

# 3D Computed Tomography vs. 2D radiography: comparison of 3D direct anthropometry with 2D norm calculations and analysis of differences in soft tissue measurements

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**Abstract. – OBJECTIVE:** The aim of this study was twofold: (1) to compare soft tissue measurements of the same distances obtained from 3D computed tomography reconstructions with 2D cephalometric radiograms, (2) to compare data from 3D measurements from direct anthropometry and 2D “norms” for the facial measurements.

**PATIENTS AND METHODS:** A total of 40 Caucasian patients that had their CBCT scans for various dental and dentoskeletal reasons were enrolled in this study. All the patients had large field of view (from the forehead to the chin). The data were stored in DICOM format and imported into a software for 3D reconstructions. After 3D facial soft tissue model generation, the distances between 18 soft tissue points were measured. The 3D soft tissue analysis was performed, and the facial indices were calculated. The mean 3D values were compared with 2D measurements performed on lateral cephalograms and Arnett's and Farkas' norms. The measurements were statistically compared using Student's *t*-test.

**RESULTS:** Assessments from 2D and 3D measurements showed no statistical difference except for the distance Pogonion (for both male and female) and Labiale superius prominence (females) to the True Vertical Line in 2D /Plane in case of 3D measurements. There was a sig-

nificant difference between all 3D measurements and Arnett's and anthropometric Farkas' “norms”. The mean difference between Farkas' “norms” and 3D measurements was within 3 mm for 70% of measurements.

**CONCLUSIONS:** According to the results, 3D soft tissue analysis allows for complete diagnostic determination. The 3D “norms” are to be verified on a greater sample.

*Key Words:*

Cephalometric measurements, Computed tomography, 3D Cephalometry, 2D Cephalometry, Soft tissue analysis, 3D Evaluation.

## Abbreviations

Gla: Glabella; N: Nasion; Se: Sellion; Pn: Pronasale; c: Columella; Sn: Subnasale; Sus: Subspinale; Ls: Labiale superius; Sto: Stomion; Li: Labiale inferius; sl: Labial sulcus; Pog: Pogonion; Me: Menton; Gn: Gnathion; ZyR/ZyL: Zygion right/left; GoR/GoL: Gonion right/left; alR/alL: Alare right/left chR/chL: Chelion right/left; Sag: Sagittal; Ax: Axial; Cor: Coronal; SFP: Superior Facial Plane; PSn: Subnasal Plane; PLs: Labial Superius Plane; Pli: Labial Inferior Plane; PM: Mental plane; TVP: True Vertical Plane.

## Introduction

Throughout the history, humans have been aware of importance of beauty and facial appearance. In our modern times, with the advances in technology and the mass media, the request for beauty enhancement has increased enormously. Currently, influenced by the society, many patients visit the dental offices not just for improvements of the stomatognathic apparatus function, but also seek to enhance their looks for having more attractive faces. It is known that social acceptance, psychological well-being, and self-image are greatly influenced by physical appearance<sup>1</sup>. To obtain successful aesthetic results in orthodontic treatment, orthognathic surgery and prosthodontics, the establishment of a correct diagnosis is imperative. This is done by gathering information from the plaster casts, cephalometric measurements, and facial analysis. Although the perception of attractiveness is subjective, there is a remarkable tendency to quantify beauty with symmetry and balance, which are the key factors accepted worldwide<sup>2</sup>. To evaluate esthetics, various soft tissues analyses have been described. Researchers have been attempting to represent a human face with a complex net of lines and angles and trying to interpret them, thereby giving an order to the infinity of facial forms. In orthodontics Burstone<sup>3</sup>, Downs<sup>4</sup>, Subtelny<sup>5</sup>, Holdaway<sup>6</sup> have incorporated soft tissue parameters into cephalometric analysis. Other authors, such as Stoner<sup>7</sup>, Arnett and Bergman have presented soft tissue analysis based on photogrammetry<sup>8,9</sup>. The main problem of 2D photogrammetry is that only lateral or frontal views are considered while presenting a 3D object, which causes an inaccuracy in measurements and calculations. Moreover, there are difficulties in the standardization of photographs which might be quite misleading in the interpretation of results. However, on the contrary, anthropometry is a direct measurement technique, which provides accurate data of facial morphology. As an additional advantage, the data that is obtained thorough anthropometry can be compared with a database of facial "norms" introduced by L.G. Farkas<sup>10</sup>.

Currently, anthropometry is being used to define relationships and general proportions between facial structures. As an example, facial index provides information about the ratio of facial height [Nasion (N) to Gnathion (Gn) relative to facial width (Zygonion (Zy) to Zy]. Major limitations of direct anthropometry include the requirement of a well experienced examiner and that it is

a very time-consuming technique. Furthermore, no permanent records of the facial analysis are maintained, so any following correction requires a repetition of the examination<sup>11</sup>.

Current advances in computer technology led to various 3D computerized anthropometry technique options, such as: optical non-contact instruments: laser surface scanning<sup>12</sup>, stereo photogrammetry<sup>13,14</sup> and contact instruments such as: electromagnetic and electromechanical digitizers and ultrasound probes<sup>15</sup>. All these techniques are non-invasive and accurate for facial morphology studies, in the limits of clinical purposes<sup>11</sup>. These mentioned techniques have various advantages and disadvantages among themselves<sup>11</sup>. On the other hand, with the progress of CT (Computed tomography) and CBCT (Cone beam Computed tomography) technologies and the introduction of software programs to analyze 3D data, it became possible to reconstruct the 3D facial models. CBCT, due to the lower dose of radiation, reduces acquisition time and costs versus traditional widespread CT and is used in diagnostic imaging and treatment planning in orthodontics, implant, and oral surgery as well as in maxillofacial surgery. However, there are still critical shortcomings like: artifacts from the cone radiation beam and dissipation of radiation<sup>16</sup>.

The next step, developed by Jacobson and Gebre<sup>17</sup>, consists of the 3D cephalometric analysis. In 3D reconstruction cephalometry, the images can be examined from any perspective. Anatomic points might be correctly found by viewing them in an axial, coronal, or sagittal window. Once every landmark is defined in space with x, y, z coordinates, it is possible to measure distances between points, lines, angles of planes and volumes. In Jacobson's analysis four primary reference planes are used: Anterior facial plane, Lower anterior facial plane, Superior facial plane, and Midsagittal plane which allows for meticulous evaluation of the cranial skeletal and soft tissue structures and their relationship<sup>17</sup>.

To the authors' knowledge, there are no studies dealing with 3D cephalometry analysis and Arnett's Soft Tissue Analysis<sup>8,9</sup>. The authors of this paper propose a novel 3D soft tissue analysis tool that consists of the combination of the Arnett's aesthetic analysis, traditionally adopted in orthodontics and orthognathic surgery.

The aims of the study were:

1. Compare the data obtained from 3D measurements with data collected from 2D cephalometric radiogram measurements.

2. Compare the data obtained from 3D measurements with Farkas<sup>10</sup> and Arnett<sup>8,9</sup> “norms” for the facial measurements.

## Patients and Methods

Out of 240 patients, 40 patients that fulfilled the inclusion criteria were included in this study. The study population consisted of patients that had 3D CBCT examinations for different dental reasons at the Dental Clinic of the Biomedical, Surgical and Dental Sciences Department, IRCCS Galeazzi Orthopedic Institute of the University of Milan, Italy from January till December of 2011. In CBCT exam, the head of all the patients was oriented in Neutral Head Posture (NHP). A large field of view, from the forehead to the chin was obtained. The data were stored in Digital Imaging and Communications in Medicine (DICOM) format and automatically imported into Ortho Pro 2.1 (Materialise, Leuven, Belgium) using a personal computer.

The Simplant Ortho Pro 2.1 software allowed to process 2D CT slices that were obtained from patients and 3D rendering was performed. The images were cleaned of artifacts and segmentation, and with appropriate thresholding levels for hard and soft tissues, a virtual model was created for each patient. The software program also allowed obtaining conventional cephalometric radiographs in norma lateralis and frontalis from CT data.

### Inclusion Criteria

All the CBCT exams were executed without facial support (forehead or chin) and all the pa-

tients were Caucasian adults with either skeletal class I, II or III and with no history of previous orthodontic or orthognathic surgery.

### Exclusion Criteria

Patients with uncomplete data, 3D soft tissues rendering impossible for any reason, patients affected by congenital craniofacial malformations.

### Soft Tissue Analysis

The landmarks, distances, planes, and angles to be measured for 3D soft tissue analysis were established by Simplant Ortho Pro software and a new cephalometry was created.

The external 3D reference plane (sagittal, coronal and axial) to internal reference plane was preferred. In the analysis some planes were constructed like: SFP Superior Facial Plane, PSn (Subnasal Plane), PLs (Labial Superius Plane), PLi (Labial Inferius Plane), PM (Mental plane), TVP (True Vertical Plane) all described in the Table I.

The analysis was divided in two main sections as A and B and included 4 parts in total:

#### Facial soft tissues analysis

Based on Farkas<sup>18</sup> 18 soft tissue landmarks were selected (Table II). Soft tissue Gnathion, Menton, Zygion were plotted by reference to Swennen's definition<sup>19</sup>.

Afterwards, according to Jacobson's 3D cephalometry<sup>17</sup> reference planes were constructed: Superior Facial Plane, Inferior Faccial Plane, True Vertical Plane and minor planes: Subnasal, Labial superior and Labial inferior Plane (Table III). The

**Table I.** Reference and construction planes used in the study.

Sign	Reference plane	Definition
Sag	Sagittal external	Plane through points: SAG 1, SAG 2, SAG 3 inserted manually on sagittal view, first image “0” obtained from TC data
Ax	Axial external	Plane through points: AX 1, AX 2, AX 3 inserted manually on axial view, first image “0” obtained from TC data
Cor	Coronal external	Plane through points: COR 1, COR 2, COR 3 inserted manually on coronal view, first image “0” obtained from TC data
Plane of construction		
SFP	Superior Facial Plane	Through point N and perpendicular to Coronal (Y) and Sagittal (X) plane
PSn	Subnasal Plane	Through point Sn and parallel to Axial (Z) plane
PLs	Labial Superius Plane	Through point Ls and parallel to Axial (Z) plane
PLi	Labial Inferius Plane	Through point Li and parallel to Axial (Z) plane
PM	Mental plane	Through point Menton and parallel to Subnasal Plane (PSn)
TVP	True Vertical Plane	Through point Sn and parallell to Coronal plane (Y)

**Table II.** Soft tissue landmarks used in the analysis.

1	Gla	Glabella	The most prominent anterior point in the mid-sagittal plane of the forehead
2	N	Soft tissue Nasion	The midpoint on the nasal root at the level of the nasofrontal suture line
3	Se	Sellion	The point of greatest concavity in the midline between the forehead and the nose
4	Pn	Pronasale	The most prominent or anterior point of the nasal tip
5	c	Columella	The midpoint of the columella crest at the level of the nostril top points
6	Sn	Subnasale	The point at which the columella merges with the upper lip in the midsagittal plane
7	Sus	Subspinale	The most posterior midpoint of the philtrum
8	Ls	Labiale superius	A point indicating the mucocutaneous border of the upper lip; the most anterior point of the upper lip
9	Sto	Stomion	The midpoint of the horizontal labial fissure. When the lips are not closed in the rest position is a constructed point defined as the midpoint of the interlabial gap
10	Li	Labiale inferius	The median point on the lower margin of the lower membranous lip
11	sl	Labial sulcus	The point of the greatest concavity in the midline of the lower lip between Li and soft tissue Pogonion
12	Pog	Soft tissue Pogonion	The most prominent or anterior point on the chin in the midsagittal plane
13	Me	Soft tissue Menton	Lowest point of the contour of the soft tissue chin. Found by dropping a perpendicular line from horizontal plane through skeletal menton
14	Gn	Soft tissue Gnathion	The most inferior midpoint on the soft tissue contour of the chin located at the level of the 3D cephalometric hard tissue Menton landmark. In 3D cephalometry, soft tissue Gnathion is a well-defined soft tissue landmark and is therefore not the same as the anthropometric gnathion landmark according to Farkas, which is identical to the bony Gnathion
15	ZyR ZyL	Soft tissue Zygion right/left	The most lateral point on the soft tissue contour of each zygomatic arch, located at the level of the 3D hard tissue cephalometric Zygion landmark. Is not the same as the anthropometric zygion landmark according to Farkas, which is identical to the bony Zygion
16	GoR GoL	Soft tissue Gonion right/left	The most lateral point on the soft tissue contour of each mandibular angle, located at the same level as the 3D hard tissue cephalometric Gonion landmark
17	alL alR	Alare right/left	The most lateral point on each alar contour
18	chR chL	Chelion right Chelion left	The point located at each labial commissure

**Table III.** Location of the brain lesions at conventional MRI performed after 3 months of stroke.

Nr analysis	Measurement	Male norm	Female norm
1	Angle Gla-Sn-Pog	169.4 (3.2)B	169.3 (3.4)B
2	Distance Sn – Ls to TVP	24.4 (2.5)A	21.0 (1.9)A
	Distance Ls-Li to TVP	2.4 (1.1)A	3.3 (1.3)A
	Lab.sup promin. Ls to TVP	3.3 (1.7)A	3.7 (1.2)A
	Lab.inf promin. Li to TVP	1.0 (2.2)A	1.9 (1.4)A
	Pogonion Pog promin. to TVP	-3.5 (1.8)A	-2.6 (1.9)A
3	Nasal promin. Pn to TVP	17.4 (1.7)A	16.0 (1.4)A
	Nasolabial angle c-Sn-Ls	106.4 (7.7)A	103.5 (6.8)A
	Distance N-Me	137.7 (6.5)A	124.6 (4.7)A
4	Distance Sn-Me	81.1 (4.7)A	71.1 (3.5)A
	ZyL-ZyR	139.1 (5.3)F	130. (4.6)F
	GoL-GR	105.6 (6.7)F	94.5 (5.0)F
	alL-alR	34.9 (2.1)F	31.4 (2.0)F
	chL-chR	54.5 (3.0)F	50.2 (3.5)F
	N-Gn	124.7 (5.7)F	111.4 (4.8)F
	Sn-Gn	72.6 (4.5)F	64.3 (4.0)F
	Sn-Sto	22.3 (2.1)F	20.1 (2.0)F
	Sto-sl	19.7 (2.1)F	17.8 (4.7)F
	Sto-Gn	50.7 (4.0)F	43.4 (3.1)F

B-Normal values BurstoneCJ,3 A-Normal values Arnett GW,20 F-Normal values Farkas LG.22 Data are presented as mean (SD). TVP-True Vertical Plane, other abbreviations explained in Table II.

following measurements, derived from Arnett's Soft Tissue Cephalometric Analysis (STCA)<sup>20</sup> were performed for the analysis:

### 1<sup>st</sup> Analysis

It describes total face harmony relationship between the forehead, upper jaw and lower jaw (facial angle (Gla-Sn-Pog))

### 2<sup>nd</sup> Analysis

- Gives the details of labial lengths: upper lip lengths, inter-labial gap;
- Represents TVL (True Vertical Line) projections – horizontal distance for each individual landmark, measured perpendicular to the TVL;
- Details naso-labial angle.

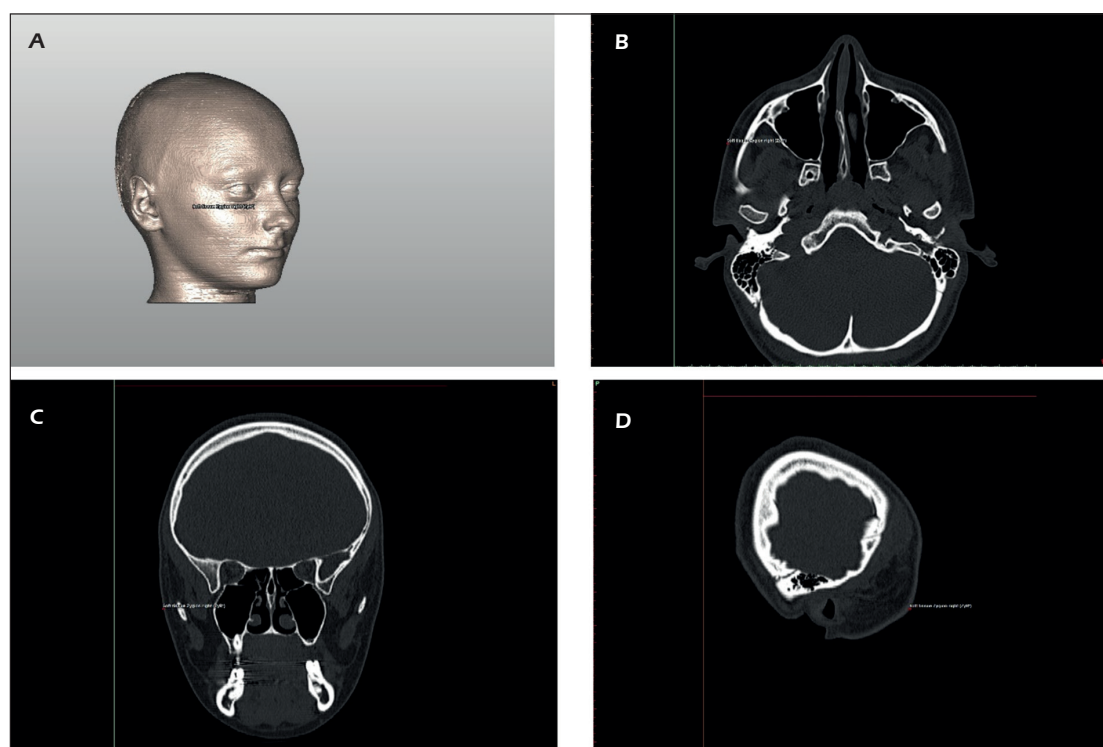
### 3<sup>rd</sup> Analysis

3<sup>rd</sup> analysis shows vertical measurements of lower facial third and total facial height to perform the analysis every landmark is viewed in axial, coronal and sagittal window and defined in space with 3 coordinates (x,y,z). Then the distances between points, lines and planes were evaluated. The same measurements were performed by the same operator (J.N.) on lateral cephalograms obtained through the software. All measurements

were compared with Arnett's "norms" (Table III). Patients were classified into skeletal malocclusion groups, according to the value of the angle ANB. In Steiner's<sup>21</sup> analysis the angle ANB (between the hard tissue points: point A, Nasion, Point B) indicates whether the skeletal relationship between the maxilla and mandible is a skeletal class I (normal relationship:  $2 \pm 2$  degrees), skeletal class II ( $ANB \geq 4$  degrees), or skeletal class III ( $ANB \leq 0$  degrees). The classification was done only for two parameters: the facial angle and the distance: Pogonion prominence to the True Vertical Plane.

### 4<sup>th</sup> Analysis

4<sup>th</sup> analysis was designed to compare digital anthropometry with the "norms" of direct anthropometry executed by Farkas<sup>22</sup>. Due to volume rendering process a 3D virtual head model was obtained. According to Farkas<sup>15</sup> specific cutaneous points were selected (Table II) and the measurements were performed between points and lines (Table III). The soft tissue landmarks were defined after viewing in axial, coronal end sagittal window and displayed on the 3D model (In Figure 1 A to D, as an example to soft tissue landmark Zygion in a selected patient can be seen in different representative views).



**Figure 1.** Soft tissue landmark Zygion representation; (A), Volume rendering 3D model; (B), Axial; (C), Frontal; (D), Sagittal view.



**Table IV.** Facial indices.

Index	Definition	Measurement	Norm male	Norm female
Facial	Face Height/Zygomatic width	N-Gn/ZyL-ZyR	88.5 (5.1)	86.2 (4.6)
Mandible- face width	Gonial width/Zygomatic width	GoR -GoL/ZyL-ZyR	70.8 (3.8)	70.1 (4.2)
Mandibular width-face height	Gonial width/Face height	GoR-GoL/N-Gn	80.3 (6.8)	81.7 (6.0)
Lower face/Face height	Lower face height/Face height	Sn-Gn/N-Gn	59.2 (2.7)	58.6 (2.9)
Mandible-Face height	Mandible height/Face height	Sto-Gn/N-Gn	51.8 (6.2)	49.8 (4.8)
Mandible-Lower face height	Mandible height/Lower face height	Sto-Gn/Sn-Gn	41.2 (2.3)	40.4 (2.1)

Normal values from Farkas LG.23.

Finally, some clinically relevant Farkas indices<sup>23</sup> were calculated (Table IV).

### ***Esthetic Analysis-Clinical Presentation***

#### ***Analysis 1***

The angle of convexity (Gla-Sn-Pog) represents a general outlook of the facial harmony. It gives a relationship between the forehead, midface and the lower part of the face. More obtuse or sharper angles may indicate maxillary and mandibular basal bone anteroposterior discrepancies. However, more detailed analysis is necessary to estimate which part of the face is engaged in the facial imbalance occurrence (The angle of convexity for different skeletal classes from selected patients can be seen in Figure 2 A-B).

#### ***Analysis 2***

The second analysis allowed for obtaining more details about the lower part of the face:

- Anteroposterior position of the nose, superior and inferior lip, chin (Soft tissue points regarding to the True Vertical Plane)

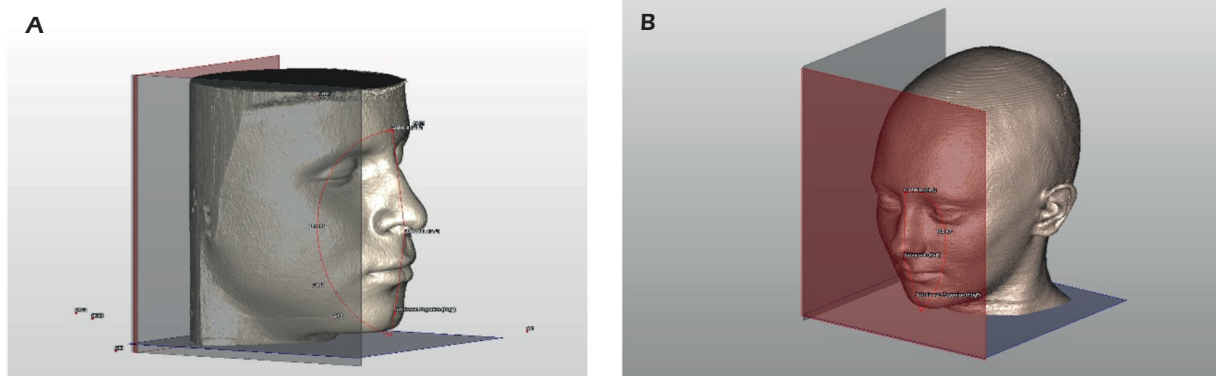
- Soft tissues length (upper lip lengths, interlabial gap)
- Naso-labial angle (the anatomic aspects that influence on its value: nasal tip, upper lip length, incisor inclination, soft tissues depth)
- Underlying hard tissue appraisal

#### ***Analysis 3***

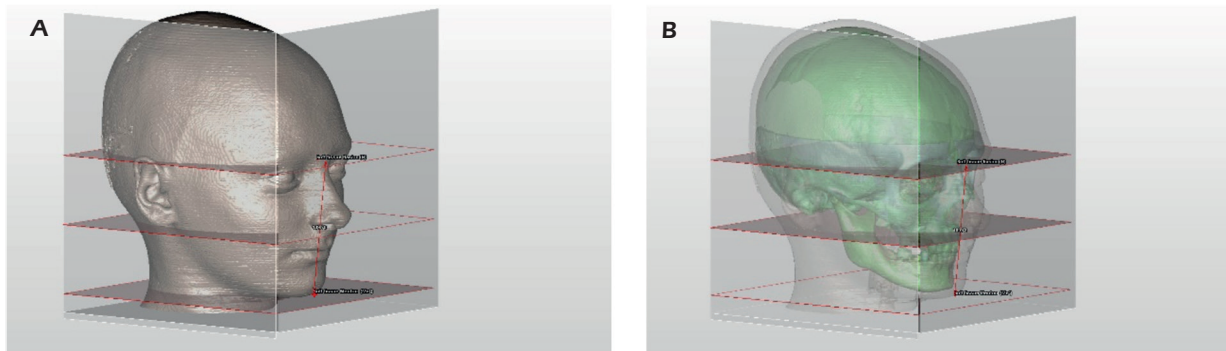
The third analysis in a simple way provided total and partial vertical dimensions (Figure 3 A-B shows analysis 3: A) vertical dimensions, B) soft tissues transparency beneath visible skeletal and dental structures).

#### ***Analysis 4 Vertical***

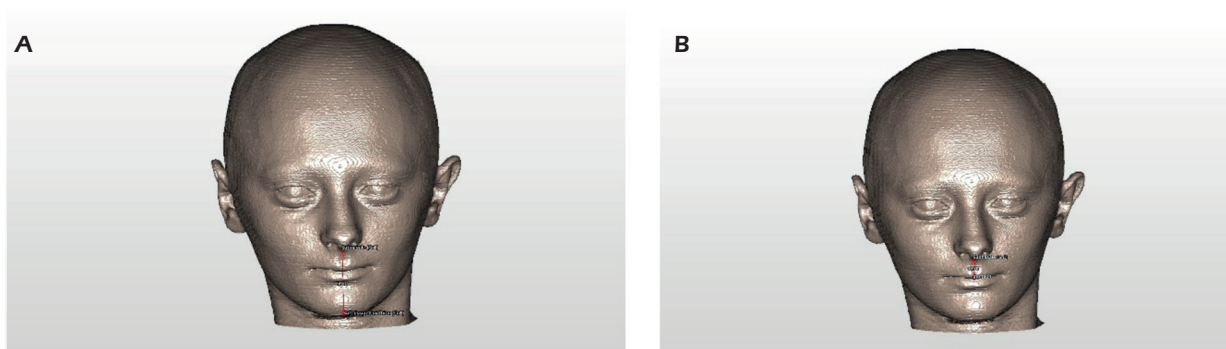
The fourth analysis is complementary to the third one. The total face height was divided in segments in order to verify the vertical dimensions of the smaller parts of the face. This approach might be useful in case of the vertical disproportions verified in analysis 3 (Figure 4 A-B shows fourth analysis with vertical measurements).



**Figure 2.** The angle of convexity for different skeletal classes from selected patients can be seen in (A) I skeletal class; (B) II skeletal class.



**Figure 3.** Third analysis; (A), Vertical dimensions; (B), Soft tissues transparency beneath visible skeletal and dental structures.



**Figure 4.** A-B, Fourth analysis with vertical measurements. Note that the analysis n. 4 might elucidate the reasons of vertical disharmony.

#### *Analysis 4 Horizontal*

The fourth horizontal analysis informs about the facial width dimensions. (Figure 5 shows fourth analysis with horizontal measurements).

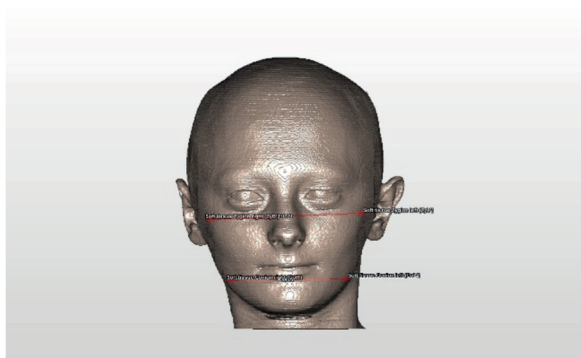
#### **Facial Indices**

Facial indices allow for facial proportions evaluation. The establishment of these ratios might be of extreme importance before deciding the treat-

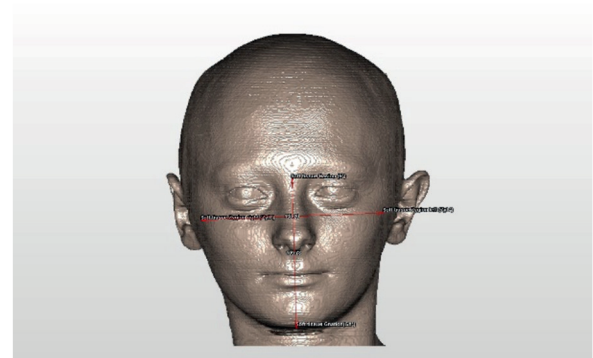
ment plan, that may cause vertical or transversal dimension changes. (Figure 6 shows facial index measurement).

#### **Statistical Analysis**

Mean, standard deviation, 95<sup>th</sup> percentile, mean difference between 3D measured values and “norms” were computed for each patient and for each analysis. The sample was divided be-



**Figure 5.** Fourth analysis with horizontal measurements.



**Figure 6.** Facial index.

tween males and females and according to skeletal classes for some parameters. Obtained data were compared by paired *t*-test Student with the 2D data and Caucasian norms. Tables V, VI, VII show the overall of the recorded data. Moreover, calculated facial indices were compared by Student's *t*-test with facial indices norms for males and females. Table VIII presents indices' records. A *p*-value <0.05 was considered as statistically significant.

## Results

From 240, only 40 patients fulfilled our inclusion criteria (18 men and 22 women) between 22 and 52 years old with different dento-skeletal discrepancies. The sample group composed of 17 patients with the skeletal class I, 13 patients with the skeletal class II, and 10 patients of skeletal class III. Ethnicity and racial background based on verbal declaration of the subjects evaluated.

### 1<sup>st</sup> Analysis: Facial Angle (Gla-Sn-Pog)

Soft tissues profile analysis showed more convexity than that of the Burstone's norm<sup>3</sup>. The sharper angle was registered for the II class. For the III class the angle was more obtuse. There was no statistically significant difference between 3D and 2D measurements. The results of the first analysis are summarized in Table V.

### 2<sup>nd</sup> Analysis

#### Labial lengths:

- upper lip lengths (Sn-Ls): the measured distance for both males and females were shorter when compared with the Arnett's norms<sup>20</sup>. The difference was statistically significant. There was no statistically significant difference between 3D and 2D measurements
- interlabial gap (Ls-Li): the measured distance was longer comparing with the Arnett's norms. The difference was statistically significant. There was no statistically significant difference between 3D and 2D measurements

#### TVP (True Vertical Plane) projections:

- Pogonion prominence: the measured distance was similar to the norm for men, for women the difference was greater. Such difference was statistically significant for both gender and for 3D and 2D measurements. For the skeletal class III the mean value was not statistically significant as compared with the norm.

- Labial superior prominence Ls to TVP, Labial inferior prominence Li to TVP:

The point Ls and Li was on the average positioned anteriorly to the TVP. Only the mean Labial inferior prominence for women was negative (located posteriorly to the TVP). A statistically significant difference between the measured values and norms was found. There was no statistically significant difference between 3D and 2D measurements except for the Labial superior prominence for females.

- Nasal prominence: The measured distance was shorter in confront to the norm. There was no statistically significant difference between 3D and 2D measurements.
- Naso-labial angle (c-Sn-Ls) 3D measurements differed significantly comparing with the norms. There was a statistically significant difference between 3D measurements and 2D for men but not for women.

The results of the second analysis are summarized in Table V.

### 3<sup>rd</sup> Analysis

Total facial height N-Me: the mean value for women was shorter compared to norms. The difference was statistically significant.

Lower facial third Sn-Me: the mean values were lower for both genders comparing with the norms. The difference was statistically significant. There was no statistically significant difference between 3D and 2D measurements.

"Total facial height" Se-Me: the mean values were approximately 2 mm lowered as compared to the total facial height measured from Nasion to Menton.

The results of the third analysis are summarized in Table VI.

### 4<sup>th</sup> Analysis

Horizontal measurements: 3D measurements comparing with "norms" of direct anthropometry<sup>22</sup> were all statistically significant. However, for Zy-Zy and al-al the difference was about 2 mm or less. There was a difference of approximately 7 mm for females comparing cr-cl measurement with the norms. Even greater difference was registered for both females and males when comparing intergonial width GoR-GoL with the same anthropometric norm.

Vertical measurements: 3D measurements comparing with "norms" of direct anthropometry were all statistically significant. The evaluation results of mean difference between 3D



Table V. Analysis 1 and 2 results.

	Angle of convexity	Pogonion prominence	Labiale sup-labiale INF	Labial prominence sup	Subnasale-Labiale sup	Angle nasolabial	Nasal prominence	Labial prominence inf,
Mean 3D (mm)	163.11 (6.7)	-4.83 (6.59)	12.82 (3.49)	0.98 (2.83)	15.29 (2.5)	116.68 (4.11)	13.56 (3.85)	-0.27 (4.33)
Mean 2D (mm)	163.89 (7.11)	-4.11 (5.91)	12.72 (3.91)	1.51 (2.37)	15.8 (2.17)	111.72 (5.91)	13.78 (3.8)	0.18
2D vs. 3D ( <i>p</i> -value)	0.27	0.00	0.69	0.01 *	0.10	0.04	0.32	0.05
3D vs. Norm ( <i>p</i> -value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean F mm	162.5 (5.74)	-5.29 (7.28)	13.05 (2.45)	1.15 (2.93)	15.11 (2.73)	115.87 (7.28)	12.43 (3.82)	-0.62 (4.38)
2D vs. 3D F ( <i>p</i> -value)	0.10	0.02 *	0.61	0.05	0.41	0.27	0.08	0.09
3D vs. Norm F ( <i>p</i> -value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3D - Norm F (mm)	-6.80 (5.74)	-2.69 (7.28)	9.75 (2.45)	-2.55 (2.93)	-5.89 (2.73)	12.37 (7.28)	-2.93 (2.81)	-2.35 (4.63)
95%3D vs. Norm min	-18.28	-17.24	4.85	-8.41	-11.35	-26.86	-8.54	-11.61
95%3D vs. Norm max	4.69	11.86	14.65	3.31	-0.42	51.60	2.68	6.91
Mean M (mm)	163.84 (7.82)	-4.26 (5.79)	12.54 (4.51)	0.77 (2.76)	15.51 (2.23)	117.68 (5.79)	14.94 (3.51)	0.15 (4.35)
2d vs.3d M ( <i>p</i> -value)	0.97	0.02 *	0.9	0.09	0.09	0.01 *	0.13	0.37
3D vs. Norm M ( <i>p</i> -value)	0.01 *	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3D - Norm M (mm)	-5.56 (7.82)	-0.76 (5.79)	10.47 (3.42)	-2.53 (2.76)	-8.90 (2.23)	11.28 (5.79)	-2.46 (3.51)	-0.85 (4.35)
95% 3D vs. Norm min	-21.19	-12.34	3.63	-8.05	-13.36	-13.44	-9.48	-9.55
95% 3D vs. Norm max	10.07	10.83	17.31	2.76	-4.43	35.99	4.56	7.85

Data are presented as mean (SD) unless otherwise indicated. M: male; F: female; 95% 3D vs. Norm min/max: 95<sup>th</sup> percentile difference between 3D mean value and the norm minimum/maximum value, other abbreviations and measurements are specified in Tables II, III. \*Statistically significant.

**Table VI.** Analysis 3 results.

	"Pseudo" total vertical dimension Selion-Me	Total vertical dimension Nasion-Me	Partial vertical dimension Sn-Me
Mean 3D (mm)	117.99 (9.06)	119.67 (8.27)	67.91 (6.66)
Mean 2D (mm)	109.56 (32.74)	119.83 (8.03)	64.28 (19.44)
2D vs. 3D ( <i>p</i> -value)	0.11	0.56	0.24
3D vs. Norm ( <i>p</i> -value)	0.00	0.00	0.00
Mean 3D F (mm)	114.16 (7.22)	116.08 (7.02)	65.55 (5.63)
2D vs. 3D F ( <i>p</i> -value)	0.19	0.54	0.29
3D vs. Norm F ( <i>p</i> -value)	0.00	0.00	0.00
3D - Norm F (mm)	-7.06 (16.02)	-8.52 (7.02)	-6.61 (7.98)
95% 3D vs. Norm min	-39.10	-22.56	-22.58
95% 3D vs. Norm max	24.99	5.52	9.36
Mean 3D M (mm)	122.68 (8.52)	124.07 (7.67)	70.79 (6.82)
2D vs. 3D M ( <i>p</i> -value)	0.38	0.19	0.59
3D vs. Norm M ( <i>p</i> -value)	0.00	0.00	0.00
3D - Norm M (mm)	-15.02 (8.52)	-13.63 (7.67)	-10.31 (6.82)
95% 3D vs. Norm min	-32.06	-28.98	-23.94
95% 3D vs. Norm max	2.08	1.72	3.32

measurements and anthropometric norms were less than 2 mm for the measurements; except for Sn-Sto in females and 2-Sto-Gn in males (it was slightly greater than 2 mm in these 2 measurements). And only for one measurement (N-Gnfemales), there was a markedly high a mean difference exceeding 4 mm.

The results of the fourth analysis can be found as a summary in Table VII.

### Facial Indices

There was no statistically significant difference between Farkas anthropometric norms<sup>23</sup> for Facial index (male measurements) and Mandible-Lower face height. There was a statistically significant difference, but of less clinical importance for facial index (for females only), Lower face/Face height index, Mandible-Face height index for both females and males. Important statistical and clinical difference was registered for indices: Mandible- face width Mandibular width -face height. No statistic correlation was found between males and females except for one measurement. The results of the facial indices analysis are summarized in Table VIII.

All P-values for comparisons performed are listed within Tables V to VIII.

## Discussion

but they may also provide general information about the facial morphology. Dedicated software generates 3D facial models, allowing the estab-

lishment of the diagnosis and the esthetic guided treatment planning. In this study, a novel 3D soft tissue analysis is proposed. A set of measurements were selected between the soft tissue landmarks. The mean values were compared to the norms established by Arnett on 2D lateral cephalograms<sup>20</sup> and anthropometric norms collected by Farkas<sup>22</sup>. The soft tissue points were selected according to the Farkas<sup>18</sup> definitions but plotted, based on a strict description of the three separate slice data of Swennen<sup>19</sup>.

In orthodontic literature, the main cause of failure in cephalometric evaluation is the error in identifying landmarks<sup>24</sup>. Richtsmeier et al<sup>25</sup> recorded that the mean error in positioning anatomic landmarks in three dimensions on CT slice images is always less than 0.5 mm. However, some landmarks that are characterized with poorer reproducibility were found. Olszewski et al<sup>26</sup> classified the landmarks into four groups, from group 1 (very high reproducibility) to group 4 (low reproducibility). With reference to their findings the critic soft tissue landmarks in this study were Gonion (classified as 3<sup>rd</sup> group), Zygon and Pogonion (4<sup>th</sup> group). Similarly, Williams and Richtsmeier<sup>27</sup> after mandibular landmarks examination confirmed less reliability for non-biological landmarks. According to the authors "biological" landmarks which are located based on anatomy are more reliable. On the contrast the landmarks that are "constructed" or "fuzzy", meaning that the definition of the landmark is larger than a single point, were less reproducible. In reference to their classification Gonion, Pogo-

**Table VII.** Analysis 4 horizontal and vertical results.

	<b>CR-CL</b>	<b>alR-aIL</b>	<b>GoR-GoL</b>	<b>ZyR-ZyL</b>	<b>Sn-Sto</b>	<b>Sto-sl</b>	<b>Sto-Gn</b>	<b>Sn-Gn</b>	<b>N-Gn</b>	<b>Selion-Gn</b>
Mean 3D (mm)	46.53 (7.3)	33.3 (4.38)	110.58 (10.1)	133.89 (7.77)	22.37 (3.12)	18.01 (3.06)	45.77 (5.35)	67.91 (6.66)	119.7 (9.5)	117.47 (9.5)
3D vs. Norm <i>p</i> -value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean 3D F (mm)	43.05 (5.83)	31.22 (3.19)	105.56 (7.35)	131.59 (6.14)	22.26 (3.34)	16.5 (2.24)	43.59 (4.03)	65.55 (5.63)	116.13 (6.94)	113.61 (7.45)
3D vs. Norm F ( <i>p</i> -value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3D - Norm F (mm)	-7.15 (5.83)	-0.18 (3.19)	11.06 (7.35)	1.59 (6.14)	2.16 (3.34)	-1.3 (2.24)	0.19 (4.03)	1.25 (5.63)	4.72 (7.01)	1.61 (7.36)
95% 3D vs. Norm min	-18.80	-6.55	-3.65	-10.7	-4.51	-5.78	-7.87	-10.01	-9.29	-13.11
95% 3D vs. Norm max	4.5	6.19	25.77	13.87	8.84	3.19	8.25	12.52	18.73	16.32
Mean 3D M (mm)	50.79 (6.74)	35.85 (4.36)	116.72 (9.73)	136.71 (8.75)	22.5 (2.93)	19.86 (2.94)	48.44 (5.66)	70.79 (6.82)	124.07 (7.67)	122.18 (9.77)
3D vs. Norm M ( <i>p</i> -value)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3D - Norm M (mm)	-3.71 (6.74)	0.95 (4.36)	11.12 (9.73)	-2.39 (8.75)	0.2 (2.93)	0.16 (2.94)	-2.26 (5.66)	-1.81 (6.82)	-0.63 (7.67)	-1.78 (9.47)
95% 3D vs. Norm min	-17.19	-7.78	-8.34	-19.89	-5.66	-5.72	-13.57	-15.44	-15.98	-20.71
95% 3D vs. Norm max	9.78	9.67	30.57	15.11	6.05	6.04	9.05	11.82	14.72	17.16

**Table VIII.** Facial indices results.

Facial N-Gn/ZyR-ZyL	Mandible face width GoR-GoL/ZyR ZyL	Mandibular width face height GoR-GoL/N-Gn	Lower face/face height Sn-Gn/N-Gn	Mandible face height Sto-Gn/N-Gn	Mandible lower face height Sto-Gn/Sn-Gn	
Mean3D	89.48 (5.98)	82.95 (5.23)	93.05 (7.9)	56.75 (3.81)	38.22 (3.16)	67.39 (3.73)
Mean 3D F	88.33 (4.78)	81.01 (4.37)	91.93 (6.54)	56.46 (3.93)	37.57 (3.23)	66.61 (3.82)
Diff. N-3D	-2.13	-10.91	-10.23	2.14	2.83	-0.11
N-3D <i>p</i> -value	0.04*	0.00	0.00	0.01*	0.00	0.9
Mean 3D M	90.88 (7.08)	85.33 (5.33)	94.42 (9.32)	57.11 (3.74)	39.02 (2.97)	68.35 (3.48)
Diff. N-3D	-2.38	-14.53	-14.12	2.09	2.18 -0.65	
N-3D <i>p</i> -value	0.16	0.00	0.00	0.02*	0.00	0.43
Correlation M/F	0.89	0.02	0.13	0.97	0.91 0.64	

nion and Gnathion in this work would be more difficult to plot. Although the scope of this study was not the soft tissue landmarks evaluation, the greatest mean difference and statistical significance observed for the measurements composed of Gonion point.

According to Farkas<sup>28</sup>: variations in the shape of the angles of the mandible and in the thickness of the soft tissue cover may create difficulties in locating the Gonions in direct anthropometry. Moreover, the author reported that the determination of the position of another soft tissues points like Zygon and Menton was easier in cephalometry than in anthropometry. In reference to the Swennen 3D cephalometry, in this study, plotting of some points like Menton, Gnathion, Zygon have been modified. They were well defined in 3D, and they are not the same as the Farkas anthropometric points.

The Nasion point was positioned according to Farkas<sup>18</sup> at the level of nasofrontal suture line. Some of the clinicians mark this point out at the deepest spot of the nasofrontal angle, at the Selion level. In this study, the measurements of the facial height were confronted incorrectly measured from Selion versus the real facial height measured from Nasion to Gnathion. Approximately 2.23 mm less for the Selion-Gnathion measurements were recorded. It was confirmed that the erroneous positioning of the landmark may influence the quality of the vertical measurements and have clinical implications.

Another contributing factor, related to the errors, was dependent on the characteristics of CT images. The presence of the CBCT artifacts, widely explained in Schulze's review<sup>29</sup> might be responsible for the difficulties in accurate positioning. One of the critic points were Chelion, that was found at a sharp transition area like oral

commissure and was not always clearly recognizable. Next point Stomion was occasionally positioned without encountering any surrounding soft tissue structure, and in these cases "floating in the space", created additional limits. According to this study the application of these points in CBCT analysis should be limited.

The first target of this study was a comparison between 2D and 3D measurements. Numeric differences between morphologically paired cephalometric 2D and our 3D measurement (mean and SD) revealed no statistically significant difference for all measurements except for the distance Pogonion (for both males and females) and Labial superius prominence (females) to the True Vertical Line in 2D /Plane in case of 3D measurements. As well as the naso-labial angle for men differed statistically. The comparison showed that the resulting values from the 3D analysis were comparable with those of traditional cephalometry. Therefore, this resulted in being exchangeable among them. However, it is important to underline that all the measurements based on the median soft tissue points easily identifiable, both on the lateral cephalograms as well as on the 3D reconstructed model. The findings of this study agree with Damstra et al<sup>30</sup> and Yitschaky et al<sup>31</sup>. The last one confirmed the possible use of identical linear and ratio measurements for both 2D and 3D analyses excluding the angular measurement depending on the Sella Turcica point (the Sella Turcica point was not used in our study). However, these data contrasts with those of Van Vlijmen<sup>32</sup> and Gribel<sup>33</sup> that found the significant differences for all the measurements. Gribel<sup>33</sup> proposed using the mathematical formula to correct 2D cephalometric measurements into a 3D CBCT measurement with accuracy.



The second purpose of this study was to compare data obtained with 3D measurements with Farkas and Arnett norms for the facial measurements. In the literature, some studies in order to verify the accuracy of linear and angular measurements in 3D, utilized dry human skulls as experimental samples<sup>34,35</sup>. The measurement error is considered to be acceptable within 1 mm<sup>36</sup> to 2 mm<sup>37</sup>. Dalessandri et al<sup>38</sup> evaluated measurement reliability using two different CBCT scanners and a fresh sacrificed lamb head. There was minimal, clinically significant difference between the measurements taken with the digital caliper or CBCT scanners. However, 5% of total measurements exceeded 5-10% measurement error.

In this study, no direct anthropometric measurements were performed, instead the 3D anthropometric data was used. The mean difference for all the measurements (analysis 4<sup>th</sup> – 10 measurements for both males and females) was statistically significant. For more than 55% of measurements the mean difference was under 2 mm for 70% of measurements under 3 mm. The source of error might be found in quite small sample, even if comparable with those of Arnett. Farkas<sup>22</sup> study group enclosed 100 people, while this study group composed of adult patients (18 males and 22 females) who had CT data that allowed for excellent soft tissues reconstruction. CBCT exams with facial supports that covered the tissues were not included. Furthermore, the selected anthropometric norms were of the North American Caucasian race. Although our patients all belonged to the Caucasian race, it is difficult not to observe how races change, as an immigration and coupling result. Therefore, even if it is mandatory to consider racial/ethnic characteristics while planning treatment, it cannot be restricted to the precise norms.

The first, second and third analysis (20 measurements) were confronted in accordance with the norms established by Arnett's soft tissue cephalometric analysis<sup>20</sup>. For all measurements a statistically significant difference was found. It was hypothesized that the difference could be influenced by a different composition of the groups. Although the size of the study groups was similar, (40 people versus 46 patients of the Arnett's study), this sample was composed of different skeletal malocclusion patients: 17 patients with the skeletal I class, 13 patients with the skeletal class II and 10 patients of skeletal class III. Instead, people that were included in Arnett's study were chosen only if characterized

as facially balanced and had natural class I occlusion. Limitations of this study include limited size of samples. Despite the limited sample size, patients according to the skeletal classes were divided and confronted according to parameters such as Facial angle and Pogonion prominence. Another important difference between both studies is that the Arnett's analysis was performed on lateral cephalograms, instead this study was 3D cephalometry. Although in this study, no statistical difference was found between 2D and 3D measurements, it is still to be verified if a 3D analysis is easier and especially more accurate in comparison with the traditional 2D representation and above all with the real object.

This study was composed of four analyses based on traditional soft tissue cephalometric analysis of Arnett and the direct anthropometry that were modified to create the new 3D cephalometry. The external reference to internal reference plane was preferred. According to Gateno et al<sup>39</sup> study, the internal reference plane is difficult to define and might be distorted by craniofacial deformity or asymmetry. This 3D soft tissue analysis depicts general facial harmony and the relationship between the lower face components, vertical and horizontal measurements. Hence, it allows clinicians to make a precise and accurate diagnosis. The possibility to calculate the facial indices might be an ulterior tool in the assessment of the facial proportions and offers guidance in judging the faces in preparation for oral rehabilitation or corrective surgery. The registration of the mean of measurements was a first step to create a new database of 3Dimensional norms. However, the authors of this work suggest using the numeric values as indicative of facial harmony or imbalance. According to Tessier<sup>40</sup> "Harmony or disharmony does not lie within angles, distances, lines, surfaces, or volumes. They arise from proportion".

## Conclusions

To the authors' knowledge, this is the first study dealing with 3D cephalometric analysis and Arnett's Soft Tissue Analysis<sup>8,9,41</sup>. The analysis performance with Ortho Pro 2.1 is simple and allows for a complete facial esthetics evaluation. The accuracy was confirmed by the absence of statistical difference between our 3D measurements and the 2D ones executed on lateral cephalograms. Moreover, the mean values of the

measurements and indices were compared with the Farkas<sup>22</sup> anthropometric norms for Caucasian race. Being aware of some sources of errors, we would like to underline that our study proposal of the Soft Tissues Analysis should be verified in the future. There is still a lack of general guidelines and clinical usefulness agreement among the practitioners. The general rules and specific analysis are still to be evaluated and sources of possible errors must be indicated. The physicians must be aware of the biologic costs that the patient undergoes when radiologic exam is performed. As it is not possible to gather a huge amount of data by performing CBCT exam in most cases of treatment, to widen the spectrum of 3D data a multicenter collaboration is needed. Those measurements, which are already being collected, must be further verified as they might be applied as a golden standard. Furthermore, 3D anatomy knowledge and 3D analysis training should constitute part of the academic background and should be practically performed.

#### Conflict of Interest

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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#### Informed Consent

A signed informed consent agreement form was obtained from all the patients before the procedures.

#### Ethics Statement

The article has been approved by the Review Board of the IRCCS Galeazzi Institute, Milan, Italy (Institutional Scientific Review Board with number Prot: 75/2019-L2057).

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#### Authors' Contributions

TG.P., F.G., O.R., T.T., J.N., A.R., G.B., G.T., M.D.F., and C.M. conceived and designed the analysis. Databases were searched and data was collected by G.P., F.G., O.R., T.T., J.N., A.R., G.B., G.T., M.D.F. All the authors contributed on analysis and interpretation of data for the work. F.G. draft-

ed the work and wrote the manuscript with input from all authors. G.P., F.G., O.R., T.T., J.N., A.R., G.B., G.T., M.D.F., and C.M. revised the work critically for intellectual content. Integrity of the work was appropriately investigated and resolved by all authors. All authors contributed and approved equally to the final version of the manuscript.

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