between the repeated conformation processes ($p > 0.05$). For the repeated conformed meshes, the mean absolute differences between the corresponding vertices mediolateral (X), vertical (Y) and anteroposterior (Z) directions were 0.31 mm, 0.27 mm and 0.29 mm, respectively.

The results of the Wilcoxson signed-ranked test for the changes in asymmetry scores of the whole face, nose and upper lip are shown in Table 1. The asymmetry scores of the whole face and the upper lip increased significantly at maximum smile.

The average facial asymmetry at rest is illustrated in Figure 4a. The residual asymmetries were identified at the vermillion of the upper lip and at the nares. Figure 4b shows the residual asymmetry in the mediolateral direction, the red colour of the philtrum representing a substantial deviation of this part of the lip towards the scar tissue on the cleft side, whereas the light blue colour of the nose represents a deviation towards the non-cleft side. In Figure 4c, the upper lip, the corner of the mouth and the cheeks of the cleft side are coloured yellow, which indicates asymmetry due to the vertical deficiency on the cleft side. In Figure 4d, the blue colour of the nares, upper lip and paranasal areas indicates the anteroposterior deficiencies on the cleft side.

In comparison with the face at rest, the average asymmetry at maximum smile has increased noticeably at the vermillion of the upper lip and at the alar base (Figure 5a). In the mediolateral direction, the philtrum of the upper lip obviously deviated towards the scar tissue on the cleft side (red colour) (Figure 5b). Table 2 shows a significant increase of the asymmetry scores of the upper lip in the X direction ($p=0.036< 0.05$). In Figure 5c, the vertical deficiencies and the related asymmetry at the upper lip and the alar base of the cleft side were noticeable. At maximum smiling, the increase in the asymmetry was noted due to the anteroposterior deficiencies of the upper lip, nares, and paranasal areas (Figure 5d).

Discussion

This study applied dense correspondence analysis for the first time to evaluate residual facial asymmetry of surgically managed UCLP cases at rest and at a maximum smile. This method quantified the disparity between the cleft and the non-cleft sides of the face by measuring the absolute linear distances between corresponding points of the original 3D images and their mirror copies. This approach provided a realistic and a comprehensive evaluation of facial asymmetry. Moreover, it provided an insight into the source of residual asymmetry through the analysis of this dysmorphology in mediolateral, vertical and anteroposterior directions. Our study showed that in the rest position, the residual asymmetries were at the nares and the philtrum at four years following the primary surgical repair of cleft lip. These finding are generally in line with previous studies. 6, 20 Unlike their findings, our study provided an actual measurement of facial asymmetry and specifically identified the location of this dysmorphology at the philtrum of the upper lip due to the imbalance in the lateral facial growth that can be attributed to the presence of the scar tissue.

This study identified a significant mediolateral shift of the upper lip towards the scar tissue of the cleft side because of the inadequate approximation of the bundles of the orbicularis oris muscle during lip repair. The superficial bundles of this muscle intersect at the midline of the lip; the philtral ridges are formed by the insertion of these bundles from each side of the lip to the contralateral direction. There are no muscle bundles inserted at the philtral dimple. 21 This scar tissue is formed during the healing process as a consequence of the tension forces on the skin due to the insufficient surgical approximation of the tissue at the cleft site. The noticeable vertical deficiency of the cleft side was identified at the corner of the mouth due to inadequate rotation of orbicularis muscle during the primary surgery.

The anteroposterior asymmetry was prominent at the nares and paranasal area as well as at the upper lip on the cleft side. This deficiency could be attributed either to the deficiency of growth potential, 2 or due to the denuded bone and scar tissue formation secondary to palatal surgery. 19, 30 Another cause for the anteroposterior growth deficiency in the nasolabial region is the formation of scar tissue at the upper lip after primary lip repair. 26

At maximum smile, the residual asymmetries at the nares and the philtrum were accentuated due to the abnormal functioning of orbicularis oris muscle and lateral aleaque nasi muscle. These abnormalities may be linked to two factors: the mechanical limitations in maximum movements (particularly during smiling) secondary to lip scarring and the impairment of the maximum force capacity of the lip muscles in cleft cases. 34, 35

Horizontally, the upper lip shifted significantly towards the scar tissue of the cleft side at maximum smile. A typical smile is generated by the contraction of the zygomatic major muscle, which pulls the corner of the mouth and the upper lip upward and laterally. In the surgically managed cleft cases, there is an impairment in the lateral movement of the orbicularis muscle due to the surgical scarring and altered anatomy after primary lip repair. The scar tissue is devoid of muscle fibres which restricts lip movements. 34 The orbicularis oris muscle consists of two portions: superficial (external) and deep (intrinsic). Each portion has a different function; the deep component is constrictor in function and extends horizontally from one modiolus to the other, whereas the superficial component is retractor in function and runs in an oblique direction and merges with the facial muscles responsible for facial expressions. The muscle tissues of both portions have to be repaired accurately in UCLP patients during primary lip surgery taking in consideration the direction of the muscle fibres of each part. 27, 29

At maximum smile, the vertical deficiency of the upper lip on the cleft side extended to the alar base. This deficiency is due to the impairment in the maximum force capacity of the lateral aleaque nasi muscle. The insertions of the muscle at the lateral alar base pulled the nares and the upper lip upwards at maximum smile.

The increase in anteroposterior asymmetry at maximum smile is partially due to the inadequate underlying bone support in complete UCLP cases which disturbs the force balance of the facial muscles. 24

Unlike the nose, the asymmetry of the upper lip has significantly increased at maximum smile. The upward forces of all perioral lifting muscles affect the lip directly, whereas the complex structure of the nose, which consists of bones, muscles and cartilage, would offer more resistance to muscular force imbalances at maximum smile. The low elasticity of the upper lip secondary to the scar tissue at the surgical site could have contributed to the noted asymmetry at maximum smile. This study brings new information to the field of cleft lip and palate and illustrates that the mediolateral asymmetry of the upper lip was significantly accentuated at maximum smile.

In this study the assessment of the asymmetry provides a realistic understanding of the magnitude of facial dysmorphology associated with UCLP at rest and at maximum smile. It also highlights the compensatory mechanisms of the muscles of the lower lip in overcoming the limited stretch of the muscles of the upper lip on the cleft side.

Trotman et al., 2000 assessed the magnitude of asymmetry associated with various facial expressions by measuring the difference of magnitude of the absolute movements of a set of anatomical landmarks on the cleft and the non cleft side. 33 The main limitation of their study is the fact that it does not disclose if the deficiency of lip movement was at the cleft or the non cleft sides. The analysis was limited to the positional changes of individual landmarks during various facial expressions and did not consider the morphological changes of the surface of the lip in its totality. The results of our study have a clear impact on the decision making and the technique of the lip revision surgery to deal with the residual symmetry and minimize the dysmorphology associated with maximum smile. The assessment of lip movement is essential and would inform the decision making process regarding the need for lip revision. Surgical correction of lip dysmorphology should have a clear objective of improving the asymmetry of the naso-labial musculature. The subdivision of the residual asymmetry of the lip into vertical, horizontal and antero-posterior directions provides an unprecedented insight into the cause and the anatomical attribution to the dysmorphology at rest and at maximum smile. The shortened elevator muscles of the lip should be lengthened, the disrupted fibres of the orbicularis oris muscle should be repaired and the abnormally attached insertions of the lateral nasal alequi nesai muscle should be dissected, mobilized and re-sutured.

The present study provides both visual and objective aids to allow the functional assessment of the lip. The method may help the decision making process regarding the need for the revision surgery, quantifies the required surgical correction, and measures the improvements. We believe the results in this study and the presented methodology of quantifying the asymmetry of lip movements would eliminate the subjectivity of assessing the aesthetics and function of the naso-labial region.

The presented innovation of displaying facial asymmetry is a useful educational tool for both the patients and their parents. To avoid unrealistic expectations, the coloured 3D facial images inform the parents on the nasolabial asymmetry which may follow the primary surgical repair of UCLP. It also identifies the asymmetric anatomical regions of the face for further surgical consideration. The presented standardised mathematical approach could be utilised to assess the quality of the surgical repair of cleft lip at different centres and provides a tool for objective outcome measures of the quality of cleft lip repair following different surgical approaches. The presented 3D analysis of facial morphology provides a standardized tool for the objective analysis of treatment needs for lip revision.

One of the main limitations of this study is the static rather than the dynamic recording of smile. Various factors could have contributed to the asymmetry of facial expression which includes the magnitude, pattern and the speed of facial muscle movements at the cleft and the non-cleft sides. This can only be investigated once the dynamics of facial movements are recorded using the 3D real time capture (4D) imaging which would be considered in future studies.

Conclusions:

Maximum smile accentuates residual facial asymmetry of the surgically managed UCLP. The dense correspondence analysis is a reliable and innovative tool for the comprehensive analysis of facial morphology. The method could inform the decision making process regarding the need for lip revision surgery.

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Legends of the figures:

Figure 1: Image of UCLP child at rest (left) and at maximum smile (right)

Figure 2: Generic facial mesh.

Figure 3: Conformed mesh of UCLP child at rest (left), at a maximum smile (right).

Figure 4: Figure 4: Colour maps of average asymmetries at rest at 4 years follow up. The discrepancies in corresponding distances between the original facial models and their mirror copies were presented in colour maps. In a perfect symmetrical face, the asymmetry score will be zero - a) the average residual asymmetries were identified at the vermillion of the

upper lip and at the nares - b) average mediolateral asymmetry (X direction). The red colour of the philtrum of the upper lip represents a substantial deviation of the philtrum towards the scar tissue on the cleft side, whereas the light blue colour of the nose represents a deviation towards the noncleft side - c) average vertical asymmetry (Y direction). The upper lip, the corner of the mouth and the cheeks of the cleft side are coloured in yellow - d) average anteroposterior asymmetry (Z direction). The nares, upper lip and paranasal areas are coloured in blue.

Figure 5: Colour maps of average asymmetries at maximum smile at 4 years follow up - a) In comparison with rest position, the average asymmetry exhibited at maximum smile increased noticeably at the vermillion of the upper lip and at the alar base - b) average mediolateral asymmetry (X direction). The philtrum of the upper lip shows deviation toward the scar tissue on the cleft side (red colour). The vertical deficiencies at the upper lip and the alar base of the cleft side were noticeable - c) average vertical asymmetry (Y direction). The upper lip, the corner of the mouth and the cheeks of the cleft side are coloured in yellow - d) average anteroposterior asymmetry (Z direction). At maximum smiling, the anteroposterior deficiencies of the upper lip, nares, and paranasal areas have increased considerably.

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Table 1: Descriptive statistics and p-value of the Wilcoxson signed-ranked test for asymmetry scores at rest and at maximum smile.

Asymmetry scores	At rest			At maximum smile			*p-value*
	Median	***Min***	***Max***	***Median***	***Min***	***Max***	
whole face	5.66	3.69	8.58	7.14	3.37	12.60	0.047*
Nose	2.23	1.18	4.05	2.63	1.31	4.88	0.216
Upper lip	1.96	1.41	3.87	4.00	1.19	9.98	0.000***

* Significant P < 0.05,

*** Extremely significant P < 0.001.

Table 2: Descriptive statistics and p-value of the Wilcoxson signed-ranked test for asymmetry scores of the upper lip in X, Y, and Z directions at rest and at maximum smile.

Asymmetry scores	At rest			At maximum smile			*p-value*
	Median	***Min***	***Max***	***Median***	***Min***	***Max***	
X-direction	0.65	0.04	2.51	1.12	0.60	2.52	0.036*
Y-direction	0.02	-0.80	1.02	-0.26	-0.60	0.38	0.473
Z-direction	0.83	-0.21	1.72	1.38	-0.79	2.45	0.383

* Significant P < 0.05.

X- direction (mediolateral); Y-direction (vertical); Z-direction(anteroposterior)