Development of the Algorithm for 3D Cephalometric Analysis of Planning Surgical Interventions for Congenital and Acquired Defects and Deformities of the Facial Skeleton

Artem M. Gusarov*, Sergey Yu. Ivanov, Alexander A. Muraev,
Dmitry V. Ermolin and Tatiana V. Bykovskaya

Abstract--- *Planning surgery for congenital and posttraumatic injuries to the bones of the facial skeleton is an important task that often determines success in treatment. Since the structure of the facial skeleton is complex, and soft tissues vary in thickness, it is very difficult to plan the outcome of surgical treatment. The authors have developed a 3DCef software, and a 3D-cephalometric analysis algorithm, which is based on this program. The authors carried out a cephalometric analysis of 40 MSCT of the facial skeleton using the 3DCef program among patients of different ages and genders. The results of the study have revealed the minimum, maximum and average values of cephalometric parameters. The authors have calculated the correlation values of the position of cephalometric points for the right and left sides of the face.*

Keywords--- *Cephalometric Analysis, Maxillofacial Surgery, MSCT, Deformities of the Facial Skeleton, Virtual Planning, Medical Software.*

I. INTRODUCTION

The problem of surgical treatment of patients with defects and deformities of the maxillofacial area is still relevant. A growing traumatism noted to date due to the increase in road traffic accidents, sports injuries, domestic conflicts contributes to a growing frequency of the related cranio-cerebral injuries [1,2]. In Russia, the number of maxillofacial area injuries has remained rather high and continued to steadily grow to-date.

An increase in congenital defects has also been seen. Congenital malformations known as the first and second branchial arch syndrome [3] constitute the deformities that are difficult to be surgically corrected. According to the data of W.R. Proffit and Jr.R.P. White [4], about 1% of adult population have invariable indications for orthognathic surgical treatment. There are various mechanisms for appearance of dento-facial system anomalies. It is common

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Artem M. Gusarov, Assistant Professor at the Maxillofacial Surgery Department, Federal State Autonomous Educational Institution of Higher Education I.M. Sechenov First Moscow State Medical University of the Ministry of Health of the Russian Federation (Sechenov University), Maxillofacial Surgery Department, 8/2 Trubetskaya Street, Moscow, Russian Federation. E-mail: doc.gusaroff@gmail.com*

Sergey Yu. Ivanov, MD, PhD, Corresponding Member of the Russian Academy of Sciences, Professor, Head of the Maxillofacial Surgery Department and Oral Surgery, Peoples' Friendship University of Russia, Maxillofacial surgery and oral Surgery Department, 6 Miklukho-Maklaya Street, Moscow, Russian Federation.

Alexander A. Muraev, MD, PhD, Associate Professor at the Maxillofacial Surgery Department and Oral Surgery, Peoples' Friendship University of Russia, Maxillofacial Surgery and oral Surgery Department, 6 Miklukho-Maklaya Street, Moscow, Russian Federation.

Dmitry V. Ermolin, MD, PhD, Associate Professor at the Maxillofacial Surgery Department, Federal State Autonomous Educational Institution of Higher Education I.M. Sechenov First Moscow State Medical University of the Ministry of Health of the Russian Federation (Sechenov University), Maxillofacial Surgery Department, 8/2 Trubetskaya Street, Moscow, Russian Federation.

Tatiana V. Bykovskaya, Assistant Professor at the Maxillofacial Surgery Department, Federal State Autonomous Educational Institution of Higher Education I.M. Sechenov First Moscow State Medical University of the Ministry of Health of the Russian Federation (Sechenov University), Maxillofacial Surgery Department, 8/2 Trubetskaya Street, Moscow, Russian Federation.

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practice in the literature to classify the reasons into two large groups: exogenic and endogenic. Approximately 25% of all dento-facial system anomalies arise due to internal reasons. Other reasons for their emergence may also involve large volume of amniotic fluid, or abnormal fetal lie; here, the elevated blood pressure is developed, which may result in appearance of anomalies owing to mechanical impact. When endocrine disorder occurs, the development of dento-facial system is delayed, or disproportion between the facial and brain parts of the skeleton appears. A special group contains genetic congenital anomalies, which lead to profound disorders of the facial skeleton: clefts in the upper jaw and the alveolar portion, Van der Woude syndrome, Shereshevsky-Turner syndrome, dysostoses, syndromes of Franceschetti, Goldenhar, Pierre Robin, Crouzon’s disease [5]. The external factors involve disturbance in nasal breathing, social habits, premature loss of teeth, hypertension of the facial muscles. For most external factors, when timely identified and properly treated, the conservative methods may be of help that will serve as a preventive measure for appearance of dento-facial deformities.

Bone defects and deformities of the maxillofacial area reduce the quality of human life. As the level of culture and education in society raises, the social and psychological role of the human appearance and requirements for the facial appearance, in particular, increase. The skull has a complex structure both in terms of anatomy, and geometry [6,7], and it becomes even more volumetrically complex owing to injuries and deformities.

Hence, enhancing the effectiveness of the methods for surgical treatment of defects and deformities of the maxillofacial area constitutes not only medical, but social problem as well.

The main method for planning reconstructive maxillofacial interventions involves analyses of various anthropometric measurements. The latter half of the XXth century saw a huge leap in the development of anthropometric methods for diagnosing the facial skeleton. It was related to invention of gnathometer, profilometer and cephalostat, and studying the facial profile became the major direction of development.

However, despite various well-developed methods and tools to assess the face, the surgeries for congenital and acquired defects and deformities of the facial skeleton were planned “by eye”, i.e. the result of treatment was largely dependent on the subjective perception of a surgeon. The operations, directed at the correction of malocclusion, were planned on the working plaster dental models (casts), that, in most cases, was possible when flattening tubercles of the separate teeth, which also brought a certain margin of error at the planning stage.

To date, to plan and assess the outcomes of treatment, cephalometric analysis has been utilised in orthognathic surgery and orthodontics. Nevertheless, this method didn’t receive wide recognition as a tool for planning reconstructive surgical interventions among maxillofacial surgeons. With recent advances in the methods of computed tomography and appearance of special-purpose programs for processing data, a 3D-cephalometric analysis (CA) in orthodontics has been developed [8-10]. Thus, from the data of study [11], 3D-cephalometry based on the CT data enables increasing the accuracy of measurements as compared with conventional 2D-cephalometry, and it provides better treatment results. Moreover, 3D-cephalometric analysis is reproducible better than 2D-cephalometry [12].

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Objective

Development of the algorithm for three-dimensional cephalometric analysis using the 3DCef software to diagnose the maxillofacial area conditions.

II. MATERIALS AND METHODS

Three-dimensional cephalometric analysis based on the computed tomography data was used to plan surgical treatment and assess its results. The advantage of this approach involved the potential measurement of both linear projection distances between the studied reference points, and absolute distances between the points in space.

The study was conducted using the 3Dcef program. The Certificate of State Registration of the computer software "3DCef" No.2018660910 dated 29.09.2018 was obtained for this software. The software product allows creating any adjustable types of computations according to the researcher's objectives. Hence, the authors have developed their own method for assessing cephalometric parameters of patients with congenital and acquired defects and deformities of the maxillofacial area.

When developing the methodology of cephalometric analysis, the authors have performed the following tasks: evaluation of the accuracy of computer-assisted measurements, identifying and drawing the plane of symmetry and reference planes for cephalometric measurements, selection of cephalometric points, detection of average discrepancies between analogous measurements for the right and left sides.

The accuracy of computer-assisted measurements was assessed as follows. Radiopaque markers (Ø0.3mm metal balls) were fastened on the skin of patients without congenital and acquired deformities of the maxillofacial area. The markers were located in the projection of points: Gl (glabella), sn (subnasale), me (menton), the nasal alae (Ala), the cheek bones (Zy).

Beam compass was utilised to make real measurements between the specified markers. The specified parameters were chosen, since it is easy to replicate them both on a patient, and 3D-models of the face; they are readily reproducible (Fig.1).

MSCT procedure was further performed; 3D-models of the face were constructed in the 3DCef software program, and the distances between radiopaque markers were measured on these models.

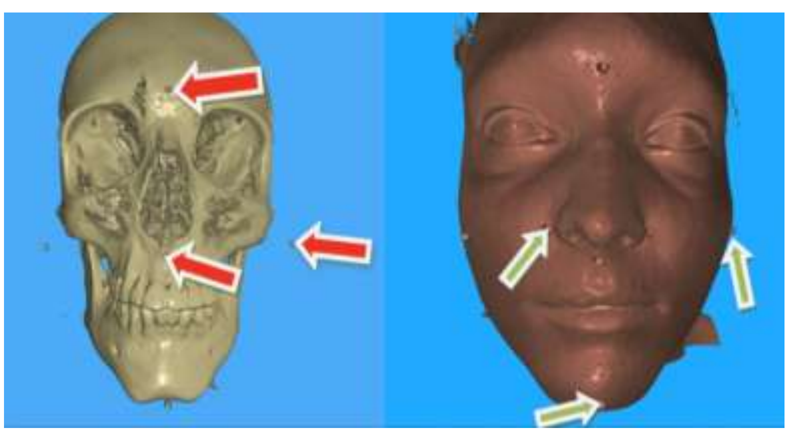

Figure 1: 3DCef. Program Interface. 3D-Model of the Skull with Radiopaque Markers (Indicated by Red Arrows); 3D-Model of the Skull with Reconstructed Soft Tissues and Radiopaque Markers (Indicated by Green Arrows)

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The obtained data were statistically processed. In all, the cephalometric data of 15 persons were processed using the described methodology. The findings of the performed analysis are given in Table 1.

Table 1: Minimum, Maximum, and Average Values of Difference in Linear Parameters When Making Real and Computer-assisted Measurements of the Position of Cephalometric Points

Measurement parameters	Minimum and maximum values of computer-assisted measurements, mm	Minimum and maximum values of real measurements, mm	Average values of difference between real and computer-assisted measurements, mm
Gl-sn	6.2-7.2	6.2-7.1	0.11±0.03
Gl-me	10.8-11.4	10.9-11.4	0.13±0.04
sn-me	4.2-5.5	4.3-5.4	0.13±0.02
AlaR-AlaL	3.3-4.0	3.2-4.1	0.12±0.05
ZyR-ZyL	10.3-11.3	10.3-11.0	0.15±0.06
AlaR-me	5.9-6.6	6.0-6.5	0.14±0.03
AlaL-me	5.9-6.4	5.9-6.5	0.13±0.03
AlaR-Gl	5.4-5.9	5.3-5.9	0.13±0.02
AlaL-Gl	5.4-6.0	5.5-6.1	0.12±0.03

A discrepancy between the data of real and computer-assisted measurements amounted to 0.15□0.06mm, which is indicative of a high degree of accuracy achieved when performing computations.

To prove that the results of measurements are reproducible, i.e. to avoid a considerable difference between the results when measurements are made in various conditions, during various time periods, and using various equipment, all cephalometric analyses were carried out by two researchers on different personal computers. The obtained data were statistically processed, to exclude an operator error related to a personal-subjective factor of assessing the specified task.

Pearson’s correlation coefficient was defined to compare the accuracy of measurements made by different operators. This coefficient for the measurements made by two researchers amounted to r = 0.9246 with p-value = 1.745e-20, i.e. it had a positive value r close to 1.0. It demonstrates a high degree of the accuracy of measurements.

The obtained values are indicative of the accuracy in performing program measurements and of the possibility for making them by one operator, without distorting the results.

The developed 3DCef software is intended to build three-dimensional models of the patient’s face and skull using a series of DICOM files with further positioning of cephalometric points on the surface of the models. These points are utilised for measuring the distances with respect to orthogonal planes.

Algorithm for three-dimensional cephalometric analysis

The algorithm for three-dimensional cephalometric analysis has further been developed. At the first stage, the data of computed tomography in the form of a series of DICOM files are imported into the 3DCef program. Based on a series of axial sections, the software reforms them into a virtual three-dimensional model of the skull, considering various densities of the bone and soft tissue structures. At the stage of constructing the virtual 3D-model of the skull, an operator can correct the level of visualisation of the structures, depending on radiological density,

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that, in its turn, makes it possible to assess the position and relationship between the bones of the skull and soft tissues.

The reference planes were specified to carry out the analysis. Three-dimensional measurements shall be strictly anchored to certain planes, which, in their turn, shall be clearly designated to ensure comparability between the measurements for various patients.

Midsagittal plane (MSP) has been chosen as the main plane of symmetry, with respect to which comparative computations between the right and left sides were performed. To draw this plane, the following cephalometric points were used: Se (Sella), point A and point Na (Nasion). Point Se (Sella) is the midpoint of the sella entrance, point A is the deepest point in the profile of the anterior wall of the maxilla alveolar portion, point Na (Nasion) is the most anterior point of the nasofrontal suture. Point Gl (Glabella), the most prominent point of the nasal process of the frontal bone, has also been used instead of point Na, in case when the nasal bones were deformed due to injury. Replacement of these points could influence the absolute values of measurements; but it didn't affect the differences between the values of the right and left sides. Since MSP passes through the centre of the skull in the antero-posterior direction and divides it into the right and left halves, restoration of the skull symmetry was assessed with respect to this plane.

Similarly, 2 additional reference planes were drawn through point Na (or Gl): upper facial plane (UFP) – a horizontal plane, perpendicular to MSP, and frontal facial plane (FFP) – a vertical plane, which is also perpendicular to MSP. Thus, there was a resulting system of 3 mutually perpendicular planes, which were equally orientated in any study (Fig.2).

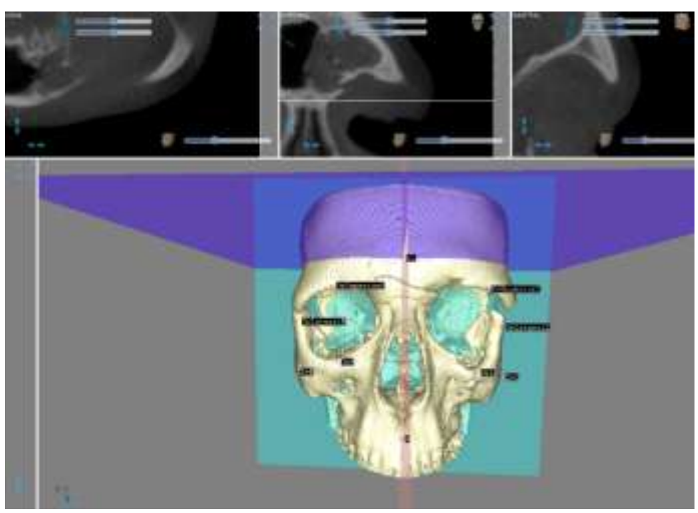

Figure 2: 3Dcef Software Program Interface.

Positioning of 3 mutually Perpendicular Planes

Height-wise position of the points of the right and left sides was assessed with respect to UFP, the position of the points of the right and left sides in the antero-posterior direction was assessed with respect to FFP.

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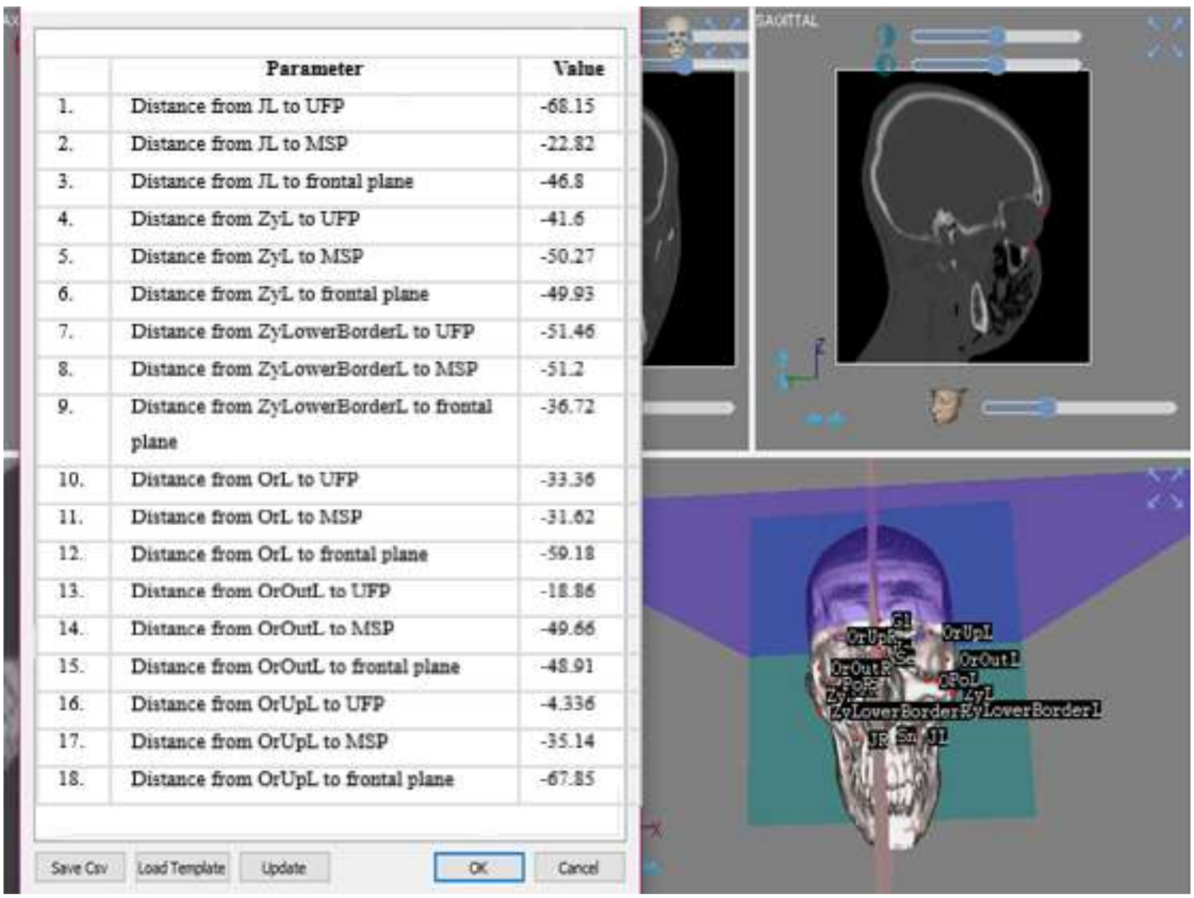
The following pair points were chosen as reference points: JR and JL (Jugularis, the base of the zygomatic-alveolar crest), ZyR and ZyL (Zygion, the most prominent point of the cheek bone), OrR and OrL (Orbitale, midpoint of the infraorbital rim), OrLateralR and OrLateralL (midpoint of the lateral, outer orbital rim), OrSuperiorR and OrSuperiorL (midpoint of the superior orbital rim). The software allows to specify any points needed for any given problem. To increase the accuracy of specifying these points, two-dimensional multiplanar reconstructions were used, which enable visualisation of the position of the points at each section in the three planes.

After positioning of the specified points, the software calculated the height of the perpendicular dropped from each cephalometric point to the three planes.

The data on the distance between cephalometric point and plane are visually summarised in the table for the right and left skull sides, respectively. Displaying the results in such a form substantially simplifies further analysis (Fig. 3)



	Parameter	Value
1.	Distance from JL to UFP	-68.15
2.	Distance from JL to MSP	-22.82
3.	Distance from JL to frontal plane	-46.8
4.	Distance from ZyL to UFP	-41.6
5.	Distance from ZyL to MSP	-50.27
6.	Distance from ZyL to frontal plane	-49.93
7.	Distance from ZyLowerBorderL to UFP	-51.46
8.	Distance from ZyLowerBorderL to MSP	-51.2
9.	Distance from ZyLowerBorderL to frontal plane	-36.72
10.	Distance from OrL to UFP	-33.36
11.	Distance from OrL to MSP	-31.62
12.	Distance from OrL to frontal plane	-59.18
13.	Distance from OrOutL to UFP	-18.86
14.	Distance from OrOutL to MSP	-49.66
15.	Distance from OrOutL to frontal plane	-48.91
16.	Distance from OrUpL to UFP	-4.336
17.	Distance from OrUpL to MSP	-35.14
18.	Distance from OrUpL to frontal plane	-67.85

Figure 3: 3Dcef Software Program Interface. Table of the Results of Measurements for the Left Side of the Skull

Cephalometric parameters depend on gender, age, race. Here, no standardised parameters of three-dimensional cephalometric analysis exist. Furthermore, the accuracy of the computations as such directly depends on the degree of precision, with which a doctor specifies the particular cephalometric points (CP). Based on the above-mentioned constraints, in the work the authors didn’t focus on the specific values of measurements between CP and reference

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planes but compared the values for the right and left sides. To verify the accuracy and reproducibility of the method for positioning CP, various doctors performed identical measurements.

III. RESULTS

For correlating the values, the authors have analysed the data of 40 computed tomography procedures conducted on patients of various gender, age, and race without any bone defects. The obtained values are given in Table 2.

Table 2: Minimum, Maximum, and Average Linear Parameters of the Position of Cephalometric Points for Patients without Defects and Deformities of the Maxillofacial Area

Measurement parameters	Minimum and maximum values, mm	Average values, mm
Distance from J to UFP	51.8-80.56	64.62±7.26
Distance from J to MSP	8.69-38.92	26.35±7.46
Distance from J to FFP	21.3-52.93	37.62±10.39
Distance from Zy to UFP	38.8-56.39	47.33±5.67
Distance from Zy to MSP	46.5-55.44	51.27±2.85
Distance from Zy to FFP	21.8-52.71	37.6±8.59
Distance from Or to UFP	29.4-51.52	39.14±5.44
Distance from Or to MSP	30.5-37.67	34.08±2.3
Distance from Or to FFP	12.8-61.95	36.2±17.42
Distance from OrLateralis to UFP	6.18-28.45	20.39±6.09
Distance from OrLateralis to MSP	46.1-53.67	49.79±2.38
Distance from OrLateralis to FFP	21-48.19	35.21±10.68
Distance from OrSuperior to UFP	1.17-13.03	6.82±3.14
Distance from OrSuperior to MSP	27.9-36.99	32.17±2.35
Distance from OrSuperior to FFP	7.72-67.22	36.87±25.01

To standardise measurements and identify permissible errors, based on the data of 40 computed tomography procedures conducted on patients without injuries to the skull, the differences in spatial position of the points of the right and left sides were detected with respect to the three planes: MSP, UFP, and FFP. As a result, for each reference point of the right and left sides, the authors obtained the value in mm: the distance to MSP, UFP, and FFP. The average difference for each distance between the right and left sides was further calculated in all 40 patients.

The difference in the length of perpendicular dropped from each pair of cephalometric points of the right and left sides to MSP was calculated for each patient. Then, analogous results of all patients were summarised, and the ratio between this sum of differences in the specific point position and the total number of measurements was calculated. Thus, an averaged difference for each coordinate of the point of the right and left sides was obtained.

Computation was made by the formula, where X – averaged difference in coordinates of cephalometric points, L_{nR} – linear distance from cephalometric point of the right side to MSP, L_{nL} – linear distance from cephalometric point of the left side to MSP, n – number of measurements.

Similarly, the difference in the position of anthropometric points was analysed with respect to UFP and FFP to the right and to the left, respectively. To this effect, in the above formula L_{nR} and L_{nL}, in their turn, denoted linear distance from cephalometric point of the right and left side to UFP or FFP. The results of the performed computations are given in Table 3.

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Table 3: Averaged Difference in Distances of Cephalometric Points to Reference Planes in the Normal Condition

Measurement parameters	Minimum and maximum values, mm	Average values, mm
Distance from J to UFP	0.03-1.56	1.89±0.72
Distance from J to MSP	0.22-4.11	2.86±0.64
Distance from J to FFP	0.05-2.35	1.15±0.95
Distance from Zy to UFP	0.88-4.04	2.8±0.73
Distance from Zy to MSP	0.09-3.46	1.87±1.02
Distance from Zy to FFP	0.26-5.10	2.59±0.48
Distance from Or to UFP	0.16-1.88	1.05±0.73
Distance from Or to MSP	0.19-3.01	1.68±1.2
Distance from Or to FFP	0.75-2.55	1.49±0.82
Distance from OrLateralis to UFP	0.07-1.40	0.93±0.31
Distance from OrLateralis to MSP	0.04-3.15	1.92±0.99
Distance from OrLateralis to FFP	0.44-3.60	2.21±0.72
Distance from OrSuperior to UFP	0.12-1.58	1.07±0.34
Distance from OrSuperior to MSP	0.10-3.14	2.02±0.88
Distance from OrSuperior to FFP	0.72-3.05	2.01±0.78

After identifying the average values of cephalometric parameters of patients without any congenital and acquired deformities of the maxillofacial area, this method was applied to analyse the data of multi-spiral computed tomography procedures conducted on patients with various deformities prior to and after surgical treatment. In the course of this study, the authors defined the minimum and maximum values of linear parameters of the position of cephalometric points prior to and after surgical treatment on the injured side, as well as these values for the "uninjured side" (in case of unilateral injury), and the average values of the specified parameters considering average deviation.

Based on the obtained data, the average difference was computed by the above formula in linear parameters of the position of cephalometric points with respect to the three planes prior to and after surgical treatment for the right and left side, respectively. The results are given in Table 4.

Table 4: Averaged Values of Difference in Linear Parameters between the Right and Left Sides at the Presurgical and Postsurgical Stages

Linear parameters	Average values of difference in linear parameters prior to surgical treatment, mm	Average values of difference in linear parameters after surgical treatment, mm
Distance from J to UFP	2.86±0.53	1.96±0.38
Distance from J to MSP	3.55±2.004	2.15±1.13
Distance from J to FFP	4.13±1.49	1.427±0.86
Distance from Zy to UFP	5.12±1.91	2.62±0.69
Distance from Zy to MSP	4.99±1.41	2.17±1.25
Distance from Zy to FFP	3.79±2.04	3.37±0.83
Distance from Or to UFP	4.26±0.98	1.26±0.26
Distance from Or to MSP	3.23±1.47	1.58±0.62
Distance from Or to FFP	5.1±0.92	1.44±0.83
Distance from OrLateralis to UFP	3.87±1.02	0.94±0.78
Distance from OrLateralis to MSP	5.04±0.96	2.83±0.926
Distance from OrLateralis to FFP	3.42±1.13	1.81±0.72
Distance from OrSuperior to UFP	3.23±1.21	1.59±0.56
Distance from OrSuperior to MSP	4.1±0.52	1.74±0.66
Distance from OrSuperior to FFP	3.07±1.43	1.88±0.745

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A retrospective analysis of the results of treatment has shown that in 100% of patients within this study, the clinical signs of the disease were fully eliminated in 6-12 months after the performed surgical intervention, and there are no individual complaints.

IV. DISCUSSION

In the course of the study, the limits of variations in cephalometric values have been identified that were caused by the original asymmetry in the right and left sides and the accuracy of positioning the points as such. The obtained results, taking into account the permissible errors, indicate that there is a considerable asymmetry in the skull in the normal condition, and the asymmetry is noted with respect to both the right and left sides, and with respect to horizontal and frontal planes from two sides, respectively. From this it may be concluded that the quest for restoring an ideal symmetry between the right and left sides should not be the main purpose of reconstructive intervention when eliminating defects and deformities of the facial skeleton bones. The averaged data show that the difference in linear parameters of the position of cephalometric points for patients with no skull deformities can achieve 3.5mm, which, in its turn, is due to the initial asymmetrical structure of the facial skeleton bones.

The authors have also found that the coordinates of the points with clearly defined spatial characteristics had minimum differences when measured by various operators. Such points include Orbitale, Orbitale Lateralis, Orbitale Superior points. The differences in the coordinates of these points amounted to 0.9mm on an average. On the contrary, the coordinates of the points, which are located on the flattened surfaces without acute angles or cavities, may considerably differ when constructed on various computed tomography scans, and it depends on the accuracy, with which these points were positioned by a doctor. For example, the differences in the coordinates of points Zygion amounted to 2.5-3.0mm. These data demonstrate that careful positioning of reference points is needed to adequately plan and assess the results of treatment.

It should be noted that when carrying out cephalometric analysis after surgical intervention, anchoring metal structures were often at the location of positioning the cephalometric points, in particular, when positioning points Or and OrL. To increase the accuracy of computations, it was required to position cephalometric points on a series of two-dimensional multiplanar sections under reconstructive plate directly on the bone. Taking into account that the thickness of the plate, depending on the manufacturer, may vary from 0.6 to 1.2mm, positioning of the cephalometric point directly on the surface of reconstructive plate in the mode of three-dimensional reconstruction may considerably distort the obtained data.

The analysis of the data of cephalometric analysis in patients with deformities of maxillofacial area has shown that at the presurgical stage the values exceeded 3.5mm for all parameters, which was indicative of breaking the symmetry between the right and left sides. These values, in their turn, after reconstructive intervention, only by the two parameters of measurements (OrLateralis - MSP, Zy – FFP) exceed the permissible limits. It, in its turn, is not indicative of low-quality planning or incorrect surgical treatment, if there are not any clinical manifestations. Since when carrying out comparative cephalometric analysis of patients with no bone defects and deformities of the skull, the authors have identified that the difference of up to 3.5mm in CP spatial characteristics may be a sign of the initial asymmetry in the structure of the facial skeleton bones. In planning and performing the surgical intervention, there is

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always a certain element of subjectivism due to a personal vision of the operating surgeon and his visual focus on the “uninjured side”, in case of the unilateral deformity. The obtained results show that there is a need for hardware verification of conducting any procedure, which enables their implementation with even higher degree of accuracy, more effective methods for planning and preparing to surgical intervention. To this effect, using intraoperative navigation systems is recommended.

Various authors in their works concluded that the element of subjectivism has a considerable influence at the different stages of reconstructive treatment, and automated control systems should be created.

There are new perspectives in the reconstructive surgery, presented by the methods for eliminating the bone defects in the maxillofacial area using individual implants [13-15]. Development of CAD/CAM, the technologies and methods of additive manufacturing, enabled the creation of individual implants based on the data of multi-spiral computed tomography (MSCT) and cone-beam computed tomography (CBCT). The major advantage of this type of manufacturing is in the ability to create small parts, cavities, and complex interior geometry. The implant may be of any specified form, while congruently resting on the implant site [16-19]. Also, a variety of methods for additive manufacturing allow to choose the implant material for each individual clinical case.

The stage of planning surgical treatment of patients with dento-facial system anomalies is one of the most complex and essential to ensure a good outcome of orthognathic operation.

With the development of computer technologies, to treat congenital and acquired dento-facial anomalies, a possibility appeared for planning the operation, which can be done using a computer program, rather than models or paper. Computer modelling is of immense importance and it has an enormous potential for analysing the facial skeleton and surgical planning the future operation. Planning the surgical stage is an integral part of all approaches used in orthognathic operations, which allows analysing aesthetic changes in the soft tissues of the face in a single step [20,21].

The existing present-day methods of restorative and reconstructive surgery made it possible to improve the results of plastics of the maxillofacial area bone defects. Introduction of computer-based technologies has marked the beginning of the new stage in developing the methods for diagnosing the facial skeleton defects and planning reconstructive interventions.

With the advance of computer technologies and improvement of the quality of examination, the methods of computed tomography have been widely used in our practice. In the last years, the articles in the foreign literature have begun to appear about comparing planar 2D and computer-based 3D capabilities. Certainly, the degree of accuracy of the obtained results is higher in three-dimensional images, since the structures do not superimpose on one another. High resolution facilitates the perception of an image, and the program makes it possible to rotate any fragment by 360 degrees. The existing computer programs to plan orthodontic and orthognathic treatment using 3D images ensure a high degree of accuracy [22-24].

To manufacture individual implants or plan complex intervention, a special-purpose software is needed, which shall perform the following tasks: first, to work with the files obtained during CT or MRT procedures (DICOM-

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files); second, to have a set of functions to make visualisation and measurements on the virtual object, reformed from DICOM-files, third, to have a number of tools for virtual modelling of individual implants; fourth, to transform virtual models into the files, which format is used by three-dimensional rapid prototyping devices [25-29]. There are multiple publicly available free and commercial software products to analyse DICOm-images (AmIDE, synedra View, UniPACs DICOm viewer, mango, XmedCon, DICOm Viewer, OsiriX, openDICOm.NET, K-PACs, Aeskulap-DICOm, package of software 3Dview (Russia)), special-purpose programs to plan surgical interventions for the cranial bones: mimics (materialise), iPlan 3.0 (Brainlab®, Feldkirchen, Germany), 3D Doctor, Amira, Analyse, BioBuild, sliceOmatic (TomoVision, Canada), InVesalius (Brazil). Virtual planning in such software programs is based on a broad set of functions, however, in the opinion of the authors, the standard features of the programs not always enable achieving the formulated objective [30-35].

V. Conclusion

In the scope of this work, a software algorithm for the three-dimensional cephalometric analysis has been developed. The analysis is conducted on a computer-based three-dimensional model of the patient skull, reformed according to the data of X-ray computed tomography and related to multi-planar reconstruction by coordinates. The Russian software “3Dcef” has been designed to process the data of computed tomography and carry out three-dimensional cephalometric analysis of the cranial bones. It enables making computations of any adjustable cephalometric parameters: vector forms of distances between cephalometric points, projection distances between the points on the reference planes. Based on the results of the performed three-dimensional cephalometric analysis of healthy persons with no defects and deformities of the maxillofacial area, it has been discovered that the asymmetry between the right and left sides may reach 2.8±0.73mm, which, in its turn, is due to the initial asymmetric structure of the cranial bones. The acquired data allowed identifying the limits of the permissible values when planning surgical treatment of patients with various skull defects and deformities. No clinical manifestations and complaints have been found in patients when analysing the treatment results, nevertheless, 3.37±0.83mm differences have been detected between the right and left sides, that exceeds the specified limits. The obtained data indicate that there is an effect of human factor (surgeon qualification) on the accuracy of performing intervention.

The developed algorithm and software have proved to be highly promising. Due to diverse adjustable parameters of measurements, it is recommended that these tools should be utilised by practicing maxillofacial surgeons, orthodontists, to plan surgical intervention and control its performance at the early and late stages of post-surgical recovery.

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