ASSESSMENT OF THE ASYMMETRY OF THE FACE BY THE PHOTOGRAMMETRIC METHOD AND ITS FEATURES

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ABSTRACT:

Three-dimensional analysis of human face change is actively implemented in various medicine area. Introduction of numerical methods of change analysis and three-dimensional visualization technologies provides analysis with simultaneous examined patient comfort enhancement due to reduction involvement time in the process of changes.

Below is described the Russian photogrammetric system development experience, that is designed for quantitative assessment of human facial shape changes, which can be used both for monitoring the patient treatment progress, and for the purposes of evidence-based medicine. The article considers step by step the process of obtaining a full-size patient's face "from ear to ear" model as a result of one-step imaging using the developed system. The offered method of asymmetry estimation by three-dimensional digital face model is a highly precise way for asymmetry objectivization, allows to reveal face's bilateral and dynamic asymmetry and to establish functional features of mimic muscles, define soft tissue volumes etc. This method can be successfully applied for diagnostics (including - expert), at therapy planning, as well as in evidence-based medicine at estimation of hardware, thread and injection manipulations in aesthetic medicine.

As a result of accuracy parameters evaluation, it was determined that the result of developed system application within the proposed method framework meets the requirements of medical standards and can be successfully applied as a means of monitoring in the process of treatment.

1. INTRODUCTION

Currently, more and more research is devoted to the study of the human face as a complex dynamic system (Sforza et al. 2006). As a result of diseases, surgery, cosmetic and plastic procedures, the face can undergo serious changes, after which recovery often requires a long step-by-step specialist effort. In all these cases, at all stages it is necessary to monitor the changes taking place and assess their dynamics (Desrosiers et al. 2017).

The modern technical level of systems for observation of the human body, and in particular - the human face, allows not only visual inspection of the patient by a specialist, but also three-dimensional modeling of facial surfaces, performance of calculation tasks and visualization of results (Deli R et al., 2013, Alagha et al., 2022).

This allows to minimize subjectivity in the facial changes assessment, and - most importantly - to express the changes occurring numerically.

Usually in therapy the changes assessment is carried out by photofixation of certain patients mimic samples, with evaluation of the marked points position on the face (Sforza et al., 2010, Kozhevnikova et al., 2012, Deli R et al., 2013, Zhou et al., 2018, Savoldelli et al., 2019). However, this method does not provide a metric estimate of a number of facial structure parameters, especially those related to dynamic asymmetry.

Various researchers have proposed approaches to construct a three-dimensional facial surface and analyze facial asymmetry. In (Yang et al., 2015) an approach to facial expression recognition in 3D, based on the normal map describing geometric facial surface attributes, was proposed. In (Chen et al., 2012) a 3D descriptor of facial expression, namely Multi-Scale Local Normal Patterns, is proposed. In (Zhen et al., 2016), automatic 3D/4D facial expression recognition is based on a muscle motion model. However, these approaches are not suitable for long-term follow-up of patient outcomes.

Against the background of many approaches to the analysis of 3D facial surfaces, only Desrosiers addresses the fundamental issue of quantification bilateral facial asymmetry over a long time interval, but in his studies he obtains 3D facial surfaces by optical scanning methods (i.e., the 3D face is not obtained one moment, which means there can be errors caused by involuntary movements of mimic muscles.

Besides, an important aspect is the patient involvement minimization during measurement procedures: taking into account the necessity of being in a static posture, in some cases prolonged participation in measurements is associated with serious discomfort for the patient (non-static facial muscles, nervous tics, etc.). At the same time, it is often necessary to make a long shooting from different angles in order to carry out a survey, the result of which will be a sufficiently complete and representative model of the face.

Given this fact, in the proposed method of work, special attention is paid to the fact that the shooting of the patient's face should be done in a single moment, while ensuring that a full-size model ("from ear to ear") is obtained. In order to obtain a highly accurate three-dimensional surface of the face, optimal shooting conditions (focal length, capture of the photographic area, selection of camera angles and lighting equipment) were

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selected experimentally so that the Semi Global Matching (SGM) algorithm works (Hirschmüller, 2008).Also in our article we consider the issue of orientation of the 3D face in space. Bringing all the patient's face models into the coordinate system of the first (reference) face. The selection of plane and reference systems, allows us to talk about the observation possibility in prolonged treatment.

Below is described the development experience of the domestic photogrammetric system intended for quantitative estimation of change of a human face form which can be applied both for monitoring of a patient treatment course, and for the purposes of evidentiary medicine is presented.

2. MATERIALS AND METHODS

2.1 Photo installation

We have designed a photographic installation that allows us to obtain a three-dimensional model of a face (from ear to ear). The setup represents a rigid frame in the form of a semi-cylinder with a radius of 0.7 m, on which 11 digital photo cameras (Canon EOS 2000D, sensor size 6000 x 4000 pixels, focal length f = 55 mm, physical pixel size 3.77 microns) and 4 LED panels which ensure uniform illumination of the whole subject are mounted (Figure 1).

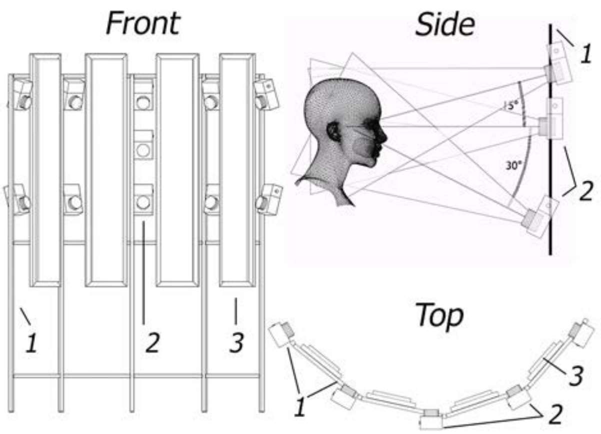

Figure 1. General scheme of the photographic installation, where 1-frame, 2-digital camera, 3-lighting equipment.

The tilt angles of each camera are chosen so as to obtain the optimal face area in the frame in terms of overlap with adjacent frames. The nominal pixel size is 0.05 mm.

The photographing process is controlled by a group of relays, which allows synchronized exposure time with an error not exceeding 1/500 of a second. Thus, synchronized shooting allows to avoid fixation of involuntary facial expressions in different images. Data storage is organized by means of a number of scripts. After the photo session, all obtained images are grouped into separate catalogs, each containing images taken at one point in time. It allows to minimize the time of data preparation, and also to exclude the human factor at selection of the initial data.

2.2 Photogrammetric processing

Photogrammetric processing involves the phototriangulation processes, building dense point clouds, three-dimensional models and digital elevation models of faces. Determination of the image projection centers and processing of all face images is performed in AgisoftMetashape Professional Edition,v. 2.0.1 (AgisoftMetashape, 2022).For external orientation of the first model the coordinates of the image projection centers are used, which were obtained during calibration of the entire imaging system with the root mean square error (RMS) not worse than 0.5 mm. Other models are oriented in the coordinate system of the first model by reference stable landmarks on the face. Such reference points are corners of eyes, bases of earlobes and a point located on the middle of forehead on the border of a hair cover.

As a result of automatic processing metrically accurate triangulated surface face models of ten standard facial mimic samples of one patient are formed. In the first face coordinate system. The coordinate system of the face is formed as follows. The x-axis passes through the inner corners of the eyes, the coordinate system origin is in the middle of this segment connecting the corners of the eyes, the y-axis passes perpendicularly to the x-axis and is the mathematical axis of the face, the z-axis completes the system to the right.

2.3 Assessment of model accuracy

The accuracy of the obtained models and the variability of the models caused by physiological non-stativity of the face were evaluated by test photography consisting of ten approaches (natural state of the face, after performing articulation exercises) Nineteen points were marked on the patient's face with a dermographic pencil for evaluation before photographing. The location of the points was chosen by studying similar studies (Sforza et al., 2010, Kozhevnikova et al., 2012, Deli R et al., 2013, Zhou et al., 2018, Savoldelli et al., 2019), as well as based on the principles of mimic muscle attachment (Radlansky and Wesker, 2014). Forty-four distances were determined from these 19 points.

Measurement repeatability (operator error) was assessed by 10 consecutive hovering over the labelled points on the facial model. Additionally, unlabelled points were measured: confidently recognizable facial elements (moles, lip corners, etc.)

Quantitative variables are expressed as mean value (RMS), standard error (RMS), coefficient of variation (CV%= (RMS/SRMS)100%).

The experiments' result is to assess the accuracy and face models repeatability obtained by photogrammetric method is as follows:

Measurements Discrepancies on labelled points averaged 0.46 mm, RMS = 0.59 mm. Measurements Discrepancies on unmarked points were on the average 1.6 mm, RMS = 2.0 mm.
Sensitivity of the method to natural changes in the face (variability of the method) was determined by the corresponding segments on different models and by differences in digital the face models.

On the measurements basis of 44 reference segments (coefficient of variability - CV) of the face models on the average does not exceed 1 %. In individual cases (after clasping - or chewing movements), this figure reached 2-3.5%.

In the analysis of facial DEM difference matrices, the CV index was higher, as it covered the entire surface of the face, averaging 3.3%, the maximum value reaching 4.2%. Nevertheless, all indices were within the clinical norm of 5%.

Thus, we can conclude that the measurements obtained using the developed three-dimensional imaging system are reliable and reproducible for the face shape assessment of adult patients and can be applied in clinical settings and for the purposes of evidence-based medicine.

2.4 Methods for assessing asymmetry

Treatment objectivization in facial neuropathies, in aesthetic and evidence-based medicine requires mathematical approaches to facial shape assessment. We suggest several ways of doing this.

2.4.1 Evaluation of facial volumes: Allows you to determine the tissue volume and skin flap area of the diseased side of the face as a percentage of the healthy side of the face.

To calculate the patient's face volume, a metrically accurate three-dimensional model is used, oriented face up. The x-axis passes through the inner corners of the eyes, and the origin of the coordinate system is in the middle of the segment that connects the corners of the eyes. The XY plane passes through the tops of the chin and forehead, and the Y axis divides the face in half, (Figure 2a,b). Further the model is cropped according to the template prepared in advance (Boolean subtraction operations are used) (Figure 2c), which allows bringing all three-dimensional models to the same area coverage as well as cropping artifacts on the edges of photogrammetric models. At the same time the polygonal mesh of model is closed, which allows further measurement not only of areas, but also of volumes of models. After that all polygonal meshes not intersecting with main model (having more sides) are deleted. Then obtained model is cut by YZ plane, as a result two new models are created - right and left sides of face (Figure 2d) To calculate volumes of polygonal mesh of final models built-in tools of Blender 3.4.1 (Uptodown, 2022) are used.

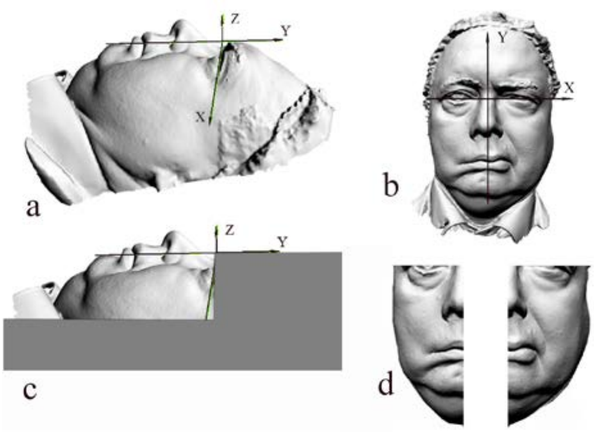

Figure 2. The process of selecting facial halves from a digital elevation model to calculate volumes.

At this point, all model trimming and measuring operations are done in Blender 3.4.1 . It is possible to develop an extension that allows you to use the Blender 3.4.1 toolbox from the command line, fully automating the proposed algorithm.

2.4.2 A Visualization of facial relief information using isolines and layer-by-layer staining: This method was first proposed in 2012 to evaluate the treatment of children with scoliosis. It involves drawing lines of equal heights on the DEM of the face with constant pitch and contrast layer-by-layer coloring to facilitate visual assessment. A step of 5 mm was chosen as optimal. The initial height is determined by the YZ plane, which is the same for all models of one patient (Figure 3).

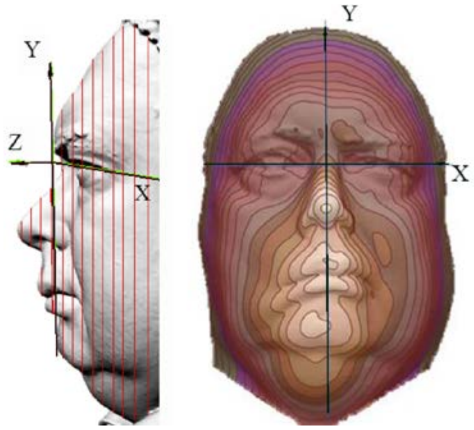

Figure 3. Schematic of visualization of the cisterns using isolines and layer-by-layer staining.

Isolines show geometric differences in the reliefs of the facial halves within a certain range.

2.4.3 Assessment of changes in muscle function relative to statics: It is performed by subtracting the DEM of a calm face from the DEM of a facial expression test (Figure 4). Bilinear interpolation method is used for subtraction. For visualization of the result a scale is set, which allows to estimate changes in facial relief.

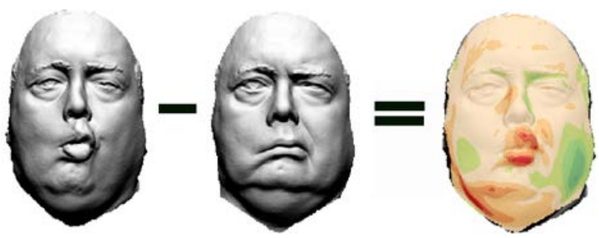

Figure 4. Schematic of the difference model construction.

This method makes it possible to detect and establish the expression degree of mimic muscles weakness, muscles hyperfunction of the healthy (contralateral) side, concomitant movements.

2.4.4 Construction of morphometric models based on facial DEM: To identify facial skin microrelief (wrinkles, skin tension direction), a morphometric method of relief modeling was used, or, more precisely, the determination of mean curvature (H), described in Florinsky (Florinsky, 2016):

$$H = \frac{1}{2}(kp_h + kq_v) \quad , \qquad (1)$$

$$k_h = -\frac{q^2 r - 2pqs + p^2 t}{(p^2+q^2)\sqrt{1+p^2+q^2}} \qquad (2)$$

$$k_v = -\frac{p^2 r + 2pqs + q^2 t}{(p^2+q^2)\sqrt{(1+p^2+q^2)^3}} . \qquad (3)$$

$$p = \frac{\partial z}{\partial x}, \quad q = \frac{\partial z}{\partial y}, \qquad (4)$$

where H = mean curvature
k_h = horizontal curvature
k_v = vertical curvature
p,q = are partial derivatives of height

Horizontal and vertical curvatures (2) were calculated in QGIS version: 3.10.5-A Coruña (QuantumGIS, 2020) in module Grass7: r.slope.aspect (GRASS Development Team, 2020) Then using raster calculator the average value was determined by formula (1) (Figure 5)

Figure 5. DEM in the Hillshaded presented (left) and the morphometric model of the middle curvature..

As a result, morphometric models of the patient's face were obtained, which described changes in the shape of the skin depending on the mimic exercises performed.

3. EXPERIMENT AND DISCUSSION

In this section, we experimentally illustrate the use of the photogrammetric method to quantify bilateral facial symmetry. We imaged three patients with different diagnoses that resulted in facial asymmetry. All patients are at different stages of disease treatment. As a of the shoots result, we obtained 8 models for each patient (P1, P2, P3): 1 - natural face, 2 - fold lips in a tube, 3 - raise eyebrows, 4 - clasp, 5 - show teeth, 6 - smile to the right, 7 - smile to the left, 8 - furrow eyebrows.

Calculation of volumes

Volumes of the right and left halves of the face were calculated, soft tissue loss and skin flap reduction were determined (Figure 6 and Table 1).

Which is important in evaluating the results of hardware techniques in aesthetic medicine and can be a determining factor for prescribing thread technologies for correction of facial asymmetry in facial nerve pathologies. When the loss in soft tissue volume exceeds 30%, thread techniques are recommended for asymmetry correction.

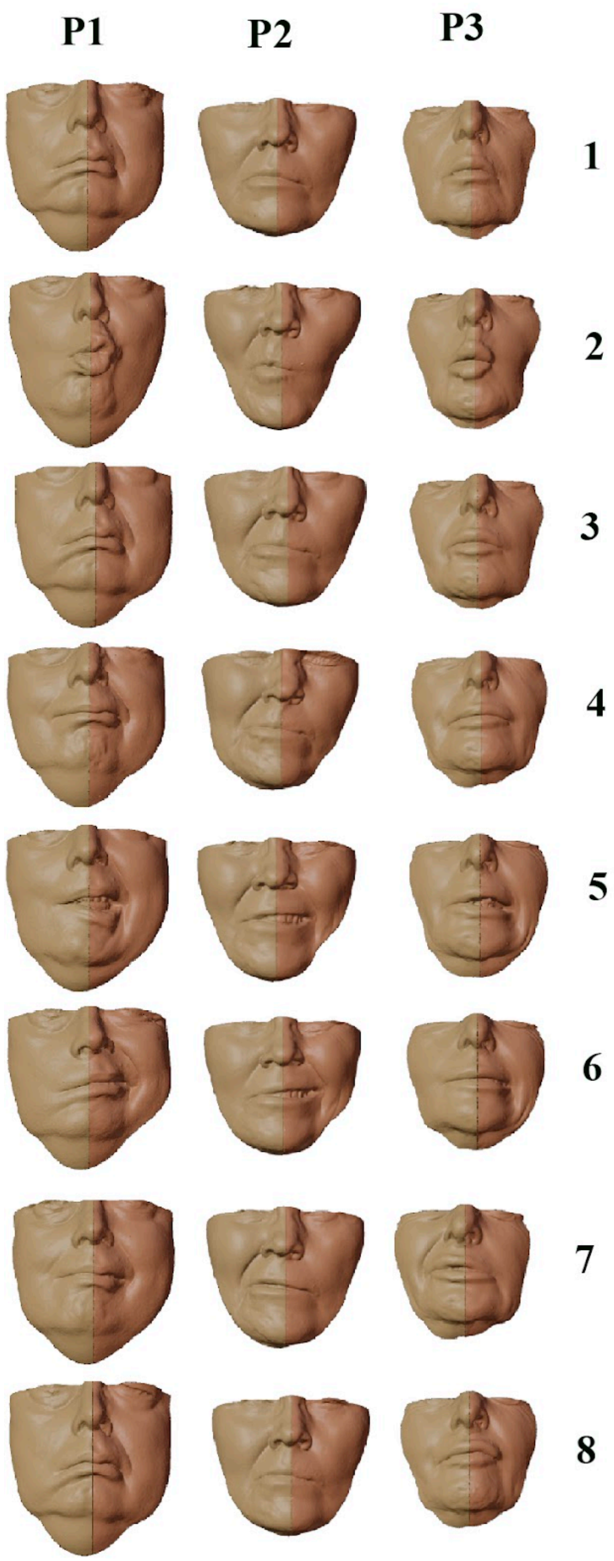

Figure 6. Model preparation for determining volumes.

As shown in Table 1, the most severe form of asymmetry is observed in P2. In P3, the volume difference is on average in the range of the clinical norm of 5%, but there is an excess of the norm when performing mimicry exercises, which is an indicator of residual dynamic asymmetry.

	Volume %			Area %		
	mean	max	min	mean	max	min
P1	13	16	12	3	-1	7
P2	18	25	11	7	11	4
P3	3	6	1	3	2	4

Table 1. Soft tissue volume loss and skin flap area reduction of the diseased side of the face.

Isolines with layer-by-layer painting

Isolines were built in QGIS version: 3.10.5-A Coruña/(QuantumGIS,2020). For all models, the horizontal spacing was set to 5 mm.

Application of isolines with layer-by-layer staining is a simple and clear way of comparative changes estimation in redistribution of volumes in three dimensions. Isolines constructed by DEM of healthy people faces have rather symmetric form not only in a quiet facial expression, but also during mimic tests. As it can be seen from Figure 6, P1 and P2 have pronounced asymmetry in the quiet state, which is aggravated when carrying out mimic tests. P1 has a shift of the symmetry axis of the face lower half to the left and hypertonicity of the right side: when performing Sample 7 (smile to the left), the right side of the face also becomes toned. In P3 after long-term treatment, we observe perfect symmetry in the calm state, when performing mimicry tests, there is a noticeable influence of concomitant movements of the mimic and temporal muscles.

Assessment of changes in muscle function in relation to statics.

By subtracting the seven mimic tests from the first static test, we obtained an overall picture of the dynamic asymmetry of patients with different diagnoses at different treatment stages (Figure 8).

This allowed us to quantitatively assess the facial muscles dynamics in different areas of the face and identify stable areas and active changes areas in the shape of the face, which, in turn, allows us to identify and determine the degree of expression of facial muscles weakness, hyperfunction of the muscles of the healthy (counterlateral) side, concomitant movements, which must be controlled when treating pathological asymmetry with the use of botulinum toxins. For example, all patients show concomitant movements, when the muscles of the forehead on the opposite side move during lip movements. On visual examination, this fact was not recorded.

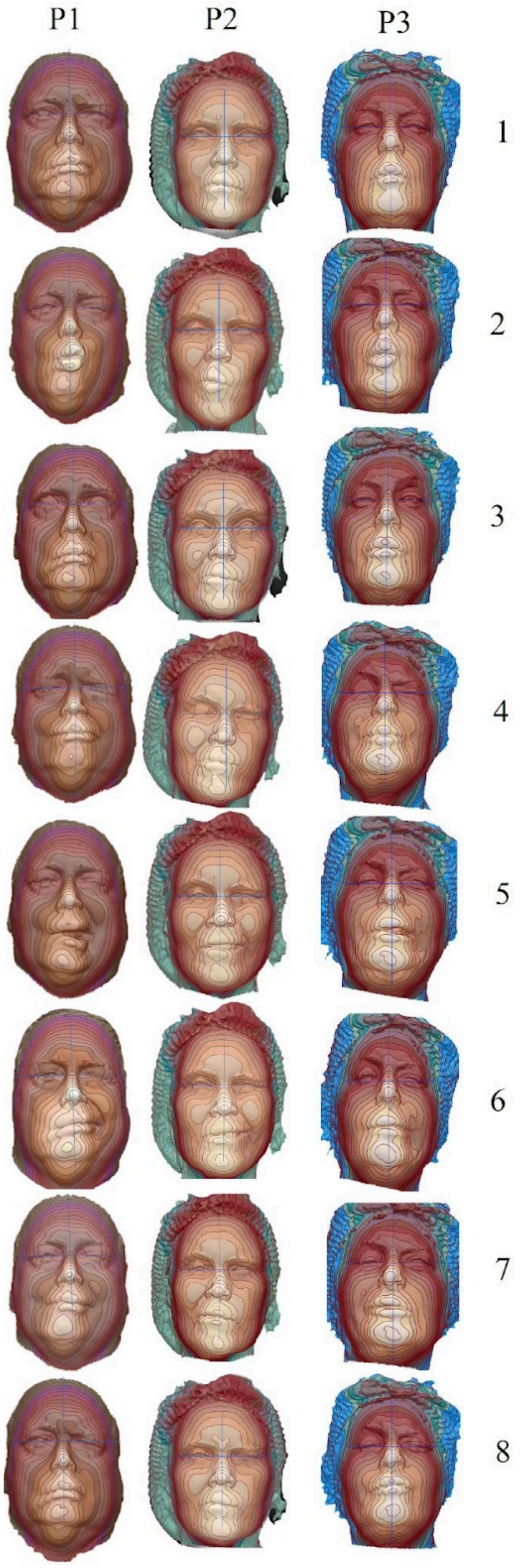

Figure 7. Isolines with layer-by-layer staining, numbers indicate sample numbers.

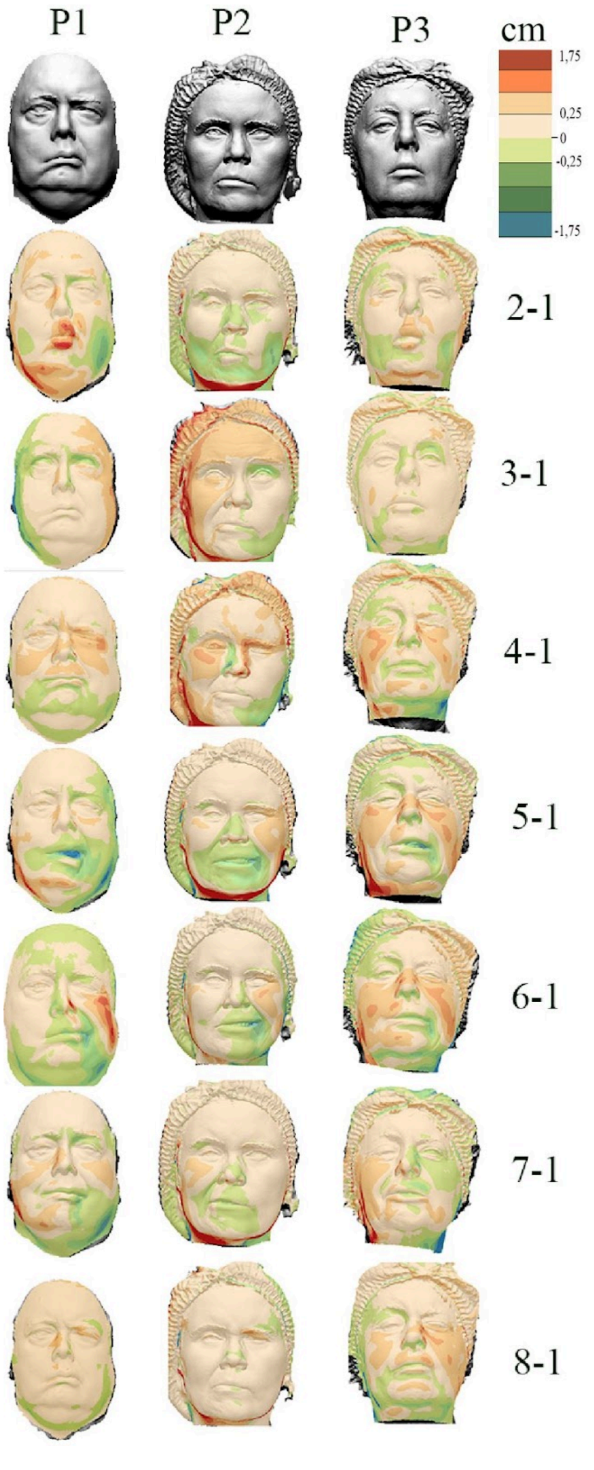

Figure 8. General picture of dynamic asymmetry in patients.

Construction of morphometric models based on facial DEM

Mean curvature represents two mechanisms of flow accumulation - convergence and relative deceleration, which allows revealing the smallest bends in relief in different directions, which are not revealed by conventional methods of relief imaging (hill shaded or isolines). For example, Figure 9 shows three morphometric models of P2. Obviously, the wrinkle pattern is revealed stronger than with the other imaging methods (see Figures 7 and 8). Such models are objectively useful in evaluating the therapeutic effect in aesthetic medicine.

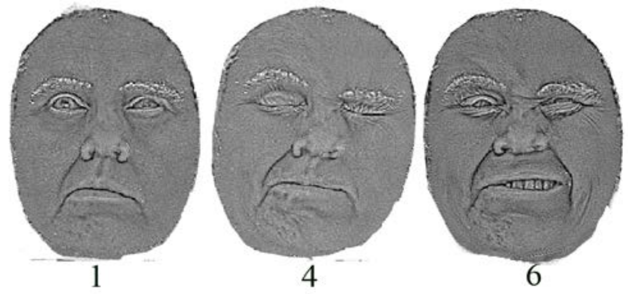

Figure 9. Examples of morphometric models for P2. Numbers indicate numbers of mimic test.

4. CONCLUSIONS

In the present study, a comprehensive methodology for analyzing human facial asymmetry was proposed, which consists of a hardware part in the form of a photogrammetric unit and presentation of the obtained results using high-precision the facial surface models. All proposed asymmetry estimation tools were tested in clinical conditions with the direct participation of physicians. It allowed selecting from a number of proposed evaluation methods those which are understandable for doctors and allow to evaluate the patient's condition in the best way.

The method of mimic asymmetry estimation using three-dimensional digital model of the face is a high-precision mimic asymmetry objectivization method. It allows to reveal bilateral and dynamic the face asymmetry and establish functional mimic muscles features, determine soft tissue volumes and skin flap areas, It can be used for diagnostics, including expert; therapy planning, as well as in evidence-based medicine when evaluating hardware, thread and injection manipulations in aesthetic medicine.

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