# The accuracy of 3D prediction of soft tissue changes following surgical correction of facial asymmetry.

Authors

**T Mundluru**, Postgraduate student, Oral & Maxillofacial Surgery, Faculty of Medicine, MVLS College, Glasgow University Dental Hospital and School, Glasgow, UK

**A Almukhtar**, Honorary Research Fellow, Glasgow University, MVLS college

**X. Ju**, Senior Software Engineer, Medical Device Unit, Department of Clinical Physics and Bioengineering, NHS Greater Glasgow and Clyde, Glasgow, UK

**Ashraf Ayoub**, Professor of Oral & maxillofacial Surgery, Glasgow University, MVLS college.

**Corresponding author:**

Prof. A F Ayoub, PhD, FDC RCS, FDS RCPS, MDS

Professor of Oral & Maxillofacial surgery, Glasgow University Medical school, MVLS College, Glasgow Dental Hospital & School, 378 Sauchiehall street, Glasgow G2 3JZ, The UK

Tel 0044 1412119600

Fax 0044 141 211 9601

Ashraf.ayoub@glasgow.ac.uk

**Abstract:**

The accuracy of three dimensional predictions of soft tissue changes following surgical correction of facial asymmetry has been evaluated in this study. The preoperative (T1) and 6-12 months postoperative (T2) CBCT scans of 13 patients were studied. All patients had surgical correction for facial asymmetry as part of the multidisciplinary treatment protocol.

The magnitude of surgical movement was measured; virtual surgery was carried out on the preoperative scans using Maxilim software. The predicted soft tissue changes were compared to the actual postoperative appearance (T2) at specific anatomic facial regions. Mean (signed) distances and the mean (absolute) distances between the predicted and actual 3D surface meshes for each region were calculated. One sample Student t-test was applied. Additionally, a novel directional soft tissue analysis was applied to analyse the accuracy of the prediction of soft tissue. The results showed that the distances between the predicted and actual postoperative soft tissue changes were within 2.0mm ($p<0.05$) at all regions. The predicted facial morphology was narrower than the actual surgical changes at the cheek regions. Three dimensional soft tissue prediction for the correction of asymmetric cases is clinically acceptable using Maxilim software.

## Introduction:

Facial asymmetry poses a challenge in craniofacial diagnosis and treatment planning. Appropriate assessment and quantification of the differences between right and left sides of the face are crucial element for diagnosis, treatment planning and follow up. Recent advancement in 3D imaging and the associated image analysis carry a potential development in the field of diagnosis of facial deformities. The advent of cone-beam computed tomography allowed examination of anatomical structures in multi-planar view that allowed the diagnosis of facial asymmetry to be more accurate and comprehensive.

To obtain the ideal facial aesthetics and functional results, accurate planning is a crucial component in orthognathic surgery which requires accurate planning, and comprehensive understanding of soft tissue response to the underlying surgical movement of jaw bones.[1]Knowledge of soft tissue response does not only help guide the surgical movements of the osteotomy segments but also informs the need of orthodontic preparation "decompansation" to achieve the required skeletal surgical correction.

Prediction planning of the surgical correction of asymmetric faces is essential to maximise the harmony of facial aesthetics following orthognathic surgery (Loh *et al.*, 2012)[2], it also plays an important role in communication between the surgeon, the orthodontist and the patient.[3,4] Realistic expectation of surgical results following the surgical correction of facial asymmetry minimises patient's dissatisfaction of surgical outcome.[5,6]

Maxilim software using the Mass tensor model algorithm has been validated by studying the CT data of combined dento-skeletal deformities in 10 patients. It has been reported that the greatest areas of changes have been observed in the lips and chin regions. Average mean distances between the real changes and the predicted changes of the soft tissue in response to orthognathic surgery were 0.6mm and the average 90% percentile was below 1.5mm .[7]

Shafi et al., 2013,[8] validated the accuracy of Maxilim software in predicting soft tissue changes following Le Fort I maxillary advancement surgery. In their study, 13 patients were included and average surgical advancement was 5.5mm±2.2mm. Accuracy of prediction was less than 3mm in the majority of the facial regions. However, prediction error in the upper lip region was more than 3mm.

Nadjmi et al., 2014,[9] showed that the mean absolute distance between the predicted and the actual post-operative soft tissue changes was 1.18mm with least reported accuracy at the lower lip region. Prediction errors in the cheek region were observed especially in the vertical maxillary excess cases where upper jaw impaction exceeded 4mm.

The accuracy of Maxilim software has also been investigated in predicting soft tissue changes following bilateral sagittal split advancement osteotomies in 100 cases by Liebregts, et al., 2015,[10], the mean absolute prediction error of the entire face was 0.9mm±0.3mm and the mean absolute 90th percentile was 1.9 mm. The absolute mean prediction error was less than 2mm at all the facial tissue regions except on the lower lip region. The lower lip area showed the least prediction accuracy with a mean absolute error of 1.2mm± 0.5mm.

In bimaxillary surgeries, accuracy of Maxilim software was 0.8mm for the full face, in upper lip 1.2mm, and 1.4 mm at the lower lip and in chin areas was 1.1mm. Mean absolute error of 90 percentile of the corresponding 3D facial surface meshes was found to be less than 2mm. The mean absolute prediction error of the whole face was less than 0.8mm.[10] It has also been inferred that the surgical correction in this group of study was less than the study conducted by shafi et al 2013.[8]

Various algorithms have been developed and incorporated in commercially available prediction software packages to quantify facial soft tissue changes in three dimensions. These include the mass spring model, finite element model and mass tensor model. Therefore, it is prudent to assess the accuracy of the soft tissue prediction especially following the surgical correction of asymmetric cases where 2D prediction planning is of a limited value, this has not been investigated before. To our knowledge, evaluation of the directional prediction accuracy of the orthognathic correction of facial asymmetry has not be reported before.

**Materials & Methods**

Study sample composed of thirteen non- syndromic adults with facial asymmetry, the midline deviation of chin point not less than 2.0mm. All the patients had had single or bimaxillary osteotomy for the correction of facial asymmetry. All the patients were examined at the same multidisciplinary clinic, the study was carried out on the and had Cone Beam Computer Tomography (CBCT) scans which were captured before surgical correction (T1) and 6 to 12 months postoperatively (T2) at 0.4 mm isotropic voxel size resolution.

*Quantifying surgical skeletal movements:*

T1 and T2 images were superimposed on the anterior cranial base which was unaffected by the surgical procedure. On-demand 3D software (version 1.0, Cybermed, Seoul, South Korea) was used for voxel based registration of the DICOM images of T2 to T1 of each case. Following a preliminary manual alignment of the images, voxel based registration was performed to match the selected regions on the two DICOM images (Almukhtar et al 2014). The method maximises the accuracy of the superimposition of the two images based on the grey scale intensity voxel by voxel. The superimposed DICOM images were transferred to Maxilim software (Medicim-Medical Image Computing, Belgium). The antero-posterior, vertical and medio-lateral surgical movements of the osteotomy segments of the maxilla and mandible were measured using a novel method which was developed by our research team.[11]

*Prediction of soft tissue changes:*

This was carried out on all the T1 images using Maxilim software guided by the measured of the actual surgical movements which were identified as explained above. Soft tissue simulation was carried out according recommended manufacturer’s instructions. The prediction of soft tissue changes using Maxilim software is based on Mass tensor algorithm. Soft tissue surface models of both the simulated and the actual postoperative images were generated and exported as Stereolithigraphy (STL) file format for further analysis.

*Assessment of the accuracy of the prediction planning:*

The surface differences between the predicted and the actual soft tissue changes were measured using VRmesh software (VirtualGrid, Bellevue City, WA), a colour coded distance map was generated to illustrate the magnitude and the anatomical regions of prediction inaccuracies. The 3D surface model was segmented into anatomical regions which included the upper lip, lower lip, right and left paranasal regions, nose, right and left cheeks and chin areas. All the models were converted into VRML (Virtual Reality Modelling Language) file format and were exported for further analysis. The surface distances between the predicted facial region and that of the actual postoperation model were measured using in house software developed for this purpose. Using this software the minimum, maximum, mean, standard deviation, absolute maximum, absolute mean and absolute standard deviation of 90% of the points of each facial anatomical region were measured.

Further, in order to understand the directional accuracy of prediction of the soft tissue changes in response to surgery, a generic model was conformed as suggested by Cheung et al., 2016,[12] to the predicted models and the postoperative models to establish surface correspondences. A generic 3D facial mesh comprises of 2000 vertices. The vertices of the generic mesh are indexed so that the magnitude and the direction of discrepancies between corresponding 3D surfaces could be accurately measured. The generic mesh underwent conformation (elastic deformation) to resemble both the predicted and the actual postoperative 3D facial morphology of each patient. The prediction discrepancies at each vertex was analysed in x, y, and z dimensions separately. The results of the differences at each direction were displayed in a colour coded facial map.[13] Areas of over prediction and under prediction of soft tissues changes in response to the correction of facial asymmetry were identified by measuring the mean corresponding differences between the predicted models and the postoperative models.

The null hypothesis is that no statistical difference between the predicted and the actual soft tissue changes at $p<0.05$ with 5% significance level of 2 mm accuracy. To evaluate the validity and the reproducibility of the study, the entire procedure of measurements was repeated twice at one week interval.

**Results:**

*Distances between the predicted and the actual soft tissue changes:*

The mean surgical correction of the asymmetry at pogonion region was 3.6+/- 4.2mm. Among the 13 patients, 10 patients undergone bimaxillary surgery (Le Fort I osteotomy and bilateral sagittal split osteotomy) in one of them an additional condylectomy was carried out. Bilateral sagittal split mandibular osteotomy was carried out in the other three cases; additional genioplasty was performed for one of them. Alar cinch suture and V-Y closure was applied on all the cases who had undergone Le Fort I osteotomies.

Table 1 shows no statistical significant differences between the repeated facial measurements. Table 2 shows the mean surface differences (mm) between the predicted and actual surface meshes of the facial soft tissue regions. The results showed a tendency towards under prediction of the soft tissue changes in response to the correction of facial asymmetry in all the anatomical regions except at the upper lip and the left cheek where a tendency of over prediction was recorded.

The p-values of the mean absolute distances at facial regions were <0.05, the null hypothesis at the 5% significance level was accepted. The red bar in the box plot (figures 1 and 2) represents the median distance, the blue box represents the inter-quartile ( 25-75%) distance range and the dotted lines indicates the 5-95% distance range. The mean signed distances between the meshes ranged from -0.55 to 0.24 mm. Positive mean indicated that majority of the predicted 3D surface mesh is over prediction in relation to the actual postoperative soft tissue changes (figure 3).

*Directional changes*

Figure 4 shows the differences in the medio-lateral direction between the predicted and the actual soft tissue changes in response to the correction of facial asymmetry. The dark blue indicated that the region was under predicted; the dark red indicated that the predicted facial changes were more than the actual changes on the direction of the surgical movements toward the left side. Most of the eyes and forehead regions showed green to light blue or yellow patches, these areas were not affected by surgery. The predicted mid-face region seems to be narrower than the actual surgical changes at the nostrils and paranasal areas. This indicated an under prediction of the surgical changes on the direction of the surgical movement (left side) while over prediction of the actual surgical changes on the asymmetric side (right side). There was over prediction of the oral commissure on the left side and under prediction on the right side. On the left cheek the software under predicted the soft tissue changes in response to surgery and over predicted the surgical changes on the right side. The genial angle region showed dark red patch on the left side and blue patch on the right side which indicates an over predicted changes at the left inferior border of the mandible and under prediction on the other side which is opposite to what was detected at the cheeks.

Figure 5 shows the differences between the predicted and the actual results following the surgical correction of facial asymmetry in the vertical direction. The dark blue indicated under prediction in the downward direction, dark red indicted over prediction in upward direction. A generalized over prediction to the surgical correction of facial asymmetry was noted at the mid-face region in the upward direction. Both the upper and lower lips showed signs of under prediction whereas over prediction was noted at chin region.

Figure 6 shows the differences between the predicted and the actual surgical changes following correction of facial asymmetry in the antero-posterior direction. The dark red indicated more forward prediction than the actual surgical changes; the blue colour indicated the opposite. The mid-face showed a generalised tendency toward under prediction, over prediction was noted at the lips. The cheeks showed a generalized red colour indicating the soft tissue prediction at these regions was more anterior than the actual surgical changes which was opposite to what was noted at the paranasal region.

**Discussion:**

The aim of this study was to determine the accuracy and validity of 3D soft tissues prediction following the surgical correction for facial asymmetry. Previous analysis of the prediction of soft tissue changes following orthognathic surgery has been limited to surgical movements in the antero-posterior and the vertical directions. Therefore, this study was carried out exclusively on cases which undergone the surgical correction of the medio-lateral facial asymmetry using Maxilim software package.

A difference of less than 2mm between the predicted and the actual postoperative soft tissue surfaces has been considered to be clinically acceptable.[14] Therefore the hypothetical threshold of significance has been setup to 2mm, prediction error less than 2mm was considered non-significant.

The validation of SurgiCase-CMF software has been attempted by Bianchi et al., 2010,[15] who reported that the prediction accuracy of the whole face was with an average absolute error of 0.94 mm. Similarly, Marchetti et al., 2011,[16] reported the average absolute error of 0.75 mm of the entire face. These two studies showed the level of error to be less than 2mm which was considered to be accurate enough for clinical applications. In these studies finite element model was the algorithm of soft tissue simulation. Sample size was limited to 10 cases in each study. No particular surgical technique was analysed; instead, a combination of various surgical procedures were evaluated in these studies. In more homogenous group of cases the accuracy of 3D soft tissue predictions using 3dMD Vultus, after Le Fort I advancement, was evaluated.[17,18] The differences between the actual and the predicted facial soft tissue changes were below 3 mm for all segmented anatomical regions. The studies proved the limited accuracy of the soft ware, which is based on mass-tensor model, in predicting the changes in response to Le Fort I osteotomy at the nasal and paranasal region. Similar to all the published data in this area the authors did not stratify the prediction accuracy in each of the three caterisia frame of reference (x, y, z coordinates). The accuracy of predicting soft tissue change s following the correction of facial asymmetry has not been reported before. We believe this is an important aspect of prediction planning in orthognathic surgery which cannot be achieved using 2D software packages.

The results of this study showed that Maxilim software has under predicted the soft tissue changes following the surgical correction of facial asymmetry at most of the facial regions except the upper lip. The right and left cheeks, however, showed different colour distribution which is indicative that the predicted face was much narrower than the actual surgical changes at the cheek regions. Considering the direction of the skeletal correction of our study sample, the symmetry was corrected by shifting the maxilla-mandibular complex towards the left side; this means Maxilim software has under predicted the soft tissue response to the surgical correction of facial asymmetry. The predicted faces were much narrower medio-laterally than the real changes following surgery. This has to be taken in consideration when planning the surgical correction of asymmetric faces using Maxilim software package.

We acknowledge the heterogeneity of the studied cases; however, this does not impact on the credibility of the study which was focused on the prediction accuracy of the correction of asymmetric faces regardless to the aetiology of the deformity or the performed surgical technique.

The use of generic mesh for facial anthropometry have been reported.[19] This method provided a superior analysis of facial anthropometry compared to the traditional colour coded surface distance map.[20] The difference lies in the ability of this method to identify the anatomical correspondence of each point on the 3D model of the face (vertex). The index of the generic mesh provides the bases for the dense anatomical correspondence analysis to measure the difference between two sets of facial images. The method has been utilized to identify positional differences at each vertex in each of the three dimensions x,y and z separately. This provided, for the first time, directional analysis of the discrepancies between the predicted and the actual soft tissue changes in response to the surgical correction of facial asymmetry.

**Conclusions**

Soft tissue prediction of facial asymmetry using Maxilim software is clinically acceptable with a prediction error less than 2mm for all facial regions. There was a general tendency for under predicted soft tissue changes around cheek and chin medio-laterally with an opposite effect at the inferior border of the mandible bilaterally.

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## Tables

**Table 1 comparison of the repeated measurements using t-test**

| Patient | Anatomic region | p - values of repeated mean absolute distances | P - values of repeated mean signed distances |
|---|---|---|---|
| **1** | Upper lip | 0.82 | 0.74 |
| **2** | Lower lip | 0.65 | 0.35 |
| **3** | Chin | 0.13 | 0.22 |
| **4** | Right paranasal region | 0.97 | 0.41 |
| **5** | Left paranasal region | 0.31 | 0.68 |
| **6** | Nose | 0.89 | 0.08 |
| **7** | Left cheek | 0.23 | 0.18 |
| **8** | Right cheek | 0.62 | 0.30 |

**Table 2 Difference between predicted and actual post-operative images**

| s.no | Anatomic region | Standard Deviation of the absolute distances | Mean of the mean absolute distances (mm) | Mean of the mean distances (mm) | P-VALUE of the mean absolute distances |
|---|---|---|---|---|---|
| **1** | Upper lip | 0.43 | 0.86 | 0.20 | <0.05 |
| **2** | Lower lip | 0.40 | 0.97 | -0.39 | <0.05 |
| **3** | Chin | 0.43 | 0.77 | -0.37 | <0.05 |
| **4** | Right paranasal | 0.52 | 0.96 | -0.55 | <0.05 |

| | | | | | |
|---|---|---|---|---|---|
| **5** | Left paranasal | 0.61 | 0.96 | -0.40 | <0.05 |
| **6** | Nose | 0.25 | 0.60 | -0.30 | <0.05 |
| **7** | Left cheek | 0.62 | 1.30 | 0.24 | <0.05 |
| **8** | Right cheek | 0.55 | 1.08 | -0.05 | <0.05 |

**Legend of the figures:**

Figure 1. The mean absolute differences in eight regions of the face.

Figure 2. The mean signed differences in eight regions of the face.

Figure 3. The difference between the predicted and the real facial changes in one case

Figure 4. The differences between the predicted and the real changes in X direction (medio-lateral)

Figure 4. The differences between the predicted and the real changes in Y direction (Vertical)

Figure 5. The differences between the predicted and the real changes in Z direction (antero-posterior)

Table 1

**Table 1 comparison of the repeated measurements using t-test**

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**Table 2**

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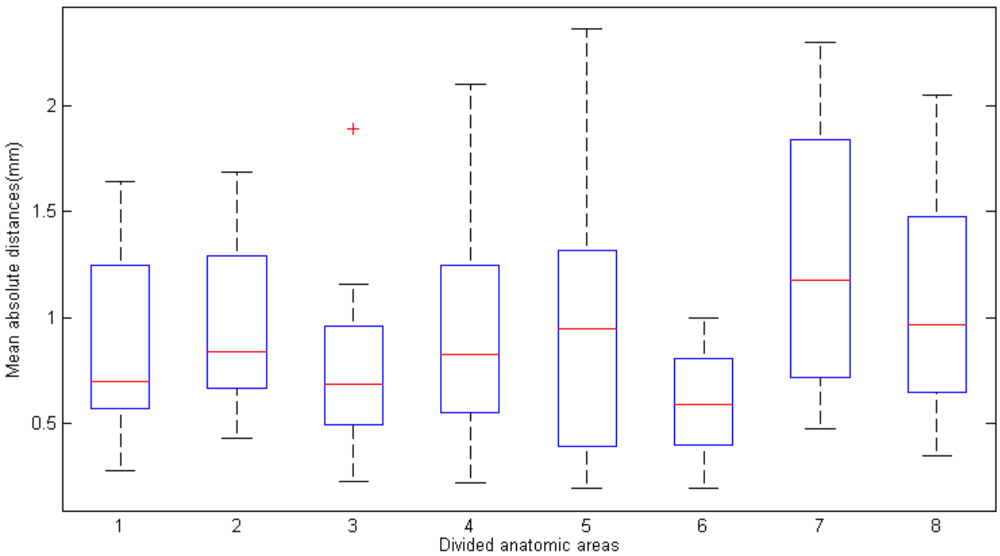
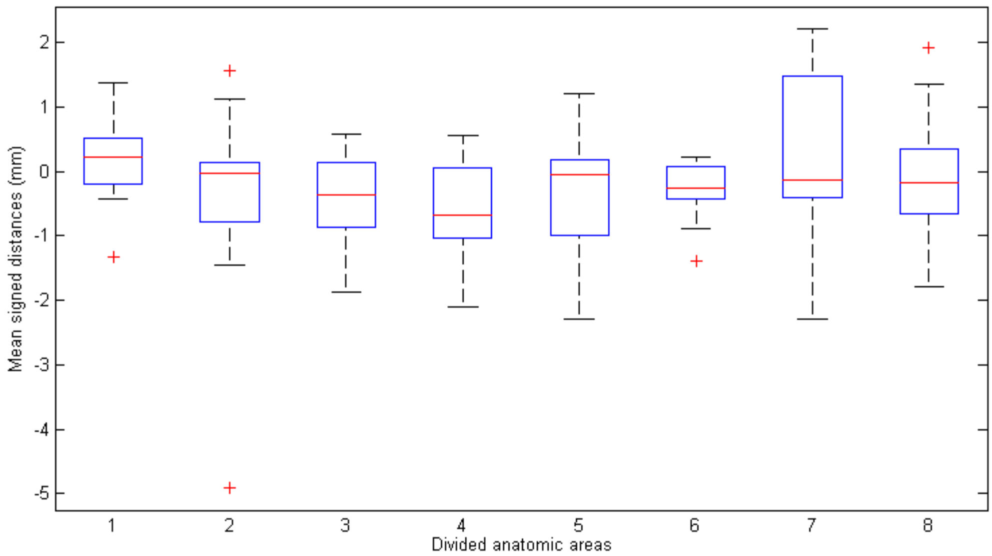
**Figure 1**



Mean absolute distances(mm)
2
1.5
1
0.5
1
2
3
4
5
6
7
8
Divided anatomic areas

**Figure 2**



2
1
0
-1
-2
-3
-4
-5
Mean signed distances (mm)
1
2
3
4
5
6
7
8
Divided anatomic areas

**Figure 3**

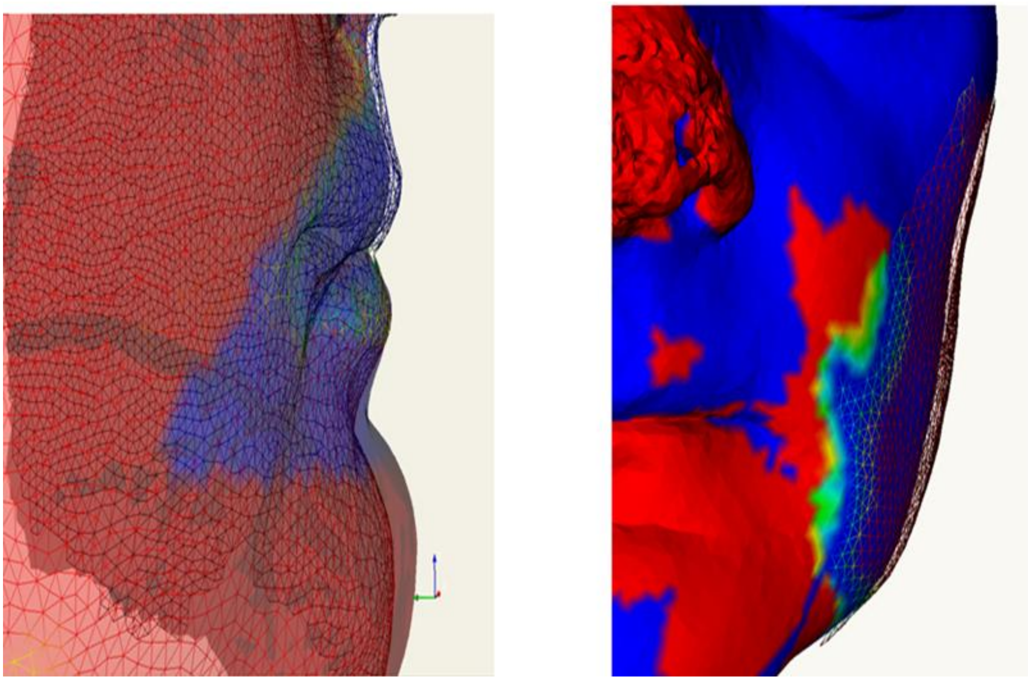


**Figure 4**

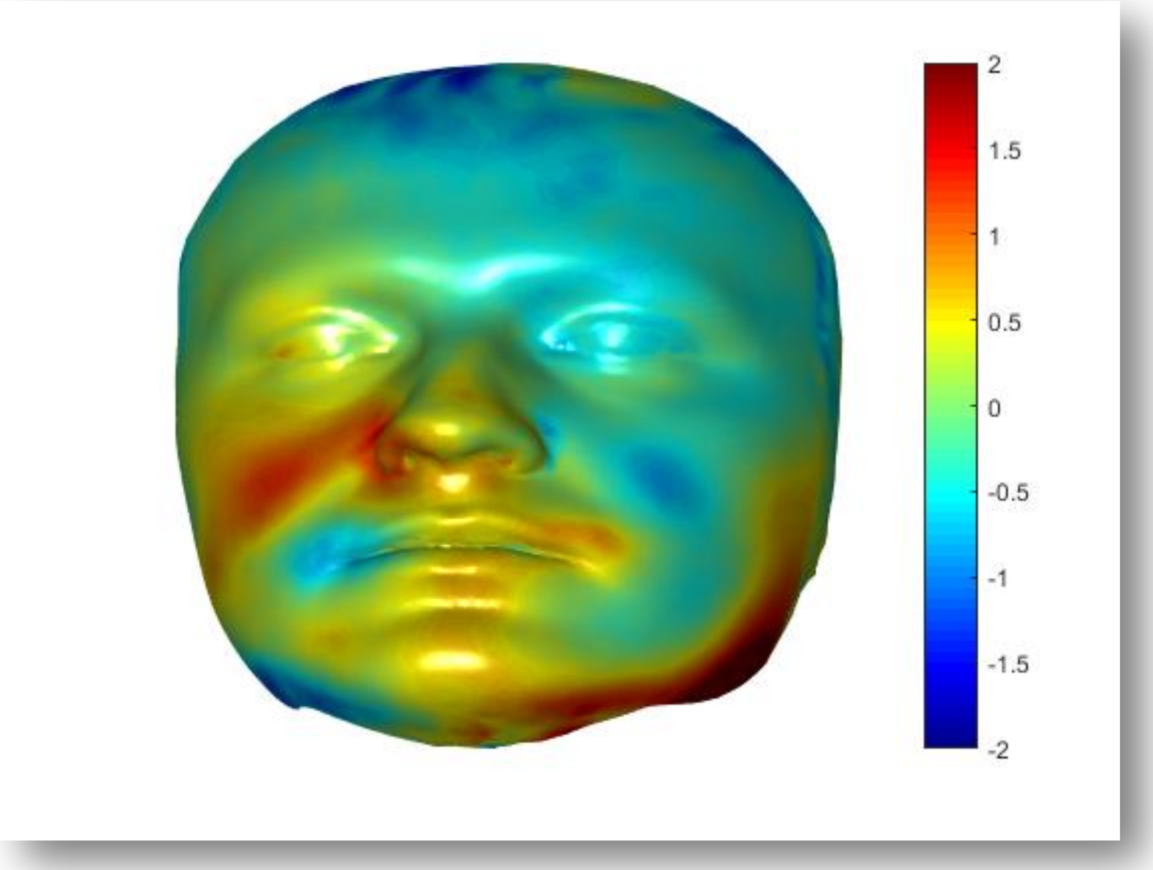


**Figure 5**

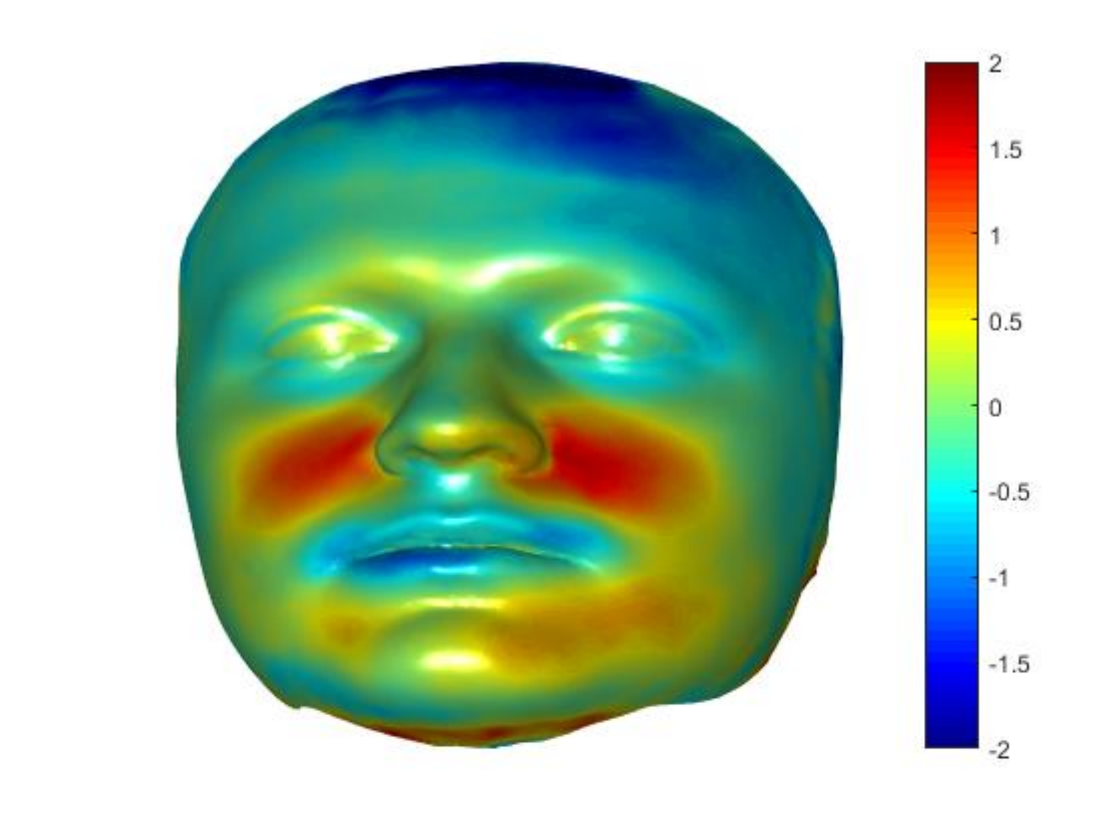


**Figure 6**