Cephalometric examination for planning of reconstructive operation based on Cone-Beam CT database

Ph.D. thesis

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Introduction

The shape and symmetry of the facial skull affects the form of a person's face, which plays an important role in developing identity and building social relationships. Considering the above, therapy is crucial in craniofacial deformities, which are most frequently caused by developmental abnormality, craniofacial trauma and tumor. In general, surgical treatment represents the only solution in this area, which is often performed by a multidisciplinary surgical team formed by a neurosurgeon, plastic surgeon and maxillofacial surgeon. As a considerable part of deformities is related to inadequate development of bones, rebuilding skeletal components has the highest priority, maxillofacial surgery is therefore an essential process of therapy.

Planning orthognathic and facial reconstruction surgeries is a complex area, where radiological imaging provides one of the pillars. Following the discovery of the X-ray, surgery planning was performed based on lateral cephalometric X-ray images and spread all over the world. Cephalometric analyses based on lateral X-rays emerged one after the other. On their base, normal values describing the form of facial skull became determinant, along with the extent and position of deviancies. With the development of digital technology, the cone-beam CT appearing at the beginning of the 2000s revolutionized both dental imaging and surgical planning. Subsequently, three-dimensional planning was established, and the enormous knowledge that has become available this way gave a huge drive to research investigating and developing preoperative planning methods and possibilities.

Objectives

The dynamic development of CBCT gradually made way for performing volume tomographic orthodontic and facial reconstruction therapy. Current surgical planning softwares have several functions but also show several deficiencies in adapting cephalometric-based measurements:

1. At 3D adaptation of reference points used in traditional cephalometry, it is crucial to evaluate the identifiability of points to determine which points can be used reliably in which direction at measurements performed on CBCT volume tomography. Although several studies from literature investigated the reliability of linear or angular measurements, these have limited significance in practice as the several hundreds of cephalometric analyses contain different

linear measurements, and the evaluation of their reliability is difficult due to their high number. Instead of linear and angular measurements it is worth-while to evaluate cephalometric point coordinates and draw a conclusion from these as to in which measurement that given point may be useful. In literature, only few publications focused on three-dimensional localization of points and these only evaluated few points, therefore its implementation is necessary.

2. Most softwares adapted cephalometric analyses and associated normal values by projecting the points to the mid-facial plane. This way, the software creates a 2D image similar to measurements carried out on traditional lateral X-ray views. Although several articles exist in literature related to this type of measurement, there is no consensus regarding the method of determining the mid-facial plane. It is therefore possible that measurements made with different softwares disagree, thereby significantly influencing preoperative planning. Thus, clarifying it is crucial.

3. Facial reconstruction softwares enable volume determination of the orbit. However, this has only diminished value from a surgical point of view as in many cases, such as when planning orbital implantation, it is important which part of the bony orbit has shrunk or enlarged and to what degree compared to the normal side. Such a software function may provide relevant information for surgical planning, therefore its implementation is reasonable.

4. In addition to 2D adaptation of cephalometric analyses, the main goal is to develop a 3D analysis and to determine related normal values for the whole population. However, there is no established method for this, thereby the development of a 3D analysis is a necessary part of the three-dimensional adaptation of cephalometry.

Taking into account all of the above, I had the following goals during my work:

Creating CBCT-based three-dimensional cephalometry with the help of CranioViewer that has been developed by our research team:

1. Project I: Adaptation of reference points used in traditional cephalometry onto the CBCT data set and evaluation of their reliability.
2. Project II: Determination of mid-facial plane applicable during surgical planning on the CBCT data set.
3. Project III: Creating an orbit module applicable for orbital reconstruction planning and its use during surgical planning.
4. Project IV: Creating three-dimensional cephalometry describing the lower part of the face by adapting the Di Paolo analysis.

Methods

The CranioViewer software - which was developed by Zsolt Markella and Tamás Vízkelety to determine the orthodontic diagnosis and to plan reconstructive operation – was used by us during the whole research. The data of CBCT can be transferred as DICOM files to software which can create X-ray, slice X-ray, CT, MIP (Maximum Intensity Projection), AMIP (Advanced Maximum Intensity Projection) imaging procedures and it can create a wireframe image from the detected points. After the detection of landmark Cranioviewer automatically determined the coordinates of each point. By the means of the coordinates angles and distances can be measured, which are the base of the treatment planning.

- **Project I.: Determination of landmark identification using CBCT database**

Thirty CBCT scans (19 male and 11 female , aged 18-30) were selected retrospectively from the database of the Oral Surgery Department of Semmelweis University. 55 hard tissue landmarks were selected and defined in three dimension. Three observers located the landmarks three times with one week interval using the Cranioviewer software. For the statistical calculation SPSS 20.0 (IBM Corporation, Chicago, USA) software was used. Intraclass correlation coefficient was used to determine the intra- and inter-observer reliability. As the determination of the real, in vivo position of the landmarks is impossible, the identification of the points were analyzed by using standard deviation.

- **Project II.: Determination of facial midplane using CBCT database**

In this study, 60 CBCT scans were selected retrospectively from the database of the Oral Surgery Department of Semmelweis University into two groups:
group I: 30 patients (19 females, 11 males, aged 18 to 30 years) with facial symmetry;
group II: 30 patients (18 females, 12 males, aged 20 to 28 years) with moderate to severe facial asymmetry.
For both groups the inclusion criteria of the enrollment were European ethnicity and age between 18 and 40. For Group II patient selection, we considered the cause of the facial deformity and exclusively selected patients with congenital anomalies.

Twenty-two hard tissue cephalometric landmarks (eight unpaired, seven paired) were marked by two observers, twice, with a 1-week interval, using CranioViewer software. Fifty regression

planes were generated by combination of three unpaired landmarks, while another 35 planes were created by means of three paired cephalometric points. For the paired landmarks, the midpoints between the paired points were used to calculate the regression plane.
The Na-ANS-PNS regression plane was used as reference plane, and the angle between the generated regression plane and this reference plane was calculated for groups I and II. We described the difference from the reference plane using the mean and standard deviation of the included angle and we further contrasted this angle between the two groups using the unpaired t-test.

- **Project III.: Creating of orbital module on CBCT database.**

In this research two groups were created:
I. Study group:
20 people (8 male, 12 female; average age 43.85 years, 14–76) Enucleation and orbital implantation had been performed on one side.
II. Control group:
20 people (7 male, 13 female; average age 37,4 years, 18–57). CBCT scans were made because of dental problems.

i-CAT Classic (Xoran Technologies, Ann Arber, Michigan, USA) CBCT volumetomograms with large field of view were made to each member of both groups. We imported the images to the CranioViewer software and by the measurements we used the orbital function, which was developed by Zsolt Markella and Tamás Vízkelety. We can outline the bony border and enclose the foramens and fissures and the program fills every slice with red color, and measures the area of the slice in mm^2.By the statistical calculation the bilateral measurements were compared to paired t-probe using SPSS 20 software (IBM Corporation, Chicago, IL, USA).

After the establishment of the orbit module, we utilized it in the practice in the case of a 37-year-old man with traumatic head injuries. Because of an accident, the patient had skull fractures and he underwent enucleation of the left eye and bone fixation with titanium plates in a rural hospital. Complications after the operation included an open bite, malocclusion, and orbital asymmetry therefore he visited the Maxillofacial and Oral Surgery Department. Reoperation was required. By the CBCT based preoperative planning, we measured the orbital volume on the intact side and the mirroring, and 3-dimensional printing enabled accurate planning of the titan plate.

- **Project IV.: Analysis of lower face on CBCT database**

The study included CBCT images from 30 patients (11 male and 19 female patients; age range, 18–30 years, mean aged : 24±3) who underwent CBCT in the Department of Oro-Maxillofacial Surgery and Stomatology, Semmelweis University. By the cephalometric measurement we used Di Paolo's analysis. In the 2D examination, we projected the detected point to the midsagittal plane as in the 3D part, we considered the actual positions of the landmarks to avoid any errors resulting from possible asymmetry.

In the statistical part, we determined firstly the mean distance and SD of the projected linear measurements and we compared it to the previous results published by Di Paolo. In the 3D analysis, the asymmetry - based on the bilateral measurement - was examined with paired t-test and we also added the posterior width of the mandible and maxillae to the original Quadrilateral analysis. We calculated the mean and standard deviation by all measurements and the correlation coefficient between each anatomical structure to create regression models for describing the lower face position.

Results

- **Project I.: Determination of landmark identification using CBCT database**

The reliability of the raters was determined by ICC for all landmarks for X, Y and Z coordinates. The intraclass correlation coefficient was greater than 0.86 for all axes and for each landmark in inter-examiner measurements and it was greater than 0.9 in intra-observer measurements.

For the landmark identification we calculated the standard deviation by each observer.

The intra-observer SD values were in most cases low (≤1 mm), only the following cases were between 1.03 mm and 2.00 mm: Orbitale Inferior (ob3:X-axis), bilateral Inferior Gonion (ob1,2,3:Y-axis), Orbitale Inferior (ob3:Y-axis), Zygomatic Arch (ob3:Y-axis), bilateral Posterior Gonion (ob1,2,3:Z-axis), J-point (ob2,3:Z-axis), Apertura Piriformis (ob3:Z-axis).The mean absolute differences were lower than 1 mm except for Orbitale Inferior (ob3:X-axis), bilateral Inferior Gonion (ob2,3:Y-axis), Apertura Piriformis (ob3:Z-axes), bilateral Posterior Gonion (ob 1,2, 3:Z-axis) .

The inter-examiner standard deviation corresponded each landmark for X, Y and Z coordinates was evaluated from the average coordinates of the three investigators. (Table 2.) For the most

part the deviation was lower than 1 mm only the following structures was it higher than 1 mm deviations:
On the X axis: Orbitale inferior right (3.44 mm) and left (3.56 mm), J-point right (1.55 mm) and left (1.77 mm).
On the Y axis: Orbitale inferior right (2.44 mm) and left (2.23 mm), J-point right (1.8 mm) and left (1.78 mm), Inferior Gonion right (2.9 mm) and left (3.38 mm), Sutura Zygomaticofrontale right (1.32 mm) and left (1.28 mm).
On the Z axis: Orbitale inferior right (2.27 mm) and left (2.25 mm), J-point right (3.37 mm) and left (3.34 mm), Sutura Frontomaxillare right (1,07 mm) bilateral Apertura Piriformis (2.59 mm; 2.56 mm) and Posterior Gonion (2.34 mm; 1.99 mm).
We divided the unreliable landmarks into different groups in accordance with the high (>2 mm) intra-or inter-observer standard deviation.

- **Project II.: Determination of facial midplane using CBCT database**

We determined the mean and standard deviation of the angle between reference plane and the generated regression planes. In the symmetric group, based on unpaired points, 86% of angles were < 5 degrees, compared to the paired points, where 74,29% were < 5 degree. In the group with facial asymmetry, 84% of the regression planes generated from unpaired landmarks and 60% of the planes based on paired points showed lower than 5 degree deviation from the reference plane degree. Furthermore, by the planes created from paired landmarks 14,29% of angles were between 5 and 10 degrees, and 11,43% of angles were > 10 degrees in the symmetric group and 8,57% of angles were between 5 and 10 degrees, and 31,43% of angles were > 10 degrees in the asymmetric group.
We compared the differences between the symmetric and asymmetric groups with unpaired *t*-tests and we selected those planes, which had minimal deviation (<2 degree) from the reference plane and did not show significant difference between the two groups. The selected planes - ANS-G-Ba, ANS-G-S, ANS-S-De, PNS-G-Ba, PNS-S-Ba, PNS-ANS-G and PNS-N-Ba – are equivalent with the ideal facial midplane.

- **Project III.: Creating the orbital module on CBCT database.**

In 5 cases, there was a significantly lower volume for the first 4 or all 5 of the measured slices in the orbit containing the implant than in the patient's own healthy orbit and in 12 cases, the measured value was significantly lower in the operated orbit in 1,2 or 3 slices. In the control group, there were no significant differences between the two sides.

By the reconstructive operation the position of the maxillae and mandible were corrected, the fractures were fixed with titan plate and we reconstructed the orbital borders. During the orthodontic treatment, we corrugated the occlusion and the open bite.

- **Project IV.: Analysis of lower face on CBCT database**

In the 2D examination the projected length of the maxillae (p=0.02), the length of mandible, (p=0.016), ALFH (p=0.00), PLFH (p=0.00) and LFH (p=0.00) showed significant difference from the result published in 1984.
In the 3D examination, the values were higher on the right side, and the difference was 0.02 mm for the maxillary length, 0.03 mm for the mandibular length, and 0.22 mm for the PLFH, but in the paired t-test, no significant differences were observed in the bilateral values (maxilla: p = 0.888, mandible: p = 0.873,; PLFH: p = 0.058,).
We determined the correlation among the transversal, vertical, and anterior-posterior linear values, considering that no significant differences were noted in the values between the two sides in the paired t-test. The r-values were above 0.3 in 13 of 15 assessments which means moderate to strong correlation. By the width of maxillae and mandible the correlation coefficients were between -0.2 and +0.2 or the p was higher than 0.05. We created a reference table with sliding norms based on linear, quadratic and multifactorial regression models

Conclusions

The aim of my dissertation was the three dimensional adaptation of conventional cephalometric measurements to CBCT database. The relevant theses were summarized in four research projects.

In the first part of my research we determined the three dimensional definition of conventional cephalometric points, and also the identification error of each landmark using CBCT database. The most reliable landmarks were close to the midline, in these cases the SD was lower than 0.2 mm. By the further points, the SD values were lower than 1 mm, except for the followings: Obitale inferior, J-point, Sutura frontomaxillare, Apertura pisiformis, Posterior gonion, Inferior gonion., Sutura Zygomatcofrontale.
As the conclusion of the intra and inter-observer examination of latest landmarks, we concluded that in the case of J-point, Sutura Zygomaticfrontale, Sutura Frontomaxillaris , Orbitale inferior the detection is improvable with a more accurate definition and more practical routine. In

oppose by the y coordinate of Arcus Zygomaticus the anatomy and the imaging quality can be the problem. By those landmarks where the intra- and inter-observer SD were also high, for example Orbitale inferior (x, y direction) , Inferior Gonion (y direction), J-pont, Apertura Piriformis, Posterior Gonion (z direction), the landmark identification is not improvable , therefore these points are not recommended for the CBCT based cephalometry.

In the second part of the research, the aim was to determine the ideal cephalometric facial midplane by using different regression planes in groups with facial symmetry and facial asymmetry. The conclusion was that the ANS-G-Ba, ANS-G-S, ANS-S-De, PNS-G-Ba, PNS-S-Ba, PNS-ANS-G and PNS-N-Ba planes are the most appropriate for the preoperative planning.

The goal of the third project was to create an orbital module, which was utilized both during ophthalmological clinical research and surgery planning in practice. During the clinical trial, we concluded that the orbital volume significantly decreased after enucleation at the peripheral parts. Knowing this may help the process of implant planning before implantation in order to achieve as few complications as possible. In the second part, the orbital module of CranioViewer software was applied in practice. We planned and printed in three-dimension the preoperative model, which was necessary for the reconstruction of the orbit.

We concluded that the CBCT based preoperative planning in oppose to the conventional planning provides a more accurate method with less complication in the postoperative phase.

In the last part of our research, we created a cephalometric analysis that can be used on the Cone Beam CT data set describing the lower face, based on the Di Paolo analysis. As a result of our research, we found a moderate-strong correlation between the anatomical structures forming the lower face, and thereby, with the aid of regression modelling, we created a sliding norm that can be used on the European facial type and that may be a great assistance during individual surgery planning.

Following further studies and validation on the Hungarian population with higher number of elements, individual software-aided cephalometric surgical planning may be implemented by using computer functions created by us and cephalometric analyses performable on cone-beam CT data set.

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